Lecture Notes in Mobility

Ciaran McNally · Páraic Carroll · Beatriz Martinez-Pastor · Bidisha Ghosh · Marina Efthymiou · Nikolaos Valantasis-Kanellos *Editors*

Transport Transitions: Advancing Sustainable and Inclusive Mobility

Proceedings of the 10th TRA Conference, 2024, Dublin, Ireland - Volume 1: Safe and Equitable Transport

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Lecture Notes in Mobility

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Editors

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Preface

We are pleased to publish the Conference Proceedings of the 10th Transport Research Arena (TRA 2024), held on April 15–18, 2024, in Dublin, Ireland. The conference brought together 4500 delegates from 57 countries who came together to discuss research findings, the latest innovations in policy, technology and practice, and the future directions of mobility and transport.

The conference tagline was *Transport Transitions: Advancing Sustainable and Inclusive Mobility*, and four primary conference themes were defined, namely

- Safe & Inclusive Transport
- Sustainable Mobility of People and Goods
- Efficient & Resilient Systems
- Collaborative Digitalization.

TRA takes place every 2 years, and TRA2024 featured an array of plenary sessions, ministerial sessions, strategic sessions and special sessions which took place alongside the technical programme. A call for papers was issued in early 2023 which resulted in 1182 submissions. A double-blind peer review process was initiated, which ultimately resulted in 784 papers that were chosen for presentation at the conference (66% conversion rate). These papers were presented in a combination of oral or poster presentations over the course of the conference.

All accepted papers presented at TRA 2024 are published in a topical collection of the journal European Transport Research Review (ETRR) or within these proceedings. Both are published in a fully open access format.

TRA is a multi-modal conference that draws on the support of key stakeholders. These include the European Commission, ACARE (Advisory Council for Aviation Research and Innovation in Europe), ALICE (Alliance for Logistics Innovation through Collaboration in Europe), CEDR (Conference of European Road Directorates), ECTP (European Construction Technology Platform), ERRAC (European Rail Research Advisory Council), ERTRAC (European Road Transport Research Advisory Council), ETRA (European Transport Research Alliance), and the Waterborne technology platform. Key Irish supporters of the event were Transport Infrastructure Ireland, Enterprise and Ireland and the Irish Government's Department of Transport.

The editors would like to express their thanks to the presenters, authors, reviewers, session chairs, committee members and sponsors for helping deliver such a successful event. TRA 2026 will take place in Budapest, Hungary.

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Beatriz Martinez-Pastor
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Nikolaos Valantasis-Kanellos
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Transport Safety

Extracting Parameters of Vulnerable Road Users' Behavior from Video Observation for Modeling of Urban Microsimulation

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Abstract. Microsimulation is an essential tool in the planning and evaluation of large infrastructure projects or the implementation of new traffic rules for the inclusion of new road users. Efficient microsimulation on a citywide scale is provided by several software solutions, however, the representation of behaviors of unmotorized vulnerable road users (VRUs i.e., pedestrians, cyclists, scooter users) with their many degrees of freedom (including suddenly stepping on the road, crossing red lights) and their close interactions due to lack of space on sidewalks and other areas tend to be highly simplified. This work utilizes camera data collected in a busy road environment with several close interactions of all types of urban road users, to define decision-making rules and models of vulnerable road user behavior to be used in microsimulation. The simulation models are based on the observed interaction statistics, through the use of Surrogate Safety Measures (SSM, in particular Time-to-Collision-(TTC-), Post Encroachment Time- (PET-)), and the assessment of the kinematic behavior of interacting users in potential traffic conflicts.

Keywords: Vulnerable Road Users · Microsimulation · SUMO · Behavioral Models · Video Analysis

1 Introduction

Microsimulation is an essential tool to investigate the interactions of road users on a large scale and for planning infrastructural adaptations or assess the impact of changes in road user behavior [1]. Microsimulation tools have been getting increasingly powerful, to the point, where using them to simulate activities in city-sized structures has become feasible for many different research questions [2]. However, with regards to the behavioral models employed in these simulations, in particular models of VRU behavior are challenging, as unlike lane-bound vehicles, VRUs have many degrees of freedom in their movement and create complex traffic situations with their sudden actions, in particular when jaywalking is considered or when an actual collision course on the road occurs. An advanced kit for

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microsimulation, the software SUMO [3], allows to address these issues by supplying detailed models for road user interactions. It would therefore be beneficial, to bring real world interaction data into a form that can be mimicked by the behavior of VRUs in the simulation.

This paper aims to provide such models by tackling 2 challenges for improving VRU models: First, a camera solution is used with an internal battery, to be deployed flexibly where road users interact the most and collect video data. That video data can be used to extract trajectories of road user behaviors through machine learning (ML) techniques (see for instance [4]). Secondly, new VRU behavioral models are fit from simulator studies and the video observations and formulate ways to bring real world behaviors into simulation.

2 Methods and Data

2.1 Mobility Observation Box

The mobility observation box (MOB) [5] is a camera solution with an internal power supply and internal encrypted file storage for video data to obtain real world data from ML based analysis of real subject movements. Road users recognized by object detection methods provide the foundation for studying the flows and interactions under everyday conditions (Fig. 1).

Fig. 1. Tracking of the MOB system, discriminating the user type that is identified, at Schwarzenbergplatz in Vienna. Image obtained from the MOB data collection.

Trajectory data was smoothed using linear interpolations on a second long timescale. This study is based on mobility observation box-based trajectory data for a large square in the city of Vienna. Video data immediately provided flows of road users on the square and therefore the necessary material to start a simulation.

Data extracted from these interactions includes maximum speeds and accelerations, minimum distance between users, X and Y coordinates of the projected trajectory in the

2D plane at the point of closest approach, relative angle between trajectories at minimum distance, longitudinal and lateral accelerations (individual and aggregate) during collision courses, TTC and PET values.

2.2 Surrogate Safety Measures

Means to quantify safety relevant interactions come in the form of surrogate safety measures (SSMs) [6]: in particular time to collision (TTC) and post-encroachment time (PET). Time to collision is defined as the time it would take 2 road users to arrive simultaneously at a linear continuation of their current movement, given their current relative speed (i.e., the time until they would be expected to collide unless they change their movement course):

$$TTC = (Distance\ to\ overlapping\ road\ user\ prediction)/(Current\ relative\ Speed) \tag{1}$$

Post encroachment time is the temporal gap between two road users arriving at the same spot (t_1 *time road user arrives in overlap area,* t_0 *time other road user arrives in overlap area*).

$$PET = t_1 - t_0 \tag{2}$$

For the MOB data, these values were calculated using R [7] based on the collected trajectories. Trajectory data was smoothed via linear interpolation for this, to provide consistent speed values and accelerations.

2.3 Machine Learning Models

Clustering methods were used on the interaction data [8] to obtain a description of subclasses of users behaviors. The implemented technique was k-means, and the optimal number of clusters was determined using the "Elbow method". This method allows to select the number of clusters from which WCSS (Within-Cluster Sum of Square) decreases in a more progressive way. The results obtained with the Elbow Method have been contrasted and validated by calculating the Silhouette coefficient [9].

Furthermore, a decision tree model [10] was run to extract decision making rules from when an interaction would fall into one cluster or another. The hyperparameters of this model, as well as the performance metrics (accuracy, precision, recall and f1-score) were obtained through the k-fold cross validation procedure with 5 iterations. The hyperparameters of the decision tree model are the splitting criterion (cross-entropy, Gini index), maximum depths (None, 3, 5, 10), minimum number of observations to split an internal node (1, 3, 5, 7,10); minimum number of observations in a node (1, 2 or 4).

3 Results

Trajectory data obtained from the MOB was collected and investigated for 3 days of observation (during daylight hours) for a total of 51 h in which road users could be identified. Using our *ad-hoc* algorithm implemented in R, all road users were found to be on either a collision course with less than or equal 2 s TTC and were in a PET relation with less than 2 s remaining.

An example outcome can be seen in Fig. 2.

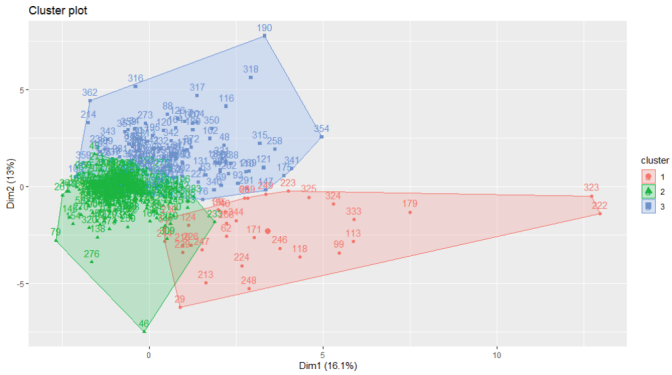

Fig. 2. Clusters extracted from the interactions of VRUs with other road users. Image generated directly from the clustering of the data in RStudio.

The total number of samples is 370 and was best fit using 3 clusters. For these clusters a decision tree analysis was ran as described above. An exemplary outcome for TTC training set can be seen in Fig. 3.

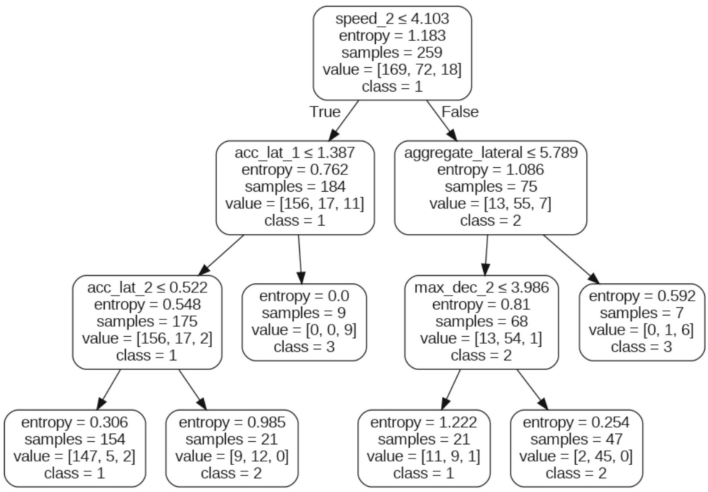

Fig. 3. A decision tree providing different split criteria on when an interaction would fall in one cluster or another.

The decision tree allows to relate the risk classes as a function of the set of variables used in the clustering. The splitting criterion that optimizes the classifier performance is cross-entropy, with a maximum depth of 3 samples, a minimum of 10 observations to split an internal node, and a minimum value of 1 sample to be in a leaf node.

The accuracy of the model is 88%, with balanced values of average precision and average recall (88% and 81%, respectively), being f1-score 83%.

Class 1 encompasses road conflict situations in which there is a higher potential danger. When the speed of the second user is less than 4.1 m/s^2, the lateral acceleration is less than 0.52 m/s^2, resulting in cases where users exhibit minimal lateral avoidance action. When the speed is high, the aggregate lateral distance is low and the deceleration of the faster user is lower, resulting in a more perilous situation. These findings are supported by the distribution of TTC cases, where cluster 1 collects the majority of the observations for TTC $<$2 m/s^2 for minimum distance lower than 2 m.

Class 2 includes moderate risk situations. Both longitudinal and lateral deceleration are higher, leading to avoidance actions involving a greater minimum distance between users (e.g., stopping, or sidestepping users in front of vehicles entering the intersection or cyclists riding in the bike lane). Finally, Class 3 comprises encounters with greater lateral actions but greater aggregate distances when speed is high. These interactions involve less risk, as the TTC and minimum distance values are higher.

These decision rules form a model of road user reactions to collision courses, meaning rules for accelerating or stopping can be extracted directly from experimental data. These rules can be used to model road user behavior in microsimulation software like SUMO, for instance by equipping a simulated VRU with a cluster membership, then choosing their choice parameters (acceleration during collision course, TTC thresholds) during the simulation of the interaction.

4 Discussion

Video data was obtained from a busy square in the city of Vienna and was used to describe interactions on this square. Consequently, a model of road user reactions to collision courses was proposed, to provide more realistic behaviors. Using techniques from machine learning, the resulting interactions were clustered, showing similarities in driven speeds, distances, TTC, PET and accelerations during interaction.

A tree-based classification analysis is conducted to provide a number of rules on the interactions, which can in turn be used in simulation to represent road users behaviors. This approach can help assessing reactions of road users (VRUs in particular) to simulated behavioral changes of other road users, such as might be induced by new assistance systems in vehicles. Additionally, this study is a first step of a cycle of development that will require validating the improvements achievable though this modeling approach in SUMO, comparing to further trajectory data and revising the model accordingly.

The real-world data helps calibrating models to more situations than an idealized simulator environment can provide. Future work will aim to connect this to earlier simulator work providing behaviors for sudden unexpected collision courses [11], based on reaction time and moving forward or backwards away from the collision area. Limitations include the need to verify on larger data sets, which fortunately can be obtained fairly quickly using the MOB, as well as the need for improvements in object recognition, as data in the traffic environment is commonly affected by problems like partial occlusion or vehicles moving close to one another.

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Equitable Mobility - Appropriate Active Travel Facilities for the Aging Population

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Abstract. To help achieve current European Road Infrastructure Management Directive (RISM) targets and Vision Zero, Transport Infrastructure Ireland (TII) has set an objective to reduce the risk and number of collisions, injuries, and deaths on Ireland's road infrastructure.

In Ireland the population has been getting steadily older since the 1980s and the 65 years and over cohort is represented as a high percentage of overall recorded collisions on the Irish Road Network.

Active travel has been highlighted as a priority by many recent policy and strategy documents including the recently published National Strategic Mobility Policy (2022) and the Climate Action Plan (2023). In May 2022 TII launched the National Cycle Network Plan (NCN) which focuses on linking cities and towns of over 5,000 people with a safe, connected and inviting cycle network. It includes plans to create cycle routes to destinations such as transport hubs, centres of education, centres of employment, leisure, and tourist destinations. Where possible, it will optimise the potential for people to cycle as part of their daily activities.

This research will provide clear conclusions and recommendations to inform national standards and the required changes to policy documents were required to ensure equitable mobility for Irelands aging population.

Keywords: Mobility · Equality · Road Safety · Active Travel · Design Standards

1 Introduction

To help achieve current European Road Infrastructure Management Directive (RISM) targets and Vision Zero[1], Transport Infrastructure Ireland (TII) has set an objective to reduce the risk and number of collisions, injuries, and deaths on Ireland's road infrastructure.

[1] The Government's Road Safety Strategy (2021–2030) 'Vision Zero' aims to reduce the number of deaths and serious injuries on Irish roads by 50% by 2030 and achieve no deaths or serious injuries on the roads by 2050.

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In Ireland the population has been getting steadily older since the 1980s. In Census 2016, 37.2% were aged 45 and over, compared with 34.4% in 2011 and 27.6% in 1986. Almost a third of the population 33.2% was less than 25 years old, while 29.5% were in the 25–44 age group. The 65 years and over age group saw the largest increase in population since 2011, rising by 102,174 to 637,567, a rise of 19.1% [1].

In February 2020 the Irish Road Safety Authority published the "Road Casualties and Collisions in Ireland 2017 Statistics" which showed that the age cohort of 65 and over were involved in 781 collisions which represents 9.8% of all collisions reported. Inside built-up areas there were 23 vulnerable road users killed while there was 2399 seriously injured which represents 53% and 54% of the total reported incidents. Outside built-up areas there were 21 vulnerable road users killed while there was 215 seriously injured which represents 19% killed and 6% of the total reported incidents [2]. Using the information contained in this report it was concluded that the 65 years and over cohort is represented as a high percentage of overall recorded collisions on the Irish Road Network and that a substantial number of these collisions involved vulnerable road users.

Active travel has been highlighted as a priority by many recent policy and strategy documents including the recently published National Strategic Mobility Policy (2022) and the Climate Action Plan (2023). In May 2022 TII launched the National Cycle Network Plan (NCN) which focuses on linking cities and towns of over 5,000 people with a safe, connected and inviting cycle network. It includes plans to create cycle routes to destinations such as transport hubs, centres of education, centres of employment, leisure, and tourist destinations. Where possible, it will optimise the potential for people to cycle as part of their daily activities.

The findings of this research will provide clear conclusions and recommendations to inform national standards and the required changes to policy documents were required to ensure equitable mobility for Irelands aging population – referred to in this study as 'age friendly active travel'. The methodology includes a literature review and targeted survey of the relevant cohort along with in-depth interviews. The research examines all forms of active travel including pedestrians, cyclists, and the use of mobility aids and including personal powered transport.

2 Literature Review

Several studies have explored the 'lived experiences' of older people wishing to travel more actively, exploring reasons they avoid it and what they perceive would make it better. In a 2011 study about rural car dependence amongst older people, participants identified safety fears as the key barrier [3]. An Austrian study showed that many older people feel unsafe walking and cycling because of their reduced vision and hearing, especially when sharing roads and paths. In the study, survey participants expressed a clear desire for completely separated active travel paths, and where possible, separation between walking and cycling [4].

A concept originating in the Netherlands is the 'forgiving cycle path', or 'forgiving kerbs', which seek to address a particular infrastructural issue from the perspective of over 55s. Acknowledging that older people have more trouble with balance on a bicycle, which may lead to them drifting off course and into the opposite lane or in traffic, a

'forgiving' cycle path or kerb can come in different forms to encourage containment within the cycle lane [5]. Further to this, a study comparing age friendly cycling in the UK and the Netherlands, older people in both countries were shown to be more willing to cycle if routes were completely segregated from traffic. Participants were happy to avoid more direct cycle routes and extend their cycling journeys if cycle paths were completely traffic free and closer to nature, making the experience safer and more enjoyable [6].

2.1 Key Findings from the Literature Review

- Safety and perceived safety amongst older people increase when active travel routes such as cycle lanes or footpaths are completely separate from motor traffic, or at least have a distinct physical barrier.
- The quality (and maintenance) of surfaces is also important for older people, reducing the likelihood of trips and falls, which could lead to collisions with other road users.
- Design and infrastructure features such as frequent seating, better lighting and distinct surface materials and colours can contribute to the safety of active travel for older people, making routes clearer and more coherent, and allowing opportunities for regular rest.
- Active travel links to public transport are especially important for older people in rural areas, who may rely on public transport for longer journeys, but struggle to reach facilities such as bus stops and train stations due to a lack of adequate active travel infrastructure.
- Other important factors include reducing speed limits, increasing crossing times on signalised crossings, and introducing low traffic neighbourhoods and modal filters to reduce motor vehicle traffic on active travel routes.

3 Survey Results

414 people aged 55 and over living in Ireland completed an online survey (quantitative stage). 30 of the survey respondents took part in a follow-up depth interview lasting between 30–60 min (qualitative stage).

The majority of survey respondents (83%) do journeys by foot once a week or more. Cycling is less common, with 17% using a cycle for journeys at least a few times a month; 72% indicated that they never cycle any journeys. A very small minority of survey respondents use either a wheelchair at least a few times a month (3%) and/or a mobility scooter (2%).

Most respondents felt that 'active travel is good for health and wellbeing' (98%), and that 'active travel in enjoyable' (88%), a much smaller percentage agreed that 'older people can walk cycle or wheel safely where I live' (35%). Those who live in rural locations are more likely than those in urban locations to agree that they don't have the time in their day for active travel and that active travel is not for older people, and less likely to agree that active travel is the norm where they live or older people can travel actively where they live. Very few respondents (14%) travel actively because they have no alternative means of getting to a destination however those who live in rural areas are more likely to give this reason than those living in urban areas.

Barriers and Safety: Those age 55 to 64 are more likely than those aged 75 or older to be deterred by a lack of separation between cyclists and pedestrians on cycle routes or footpaths and unsafe roads. They are also more likely than all other age groups to be deterred by poor quality surfaces on cycle routes or footpaths and traffic volume/speed.

Those who cycle are less likely to report their health and fitness and a preference for traveling by car are barriers to active travel than those who never cycle, and are more likely to report the following barriers:

- Barriers, gates or other infrastructure on cycle routes or footpaths
- Poor quality surface on cycle routes or footpaths
- Lack of separation between cyclists and pedestrians on cycle routes or footpaths
- Traffic volume and/or speed
- Unsafe roads, including junctions
- Having to transport other people

The most commonly reported factors that would make people feel safer when travelling actively are routes being well-maintained (55%), well-lit (49%) and separated from motorised traffic (45%). Although longer crossing times at pedestrian and cycle crossings is the least common response, this is still an issue for over 30% of survey respondents, and those with a disability in particular.

4 Interview Findings

4.1 Travel Patterns

Cycling: Ten interviewees cycled journeys at least some of the time so there was an opportunity to explore their motivations for using this mode of active travel. Cycling is considered a quicker way of undertaking journeys that are perceived to be too far to walk or that would take too long on foot. Interviewees typically cycle for journeys of 'a few' km, with one person cycling up to 10 km.

Aside from these ten people, a few others cycle for leisure, recreation, or exercise, but not for purposeful journeys. Some are comfortable cycling for leisure on the roads close to where they live (but would still choose quieter times on the roads where possible), but others prefer to drive to somewhere they can cycle off the road, such as a Greenway.

There are definite safety concerns regarding traffic that is limiting the amount of cycling done by interviewees. Those who did not cycle often referred to their safety in traffic as a reason for not travelling in this way.

Walking: All but one of the people interviewed walk at least a few times a month, and most walk once a week or more. Interviewees are very motivated to walk in order to 'keep moving' and help them stay healthy, not just physically but mentally too. Particularly for those who are retired, 'getting out of the house' regularly is considered important.

Those living in rural areas identify fewer opportunities to walk for functional journeys due to the distance between their home and the desired destination. One person had recently moved to a town from a more rural area to be in walking distance of shops

and other facilities and so they did not have to rely on driving. Others who live rurally describe travelling to a local big town or city, either by car or public transport, and walking extensively to do what they needed when they were there.

A high proportion of the sample are retired and report that they have the time available to walk both for function (rather than having to use the most time-efficient method of transport) and leisure. They also have the flexibility to choose the most appropriate time for them to walk, for example, in order to avoid the bad weather or dark mornings or evenings in the winter. They can meet up with others to walk and socialise at the same time. In contrast, those who are still working typically walk at weekends or during their lunch break.

Car Travel: Those living in rural areas are typically motivated to go by car (either driving themselves or being driven by others) rather than by cycle or on foot by the distance they need to travel to meet certain needs; for example, to get to a 'large' supermarket to do a full grocery shop. Those in rural areas also report that there are infrequent or no public transport options to take them where they need to go, so they have to drive.

4.2 Suggested Improvements to Infrastructure

Many suggestions were made by interviewees as to how infrastructure could be improved to enable more older people to travel actively more of the time. A view shared by a number of interviewees is that cyclists and pedestrians are not afforded the same priority as car drivers when it comes to town planning and the development of infrastructure. A few of the suggestions relate more specifically to *safer* active travel.

Cycling: A lack of cycle routes is a major barrier for people not continuing to cycle into older age – roads are perceived to be too unsafe and so specific or segregated cycling infrastructure is required. Not being able to park a cycle and leave it safely puts people off cycling. Some suggested road changes to enhance the safety of cyclists in traffic; these included an advance green light for cyclists and other changes to at junctions, such as more protected spaces for cyclists.

Walking, Wheeling and Scooting: More footpaths in rural areas in particular could encourage more walking. Other suggested changes include: pedestrian crossings that are more responsive to the needs of the pedestrian rather than the car driver; more dropped kerbs in the correct places for wheelchair and mobility scooter users and people who are not comfortable with steps; improvements in seating, including some with shelters to protect against the weather; wider and better maintained footpaths in order to better accommodate mobility scooters and wheelchairs.

Shared use paths are recognised by most people as giving more space to active travelers as a group, but these can also lead to pedestrians feeling vulnerable and unsafe when sharing a space with cyclists. Many felt that more public toilets, shelters and rest stops are essential for encouraging older people to travel actively, and to take longer journeys on foot in particular. Reducing the speed of traffic - including extra speed bumps and chicanes, lower speed limits in areas where people walk a lot and more crossings to slow traffic down, as well as more speed cameras and better enforcement of speed limit, were suggested to improve safety.

Next Steps: Future stages of this research will focus on the current practices of the professional stakeholders in the active travel arena. This will include desk-based research, interviews with relevant professionals across multi-disciplinary teams and a workshop to highlight, discuss and find solutions to the various issues identified.

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VRUs Safety Models Based on Risk Exposure for Safe Routing Algorithms

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Abstract. Current routing applications allow for the selection of routes based on factors like cost, travel time, or distance but do not consider safety concerns with regard to different types of travel modes and travel times. This poses an issue for the safety of vulnerable road users (VRUs). To create safe route options, it is crucial to assess accident probabilities at various sections and intersections. Measuring only the accident frequency while ignoring the time-dependent traffic count at locations is insufficient, as it does not allow to assess a persons' accident risk. Additionally, accident frequencies underly statistical fluctuations which requires the implementation of accident models.

Another important consideration for VRUs is their sensitivity to detours. Safe route options might deviate from the shortest path, so a spatial weighting method is needed to balance safety benefits against longer or complex routes. In the EU-funded project "SOTERIA" statistical models as well as machine learning techniques are being used to assess road design variants, highlight accident-prone areas, and identify factors leading to accidents. These models will guide the creation of safe routes to provide users with information on possible safety benefits.

Keywords: transport safety · safety assessment · accident analysis · accident modelling

1 Introduction

1.1 Purpose

Accident prediction models (APM) help to estimate the expected number of accidents on parts of the street network regarding multiple influences. By comparing the estimated and actual number of accidents they are commonly used to highlight conspicuous areas

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of the street network or to compare different potential infrastructure design variants. However, since they allow to quantify the risk of street network elements, they can also be used as basis to derive safe routes for different road users and thereby complement common routing options. Within the EU-funded project "SOTERIA", multiple data driven models especially for vulnerable road users (VRU) are created to identify and quantify numerous independent effects on accident frequency.

1.2 Factors Associated with VRU Accident Frequency

Previous studies have demonstrated that accident frequencies mostly vary by traffic volume. Thereby, studies equally use traffic volumes of motorized traffic as well as of non-motorized traffic. Higher volumes of non-motorized traffic evidently lead to higher accident frequencies of VRUs, however, it must be pointed out that more recent studies show a degressive relationship between both values [1–3]. Studies only regarding the influence of motorized traffic volume commonly describe an increasing effect on VRU accident counts [1] but also opposing effects were found [4] which may be caused by differences in focused study areas. Vehicle speeds seem to reduce VRU accident frequency [5]. However, this effect may only be a proxy for more higher motorized traffic again correlating with a higher design standard for crossing facilities.

Concerning infrastructure design, wider streets or with more lanes have been found to increase accident frequency of VRUs [6]. In comparison, mainline medians and crossing medians help to decrease VRU accidents [1]. Furthermore, accident frequencies are lower at signal-controlled sites [6] and at segments with one- or two-sided parking [5].

As socio-demographic influence, a higher population density [3, 4] as well as a high share of both elderly [3, 4] or young people [1, 7] living in the vicinity of streets increased accident frequencies. Regarding land-use influences, commercially used street surroundings [1, 2, 4] as well as heterogenous land-use [7] seem to be linked to higher accident frequencies of VRUs. Analogously, higher crossing density [2, 5] and amount of bus stops [4, 6] in the vicinity increase VRU accidents.

2 Data and Methods

Since characteristics influence accidents of each mode of transport differently or to a different degree, models for each VRU transport mode were created. By way of illustration, in this paper we focus on pedestrian accidents in the State of Saxony, Germany.

2.1 Data

The database was generated via GIS analysis of different data sources. Police-recorded accidents of a 5-year period (2018–2022) were used and filtered to obtain pedestrian accidents. OpenStreetMap data (OSM) was used and narrowed down to segments for pedestrians and information of adjacent streets were annotated. Environmental information in the vicinity was derived from rasterized data from the IÖR monitor [8] as well as from the Federal Agency for Cartography and Geodesy in Germany [9]. Table 1 shows an extract of used parameters in model development.

Table 1. Descriptions and descriptive statistics of variables (N = 18,769 segments)

Parameter	Description	Categories	Mean	SD
Industrial/ Commercial	% of industrial/commercial land use site (100m x 100m grid)	- (continuous)	5.85	18.2
Grazing_Area	% of grazing land (100m x 100m grid)	- (continuous)	2.32	11.02
Relief_Energy	Difference between maximum and minimum height (in 100m x 100m grid) [m]	- (continuous)	6.39	4.68
Road_Density	length of classified road network (in 100m x 100m grid) [km/km^2]	- (continuous)	10.79	8.61
Households	Number of households (in100m x 100m grid)	- (continuous)	41.16	31.73
Inhabitants	Number of inhabitants (in 100m x 100m grid)	- (continuous)	68.08	52.05
Lanes	Number of street lanes of adjoining road	- (continuous)	2.01	0.26
Width	Road width	- (continuous)	5.37	0.39
Length	Length of pedestrian segment	- (continuous)	84.50	142.00
N_accidents	Number of accidents per pedestrian segment	- (continuous)	0.02	0.16
Traffic_signals	Presence of traffic signals	yes, no	-	-
Bicycle	Presence of cycling facility stop	yes, no	-	-
Street_class	Street class of adjoining road	other, primary, secondary, tertiary	-	-
Speed_limit	Categorized speed limit of adjoining road	$<$50 kph, $\geq$50 kph	-	-
Smoothness	Categorized physical usability of adjoining road	unknown, good, deficient	-	-
Parking	Presence of parking facilities on adjoining road	yes, no	-	-

2.2 Methods for Modelling Accident Frequency

Accident frequency data is usually skewed and discrete making conventional linear regression-based models inappropriate. Poisson-based models have proven to outperform linear regression models, but the underlying distribution consists of only one

parameter "λ" which simultaneously describes the expected value and its variance. However, due to a multitude of factors, the found variance in accident counts likely exceeds this assumption in practice (over dispersion), wherefor negative binomial (NB) are more widely used [10] which allow to model expected value and variance independently. NB-models may, however, may be limited in case of an excess of analysis units with no accidents for which zero-inflated NB-models (ZINB) have been introduced in the past [11]. These link NB-models with logit or probit models. The logit-/ probit-model part accounts for excessing zero counts, whereas remaining counts are modelled by NB-models. This allows the modelling of two different generation processes: with a probability of φk no accidents will be estimated and with a probability of 1- φk more accidents are estimated by a NB-model. Typical statistical measures were used to evaluate the prediction quality of NB or ZINB as well as their preliminary models during model development, to prevent over-/underfitting and to control for multicollinearity.

3 Results (Model)

Table 2. NB regression model results for pedestrian accidents on segments

Variable		Coefficient	SE	Z-statistic	Two-sided p-value	CI (95%)	
						Lower	Upper
Zero-inflation-model (Logit)							
Intercept		4.0176	0.4761	8.44	<0.001	3.0844	4,9507
Log(Length)		−0.9846	0.1711	−5.75	<0.001	−1.3200	−0.6492
Count model (NB)							
Intercept		−3.6550	0.3320	−11.01	<0.001	−4.3056	−3.0043
Industrial/Commercial		0.0113	0.0026	4.41	<0.001	0.0063	0.0164
Grazing_Area		−0.0201	0.0098	−2.07	0.039	−0.0393	−0.0010
Relief_Energy		−0.0733	0.0189	−3.87	<0.001	−0.1104	−0.0362
Road_Density		0.0404	0.0072	5.57	<0.001	0.0262	0.0546
Length		0.0010	0.0004	2.67	0.008	0.0003	0.0017
Bicycle:	yes	0.6241	0.1440	4.33	<0.001	0.3418	0.9064
Street_class:	primary	1.3321	0.2285	5.83	<0.001	0.8843	1.7798
	secondary	1.1323	0.2010	5.63	<0.001	0.7383	1.5262
	tertiary	1.1213	0.2117	5.3	<0.001	0.7063	1.5362
Speed_limit:	≥50 kph	−0.5402	0.1756	−3.08	0.002	−0.8843	−0.1961
Smoothness:	deficient	−0.7133	0.5364	−1.33	0.184	−1.7646	0.3380
	good	0.5868	0.1505	3.9	<0.001	0.2917	0.8818
Parking:	yes	0.6734	0.3106	2.17	0.030	0.0646	1.2822
Traffic_signals:	yes	0.6883	0.1771	3.89	<0.001	0.3412	1.0353

For the final model, a ZINB-model was used to estimate pedestrian accident counts on segments and includes eleven explanatory variables. Table 2 shows the results separately for the zero-inflation and count-model part of the ZINB. Within the zero-inflation-model

part, segment length was found to be the strongest influence. As part of the zero-inflation-model part, a negative coefficient for length represents an increase of accidents. During the stepwise model development, it was found that logarithmic length values provided better model results.

Segment length also appears as parameter to model higher accident counts. Higher accident counts were found at segments in areas with a high share of industrial/commercial land use which may be a proxy to define higher exposure rates of pedestrian and motorized traffic. Conversely, the proportion of grazing land is likely to describe remote pedestrian facilities with low pedestrian volumes and exposure to motorized traffic resulting in lower accident counts. Relief energy, describing rolling terrain, significantly lowers accident counts and may be due to an unlikely usage of these facilities by pedestrians. As last continuous parameter, road density demonstrates a positive correlation with pedestrian accident counts. It is likely that this parameter, again, highlights areas of high urbanity and thus high pedestrian and motorized traffic flow.

The existence of cycling facilities along pedestrian facilities was included as categorical parameter and increased pedestrian accident counts and is plausible with regard to cyclists being the second most common accident opponent of pedestrians. Compared to the baseline of unclassified streets ("other"), higher pedestrian accident counts can be found on classified streets which may describe streets with higher motorized traffic volume and/or wider streets. In comparison, speed limits of at least 50 kph significantly have lower pedestrian accident counts. This unintuitive effect could be explained by speed limit having a direct influence on design standards and thus represent safer pedestrian infrastructure standards. A deficient smoothness on the adjoining road decreased pedestrian accidents counts and vice versa be explained by deficient smoothness preventing higher speeds and thus reducing the risk of an accident. Allowed parking along the street adjoining pedestrian facilities significantly increases pedestrian accident counts and likely describes the effect of a limited visibility of pedestrians between parking cars before crossing streets. Finally, the presence of traffic signals increases the estimated number of pedestrian accidents. However, since traffic signals are installed as a countermeasure to prevent high accident counts, they do not cause more accidents by themselves, but only function as proxy in the model.

4 Outlook

The presented ZINB model does not include influences of traffic volume information yet, but several explanatory parameters which mask effects of exposure both of pedestrians and motorized traffic. Thus, possible derived routing algorithms would more likely represent the subjective perception of safety of road users in the sense that many observed accidents hint on an unsafe area. They, however, do not represent an objective accident risk of a road user. Models in the next project step will include information on trip flows, including volume by road user type, in order to relate accident counts to a personal risk as well as to identify traffic-related explaining factors for accident occurrence. This will enable the development of more accurate predictive models and the definition of objective safety measures.

For this purpose, a travel demand model will be developed which will use anonymized Mobile Network Data (MND) to reconstruct mobility patterns (travel demand). This information will be enriched through machine learning (ML) techniques to overcome the lack of some traveler and journey information. Via aggregation, mobility indicators such as traffic volume per road section and type of VRUs will be generated.

Based on the future models with implemented effect of traffic volume, weights can be derived per segment which then truly represent the risk for each type of road and road user and can be used as criteria for a safe route option. This finally allows to develop a 'safe' routes planner as part of the SOTERIA project. The proposed routing solution utilizes the aforementioned models using different sub-components:

- routing graph management: dynamical updating of weights on edges
- search graph: algorithms to create a least cost path
- travel scenarios composition: generation of multi-modal routes
- route recommender: provision of route by 'hard' (e.g. maximum distance) and 'soft' (personalized preferences) constraints

The SOTERIA route planner is being implemented using a micro-services architecture that enables the deployment of the above-described components as individual services. The implementation allows the seamless integration of new data sources and APIs, deployment of the solution in computer clusters for improved performance and operational resilience as well as an easy introduction of additional routing scenarios.

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Oxford Roundabout and the Art of Safety: Resistance to Cycling Infrastructure Intervention

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Abstract. Improving cycling infrastructure enables a sustainable alternative to short car trips and last-mile solution, but change relies on interventions with resistance to policy deprioritizing automobiles. This research evaluates improvement (completed 2015) to the Plain Roundabout in Oxford, UK, a 'safety hot spot' and cyclist deterrent, focusing on procedural elements of cycling design. Thirteen semi-structured interviews with expert stakeholders (February-May 2015) and cyclist testimonials were collected. Thematic and discourse analysis investigated transcripts and documents, identifying four main 'resistance in experimentation' themes with 11 sub-themes. Materiality identified physical layout, design details, and geographical boundaries as problematic. Institutionalisation identified modelling tools and data availability, built-in skillsets, and experimentation culture as important to successful intervention. Agency/Politics identified stakeholder involvement, time, and resources as further key elements. Discourses identified a norm of unfettered motorised movement, the freedom of choice and self-responsibility, and compromises and balancing as additional important considerations. Results challenge experimentation as a sure way to enable sustainable mobility changes. Infrastructure deprioritising motorised modes requires questioning modernist values of speed and (car) flows. Safety, though touted as important, does not sufficiently justify radical change. These findings provide considerations about potential experimentation pitfalls to policy-makers, ideally improving approaches to cycling infrastructure interventions.

Keywords: urban planning · transport policy, · built environment · experimentation · cycling

1 Introduction

Cycling is reviving globally for urban transportation, potentially exacerbated by the COVID-19 pandemic [4] and e-cycling popularity, though with city-dependent variations [3, 11]. Mature cycling cities like Copenhagen started reversing automobile-centric development in the mid-1970s [7], eventually achieving substantial increases in cycling's

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mode share up to 56% [31]. Cycling is inexpensive, eco-friendly, healthy, space-efficient, accessible for many, and may contribute to social inclusion, liveability, sprawl reduction, urban decongestion, noise reduction, economic benefits and city branding [1, 13, 29], and therefore hailed as sustainable, contingent on driving substitution [15]. Monetizing benefits is notoriously difficult, but the societal costs of cars might be six times higher than cycling when these benefits are internalised [12]. Analysing cycling's integration into an existing transport planning regime is crucial for facilitating sustainable transitions.

In most cities, a majority of trips are below 10 kms [17]. E-bicycles extend these distances within daily travel time budgets [18], and better support trips in hilly terrain. Despite this potential, cycling does not happen without nudging and improving safety perceptions, with Copenhagen-style dedicated bicycle facilities being most effective in reducing perceived and objective threats [8, 16, 22, 24]. UK best-practice guidance recommends separated carriageways in high-speed and -traffic environments [30], and is therefore a key policy measure in attracting 'interested but concerned' cyclists (i.e. latent demand) and achieving cycling uptake [15, 23].

Resistance to new (cycling) infrastructure stems from automobile-dominant path dependency [28]. Motorists may resist new cycling infrastructure if they perceive it threatens convenience, existing road space, increased congestion, longer travel times, or reduced parking availability, or if they perceive cyclists as a nuisance or risk to traffic safety. Public transport operators may resist competition for road space or ridership. Business owners relying on curbside parking might resist a threat to customer accessibility. Government agencies may resist due to budgetary constraints, allocating funds to 'higher-priority' projects. Understanding how cycling infrastructure resistance manifests can inform the policy-making process.

This paper examines the barriers, explicit and implicit, to experimenting with cycling infrastructure through a case study of the Plain Roundabout in Oxford, UK. It analyses four aspects through qualitative thematic and discourse analysis of expert interviews: the spatial context within an existing transport network [6, 9, 25], legitimation through policy and cultural discourses [5, 26], institutionalisation potential [5, 20], and the politics and agency [26, 27]. We argue that transitions towards sustainable urban mobility via experimentation face many constraints. Understanding these barriers can inform how abstract concepts of sustainable mobility are adopted by local actors, how (and if) car dominance is challenged in public debate, and whether, by challenging entrenched power and privilege, access to capital and political influence can become more equitable [2].

1.1 The Plain Roundabout

In April 2013, Oxfordshire County Council submitted a bid to improve The Plain roundabout as part of the Cycle City Ambition Grants program [21]. This roundabout, serving as the primary eastern entry into town, had multiple functions but was not performing adequately for any user group. Given that 70% of Oxford's population resides in East Oxford, The Plain was a critical junction for East Oxford residents' access to the town centre, with limited alternatives [21]. Despite previous renovations approximately 7 years earlier, The Plain had experienced 35 non-fatal collisions in the previous 5 years,

marking it as a safety 'hot spot' and a potential deterrent to cyclists [21]. The successful bid secured just under £1 million for the roundabout's renewal.

The Plain is an unusual 5-arm roundabout, with two entries (Iffley and Cowley Road) forming a narrow angle to each other [21]. Although the roundabout appears spacious, the central island's size cannot be reduced due to the presence of an old churchyard and a large tree at its centre. Additionally, facing the Magdalen Bridge entrance, there is a listed Victorian Fountain with a roof, stone columns, and a clock tower.

2 Data and Methods

Thirteen in-depth interviews were conducted with mobility expert stakeholders including representatives from the Oxford Bus Company, community action groups, city and county governments, technical experts, and Oxford University, and one meeting of the community action group was attended to collect cyclist testimonials. Semi-structured interviews were collected between February and May 2015, with additional follow-up interviews in January and February 2016, and lasted approximately 60 min. Participants were recruited by contacting individuals mentioned in the documentation analysis (City Cycling Grant bid material, transport plans, infrastructure guidelines, media articles, and design versions), in the Oxford City Council, and through further snowball sampling. An interview guide was used, consisting of a short introduction, then questioning 1) participant background and role, 2) perspective on the project timeline, 3) controversies and trade-offs, 4) issues emerging in previous interviews, and 5) the data, evidence or KPIs that formed their views and decisions. The semi-structured format allows for flexibility in the questioning approach and provides an ultimately richer dataset to understand the attitudes and opinions of the experts. The interviews were recorded and transcribed by the authors to ensure accuracy. Additional documentation including planning designs, City Cycling Grant bid material, infrastructure guidelines, and media coverage were also included in the analysis.

A combination of qualitative thematic and discourse analyses were employed to identify relevant themes and understand the social context of the language used relating to different forms of resistance leading to the failure of this cycling infrastructure experiment. In terms of discourse analysis, patterns of speech, socio-cultural norms, or common references, for example, become the unit of analysis in place of the participants [14]. In other words, as individuals tend to select language that justifies their actions or beliefs, the identification of commonly-used discourses can be useful for understanding their relationships to action. In both types of analysis, inductive coding (or the 'emic' approach) was employed, allowing the themes and narratives to be derived from the data instead of predefining the themes [10].

3 Results

Resistance to experimentation with path-breaking change in the Oxford transport regime manifested in four different categories, with 11 sub-themes (Table 1), discussed below. Materiality analysed the physicality of The Plain, and to what extent stakeholders rationalised that this physicality allowed or constrained the possibility for experimenting

with novel cycling designs. Institutionalisation explored how transport institutions form constraints. Institutionalisation analysed in detail the power held by various stakeholders within reflexive governance. Discourses uncovered certain implicit 'mindsets' that can help explain the decisions made and the 'limits of the possible'.

Table 1. Resistance to experimentation with path-breaking change in Oxford transport regime

Materiality	Institutionalisation	Agency/Politics	Discourses
Physical layout and vehicle sizes	Modelling tools and data availability	Levels of stakeholder involvement	Unfettered motorised movement
Experimenting with protected cycle tracks	Built-in skillsets, experience and expertise	Time and resources	Freedom of choice and self-responsibility
Attention to design details	Culture of experimentation		Cycling as mainstream

4 Discussion and Conclusion

The case study presented at The Plain offers insight into resistance toward experimentation that challenges historical norms of unfettered motorised movement. Though the arena of automotility of the past has minimised through Oxford's shift toward buses and cycling tracks, The Plain remains in an arena of high-flow shared space with resistance through Materiality, Institutionalisation, Agency and Discourses preventing a shift toward nearly car-free shared space. This presents a point of decision about the future of mobility - should mode-specific infrastructure be prioritised or should vehicle-dominance remain unchallenged? As decarbonising transport can be expected to bring more diversification in transport vehicles in the future, deciding what will be allowed to run where is likely to become increasingly relevant. Further, as high-flow shared space does not provide a safe space for movement for all travellers (in fact, road-safety protests have been hosted at The Plain as recently as 30 September 2023 following the release of road death figures [19] and a cycling fatality at The Plain in March 2023), choices must be made about what the goal should be for mobility space and which travellers should be prioritised.

In sum, the example of The Plain challenges the notion of experimentation as a sure way to break the status quo and enable change towards more sustainable mobility. Changes toward infrastructure that deprioritize motorised modes will require the questioning of modernist values of speed and unfettered movement. Safety, though touted as an important issue, is not sufficient to justify radical change. Infrastructure interventions are more than just a prioritisation of mode and space, but a product of geographical and material reality, the historical-institutional perspective, and the validity of some discourses against others. These findings can help to provide considerations and information about potential pitfalls in experimentation to policy-makers, ideally improving approaches to new cycling infrastructure interventions.

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Characterization of Accidents with Cyclists in Lisbon: Study on the Built Environment Factors

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Abstract. This study analyses the built environment factors that most impact the severity of injuries in cyclist accidents in Lisbon, Portugal.

The most common type of bike lane in Lisbon is the protected bike lane, making up 49% of all bike lanes. This is positive from a safety point of view since the physically separated bike lanes offer the best protection for cyclists. On the other hand, of the 24 districts that compose the city of Lisbon, there are 7 with less than 1 km of protected bike lanes, showing that the distribution of the bicycle infrastructures can be improved upon.

The data on which this study is based are for the years 2015 to 2019 (inclusive). To determine which built environment is most relevant in injury severity, 2 modeling runs were performed: multinomial logistic regression, and ordinal logistic regression. The dependent variable chosen was "Injury severity", with 3 distinct categories: unharmed (40 cases), slight (387), and severe (12).

It was seen that accidents that occurred at intersections, at night, or in the central zone of Lisbon had a higher probability of resulting in severe injuries than accidents that occurred outside of these conditions.

Keywords: Bicycle accidents · Injury severity · Cycling infrastructure

1 Introduction

Many European cities encourage the use of bicycles, due to factors such as air pollution, congestion, and parking problems, among others (ANSR, 2017). However, with an increase in cyclists comes an increase in accidents and severe injuries. It is essential to understand which built environment factors have the greatest impact on injury severity, in order to understand the best measures to mitigate accidents involving cyclists.

Cyclists are more fragile than other drivers. While other drivers are injured 48% of the time they are involved in an accident, cyclists are injured 95% of the time (ANSR, 2017).

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Cycling infrastructure, when implemented correctly, increase safety not only for cyclists but also for all other users of public space (Skoczyński, 2021). Since Lisbon was chosen as the city of study, it is important to understand the distribution of cycling infrastructure in the city and their respective kilometers.

Lisbon has a good density of cycle paths in some areas, but it also sometimes shows a lack of continuity in these infrastructures and a lack of homogeneity in terms of distribution across the different areas of the city.

In order to understand which factors lead to the most severe injuries, the analysis of this study focused on intersections, time of the day, cycling (and non-cycling) infrastructure, and different areas of Lisbon (called clusters). The data used was taken from ANSR (Portuguese National Road Safety Authority) and Câmara Municipal de Lisboa (Lisbon City Hall).

2 Lisbon as a Case Study

Lisbon is a low cycling mature city, which means that it has a very small modal share, to be more precise, it has less than 1% (Félix, 2019). Additionally, Lisbon's incipient cycle infrastructure is one of the main reasons for its lower modal share of bikes (Moura et al., 2017).

Lisbon is known for having high gradients, but 73% of its streets have slopes below 5%, making it an accessible city for most cyclists (Câmara Municipal de Lisboa, 2020). Lisbon has 49% of all cycle infrastructures being protected bike lanes, which means that 49% of all bike lanes offer a physical separation between cyclists and other drivers. The second most common type of bike lane in Lisbon is the mountain bike trail, making up 26.8% of all bike lanes. It's important to note that this type of cycle path is usually used for leisure rather than for commuting.

Figure 1 shows the different types of bike lanes in Lisbon and their distribution across the map. The dark blue line represents protected bike lanes, the dark green line represents mountain bike trails, the red line represents sharrows, the orange line represents buffered bike lanes, and the light green line represents bike lanes shared between pedestrians and cyclists.

Most of the mountain bike trails can be found in the Monsanto area, an area characterized by having a dense forest. The protected bike lanes are distributed throughout the city, and alongside the Tagus River (south border of the map). The sharrows are mostly located in the inner areas of the city since they are commonly used in residential areas. The other types of bike lanes are less common, which can also be seen in Fig. 1.

Lisbon has 24 districts. To better understand the characteristics of each zone of Lisbon, the 24 districts were grouped into 5 distinct clusters. This grouping was done by joining the most homogeneous districts together, but also by taking geography into account (sharing borders with each other).

The districts were grouped as follows:

1. Cluster 1 (in green in Fig. 2) groups Benfica, São Domingos de Benfica, Carnide, Lumiar, and Santa Clara
2. Cluster 2 (in orange) groups Santo António, Arroios, Campolide, Avenidas Novas, Areeiro, and Alvalade

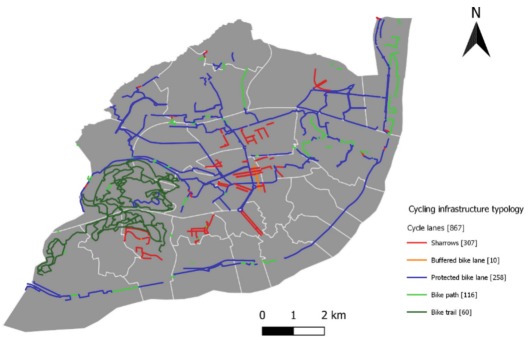

Fig. 1. Cycle infrastructure in Lisbon. Source: Created by the authors using GIS software.

3. Cluster 3 (in purple) groups Campo de Ourique, Estrela, Misericórdia, Santa Maria Maior, São Vicente, and Penha de França.
4. Cluster 4 (in blue) groups Beato, Marvila, Olivais, and Parque das Nações
5. Cluster 5 (in yellow) groups Belém, Ajuda, and Alcântara.

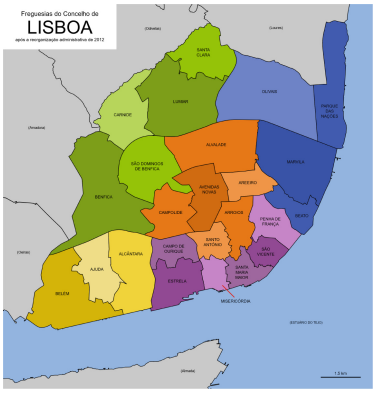

Fig. 2. District divided into 5 different zones (Organização administrativa de Lisboa, 2012). Retrived from https://www.am-lisboa.pt/451600/1/009001,000531/index.htm.

With this grouping, it can be seen that the number of accidents in clusters 4 and 5 is the lowest (Table 1). For this reason, these two clusters were merged for the modeling, forming a new cluster, named "Cluster 4 and 5".

Table 2 shows the kilometers of cycle infrastructure in each cluster, with Cluster 1 and Cluster 2 having the highest values.

Table 1. Number of accidents per Cluster

Zone	Number of accidents
Cluster 2	153
Cluster 3	100
Cluster 1	81
Cluster 4	61
Cluster 5	56

Table 2. Kilometers of cycle infrastructure per Cluster

Zone	Cycle infrastructure (km)
Cluster 1	69,4
Cluster 2	53,3
Cluster 4	43,9
Cluster 5	41,6
Cluster 3	12,6

3 Analysis of Model Results

3.1 Regression's Overview

For the modeling, two regressions were carried out with good results. One was multinomial logistic regression, and the other was ordinal logistic regression. Although they are similar, they differ in the nature of their dependent variable. Multinomial logistic regression uses a nominal categorical dependent variable, which means that the categories of the variable do not have an inherent order. Ordinal logistic regression uses a categorical ordinal dependent variable, which means that the categories have an inherent order between them.

The dependent variable used, and its categories, were the same for both regressions, but in the multinomial, it was considered that there was no order between the categories, while in the ordinal it was considered that there was an inherent order between categories. The dependent variable chosen was injury severity, with 3 categories, Unharmed, Slight injury, and Severe injury. For the ordinal case, it was considered the order of least severe injury (Unharmed) to most severe (Severe injury).

For both regressions, 10 independent variables were considered, but for the analysis that follows, the focus will be on just 4 of these 10, as they are the ones that most meet the objective of this study. The 4 independent variables to be analyzed are:

- Intersections – This variable considers whether the accident occurred outside or inside an intersection
- Hour – This variable represents the time of day the accident occurred, with 3 categories, Morning, Afternoon, and Night

- Cluster – As seen earlier, this variable represents the different areas of Lisbon, and provides information on which cluster the accident occurred in
- Bike infrastructure - This variable considers whether the accident occurred outside or inside a bike infrastructure

3.2 Multinomial Logistic Regression

Multinomial logistic regression showed that when compared to slight injuries, accidents that occur at intersections have a higher chance of resulting in severe injuries.

Accidents that occur at night also have a higher chance of resulting in severe injuries than slight injuries or even unharmed.

As for the different clusters, it was seen that the probability of an accident resulting in severe injury (compared to unharmed) is higher in Cluster 2 than in Cluster 3 and Cluster 4 and 5.

The results for bike infrastructure were not significant. Although it was not possible to prove that bike infrastructure has an impact on injury severity, this does not prove that bicycle infrastructure has no impact on injury severity.

3.3 Ordinal Logistic Regression

The ordinal logistic regression showed similar results to the multinomial logistic regression, corroborating the inferences of the multinomial model.

Accidents that occur in the evening showed a higher probability of resulting in severe injuries, compared to accidents that occur in the morning.

Accidents that occur in Cluster 2 showed a higher probability of resulting in severe injuries than in Cluster 3 and Cluster 4 and 5.

The variables intersections and bike infrastructures didn't show any significant values for this regression, so no conclusion was taken from this part of the analysis.

4 Conclusions

A few conclusions were taken from this study. At night, accidents are more likely to result in serious injuries, possibly due to poor visibility, and excessive alcohol consumption, among other possible reasons. It was also found that accidents at intersections lead to more serious injuries. As for the cycle infrastructure variable, no conclusive results were obtained, since none of the regressions led to statistically significant values.

Cluster 2 had a higher chance of severe injuries. This result makes sense given that this is the cluster with the highest number of intersections per km^2. On the other hand, this cluster has the highest value of km of cycle infrastructure, which could indicate that it would be safer for cyclists. One reason for the contradictory result could be that there is simply a greater flow of cyclists in this area, which could lead to more accidents and more severe injuries.

With this information, some accident mitigation measures are suggested below:

- Improvement of visibility at night, especially in the cluster 2 zone, and in intersections
- Implementation of more bike lanes that offer physical separation. Even though in this analysis it was not possible to fully understand the impact of cycle infrastructures on the injury severity of bicycle accidents, the bike lanes that offer a physical separation are one of the most secure options for cyclists (Cohen, 2013), and the increasing development of bicycle lanes should decrease some dangers of cycling (Skoczyński, 2021)
- The implementation of speed bumps (Broach et al., 2012) and sharrows (Skoczyński, 2021) especially in residential zones to not worsen the overall traffic of the city
- Implementation of a road safety system that allows for infrastructure treatment of accumulation spots (Carvalheira & Picado-Santos, 2008)

In conclusion, this study shows that there are a few factors that are of paramount importance when dealing with severe injuries of cyclists, and that those factors should be one of the main focus areas when developing mitigation strategies.

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Next-Day Effects of Social Drinking on Driver Fatigue and Driving Performance

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Abstract. Binge drinking of alcohol leads to worsened driving performance the following morning, even when the blood alcohol concentration (BAC) has returned to or is close to zero. The objective of this study was to investigate the effects of social drinking (BAC = 0.05%) on next-day driver fatigue and driving performance. A homogenous sample of 32 experienced male drivers drove for 35 min on rural and urban roads in a driving simulator, both the day after drinking alcohol and the day after a sober evening. The main effects on next-day performance were ambiguous, where self-assessments showed lower next-day performance and higher subjective sleepiness after drinking alcohol in the evening, whereas variability in lateral position, heart rate variability and attention showed worse next-day performance in the control condition. Overall, the effect sizes were small. The results indicate that a BAC level of 0.05% does not influence next-day performance after a full night's sleep to any greater extent. Further studies including a placebo condition are needed to verify this result, also considering more BAC levels, long-term effects of habitual drinking, and longer driving times.

Keywords: Alcohol · intoxication · next-day performance · driver fatigue

1 Introduction

Alcohol impairs performance and has a clear negative impact on traffic safety [1, 2]. Beyond the direct effects of alcohol there are also next-day hangover effects with performance impairments for several tasks related to short- and long-term memory, psychomotor speed, and sustained attention [3].

It has been hypothesized that alcohol induced impairments in sleep quality/duration, in combination with subsequent daytime sleepiness, is a contributing factor to the next-day effects on cognitive performance [4]. In a driving setting, post-alcohol and next-day effects of larger amounts of alcohol have been established in several studies [5–8], however, next-day effects of low or moderate amounts of alcohol on driver fatigue are largely unknown.

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The purpose of the present study was to investigate next-day effects of alcohol in the evening on subjective and objective indicators of fatigue and driving performance. The underlying hypothesis was that alcohol in the evening would affect night-time sleep which in turn would lead to increased fatigue levels and impaired driving performance the following day. A study was thus set up to compare the development of driver fatigue while driving in a simulator both the morning after drinking alcohol (target BAC = 0.05%) and when driving on a morning with no alcohol in the evening.

2 Methods

A homogenous sample of 32 experienced male drivers aged 25–60 years, with a body mass index < 35, and with moderate drinking habits with an Alcohol Use Disorders Identification Test [AUDIT; 9] score ≤ 7, were recruited for the study. All participants gave their informed consent. The study was approved by the Swedish Ethical Review Authority (Dnr 2021–05701-01).

The study had a within-subject 2×2 design with a factor for next-day effects (after alcohol in the evening vs a control condition with no alcohol in the evening) and a factor for drive time (morning/forenoon). Next-day effects data were collected on two separate occasions in counterbalanced order. Before the next-day alcohol condition, the participant came to the lab in the evening, made a baseline drive, drank alcohol, made an intoxicated drive, and then went home to sleep. Alcohol doses were determined based on Hume–Weyers formula [10]. The targeted BAC level was 0.05% which corresponds to "social drinking". The achieved mean BAC level was $0.055 \pm 0.009\%$, as measured with a Dräger 6820 breathalyser (Drägerwerk AG & Co, Lübeck, Germany).

The tests were conducted in a fixed-base driving simulator with a vehicle mock-up and three computer screens with a visual angle of about 150 degrees. The simulated route consisted of two parts, a rural road that took about 25 min to drive followed by an urban scenario that took about 10 min to drive. The rural road had a speed limit of 70 km/h and was intended to be monotonous and fatigue-inducing. There was no traffic in the own lane and only scarce traffic in the oncoming lane. The urban scenario was more active, requiring planning ahead for smooth progress. Other road users were present, including pedestrians and bicyclists. Several changes in the speed limit occurred (the main speed limit was 50 km/h, with 3 temporary changes to 30 km/h and 1 change to 70 km/h). The goal was to create a scenario that required the driver to attend to numerous targets in several directions, but without any unpredictable critical incidents. The driving simulator was equipped with a 4-camera eye tracking system (Smart Eye Embedded Tracking SDK v12.0, Smart Eye AB, Gothenburg, Sweden). An electrocardiogram (ECG, lead II) and a vertical electrooculogram (EOG) were recorded with a Vitaport 3 bio-amplifier (Temec Instruments BV, the Netherlands). A 3-min psychomotor vigilance task [PVT; 11] was performed before and after each drive in the simulator.

Several indicators targeting driving performance in general, and fatigue in particular, were calculated. Sleep quality the night before the experiment was assessed via a sleep diary where the participants logged when falling asleep and waking up. They also rated their sleepiness level when waking up on the subjective 9-level Karolinska Sleepiness Scale [KSS; 12], and assessed if it had been difficult falling asleep(1 – very difficult, 5 – not at all), if they had gotten enough sleep during the night (1 – not at all, 5 – definitely),

if they felt rested (1 – not at all, 5 – definitely), and how many times they had woken up during the night (0, 1, 2, 3 or more).

Results from the PVT tests were quantified as the mean reaction time and the number of lapses (≥355 ms). Before the PVT test started, they rated their sleepiness level on the KSS scale, how they believed that alcohol would affect their driving (scale 0–10), and how well they would likely drive (scale 0–10). The two latter questions were rephrased in the post-drive assessments to reflect how well they had performed during the drive.

Performance indicators were calculated in 3 km segments during the rural drives. The shorter urban route was treated as one segment. KSS was rated every fifth minute during the drives and the nearest rating in each segment was used throughout the drives. Driving performance was assessed as the standard deviation of lateral position (SDLP), as the proportion of the drive exceeding the speed limit weighted by the amount of speeding (speeding index), and as the number of times that the time headway (THW) was ≤ 2 s. SDLP was only assessed on the rural road since the road geometry had a large impact on the indicator in the urban scenario, and THW was only used in the urban analyses since there were no other traffic in the own lane on the rural road. Blink duration and peak eyelid closing velocity were extracted from the EOG, heart rate and the normalize low and high frequency components (LF and HF) of the heart beat signal were extracted from the ECG, and the pupil diameter and attention level [13] were extracted from the eye tracking data.

The performance indicators were analysed with mixed-model analyses of variance (ANOVA), using fixed factors for *next-day* effects (after alcohol in the evening versus a control condition with no alcohol in the evening), *drive time* (morning/forenoon), before versus after each drive (before/after), distance driven (10 segments from 0 – 30 km). Participant (1–32) was included as a random factor. The significance level was set to 0.05. Bonferroni correction was used to compensate for multiple comparisons. Data preparation and statistical analyses were performed in MATLAB 9.9 (The Mathworks Inc., Natick, MA, USA).

3 Results

The subjective sleep diaries after the night with alcohol in the evening versus the control night showed no significant differences in total sleep time, KSS, difficulty falling asleep, and feeling well rested in the morning. The participants woke up more often after drinking alcohol in the evening (mean ± standard error alcohol vs control, 4.22 ± 0.14 vs 3.56 ± 0.13, $F_{(1,54)} = 10.55$, $p = 0.003$), and provided lower ratings on the question whether they had slept enough during the night (1.09 ± 0.15 vs 1.78 ± 0.15, $F_{(1,54)} = 10.74$, $p = 0.003$).

The PVT measurements indicated slower reaction times and more frequent lapses after the sober evening, but these differences were not significant. The self-ratings done in connection with the PVT showed slightly higher KSS ratings the day after drinking alcohol compared to after a sober evening (4.41 ± 0.06 vs 3.79 ± 0.06, $F_{(1,184)} = 20.41$, $p < 0.001$). They also felt more affected by alcohol (0.58 ± 0.06 vs 0.00 ± 0.00, $F_{(1,183)} = 52.50$, $p < 0.001$) and believed that their driving quality was better (7.23 ± 0.09 vs 7.56 ± 0.09, $F_{(1,183)} = 6.26$, $p = 0.01$).

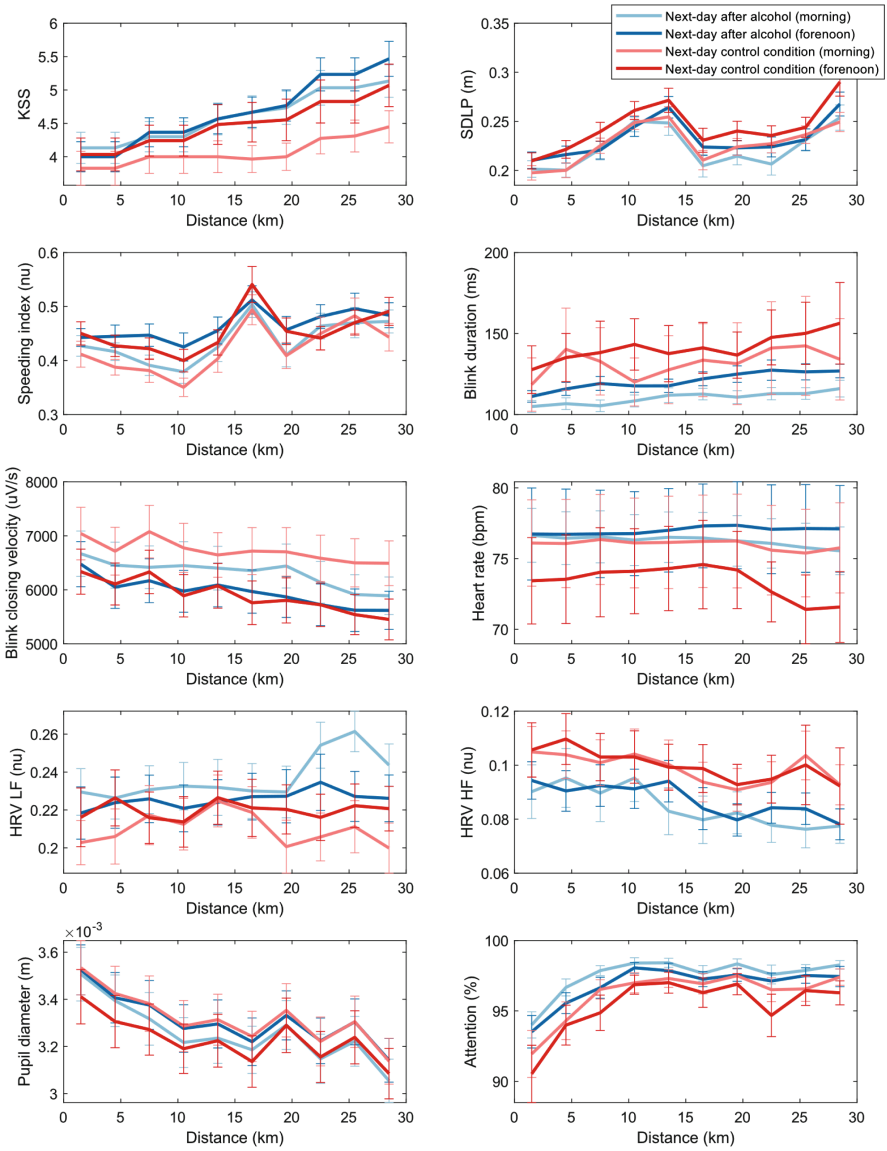

Fig. 1. The mean values of each performance indicator computed on the rural road for each of the 10 segments (distance driven), separated by the next-day condition (after alcohol vs control) and by the two driving sessions (morning, forenoon). The error bars represent standard error of mean.

When driving on the rural road stretch, the participants rated themselves as more fatigued the day after drinking alcohol (4.63 ± 0.03 vs 4.28 ± 0.03, $F_{(1,1138)} = 51.48$, $p < 0.001$), while SDLP was larger (0.228 ± 0.001 vs 0.234 ± 0.001, $F_{(1,1138)} = 7.40$, $p = 0.007$) and blink durations were longer (114.37 ± 2.48 vs 135.78 ± 2.58, $F_{(1,1048)} =$

35.32, $p < 0.001$) in the control condition,. Elevated HRV LF (0.21 ± 0.002 vs 0.23 ± 0.002, $F_{(1,1041)} = 25.81$, $p < 0.001$) and higher attention levels (96.84 ± 0.12 vs 95.86 ± 0.13, $F_{(1,1058)} = 28.50$, $p < 0.001$) in the alcohol condition indicates that the participants try to compensate in order to perform well. Significant effects were also found for HRV HF (0.098 ± 0.001 vs 0.087 ± 0.001, $F_{(1,1041)} = 33.62$, $p < 0.001$) and pupil diameter (3.33 ± 0.006 vs 3.28 ± 0.006, $F_{(1,1048)} = 39.41$, $p < 0.001$). Note that all differences in next-day performance, even though significant, are small (fractions of a KSS unit, centimetres of SDLP, a few milliseconds of blink durations, etc.), see also Fig. 1. Like the PVT results and pre/post drive ratings, the subjective and objective ratings go in different directions in terms of fatigue. For the other factors in the analyses, there were expected and clear time on task effects in most indicators. Performance and fatigue were also worse/higher in the morning drive compared to the forenoon drive, regardless of alcohol.

For the urban road stretch, no significant next-day differences were found except for KSS ($F_{(1,321)} = 34.01$, $p < 0.001$) and attention level ($F_{(1,296)} = 8.42$, $p < 0.001$), which can both be explained as carryover effects from the rural scenario. Note that a different set of performance indicators were used for the urban scenario, aiming to bring out possible next-day differences in visual perception and anticipatory driving.

4 Conclusions

Taken together, our results indicate that a low amount of alcohol in the evening (BAC $\leq 0.05\%$) does not affect driver fatigue, driving performance or sustained attention after a normal night's sleep. Subjectively rated performance measures indicated higher fatigue levels the next day, while objective measures went in the other direction or were insignificant. Overall, detected differences in performance were small when comparing next-day performance after drinking alcohol compared to a control condition with no alcohol in the evening. There might still be a next-day risk of long-term fatigue on longer drives, especially if drivers are over-compensating and thus risk becoming fatigued due to overload. Further studies including a placebo condition are needed to verify the results, also considering longer driving times and more BAC levels.

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Spatio-Temporal Analysis of Speed Limit Exceedances in Dublin Using Low-Cost Sensors and Citizen Science

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Abstract. Driving above the speed limit increases the risk of a crash scenario, and poses a safety risk to the driver, to passengers and to bystanders. The relationship between vehicle speed and risk of an accident is exponential, e.g. a 2 km/h increase in speed increases the risk of a fatal accident by 20%, while a 10 km/h increase raises the risk by 120%.

The EU H2020 WeCount project used low-cost traffic sensors in five case study areas across Europe to enable citizens to measure traffic and car speeds on their streets. In Dublin 147 citizens participated in the project and installed a camera based sensor in their window.

The aim of this study is to analyse the influence of environmental factors, e.g. road layout, traffic volume, weather, on the proportion of cars exceeding the speed limit during a six month study period. Data was collected between 6:00 and 18:00 from 21/3/2021 to 21/9/2021. The statistical analyses included descriptive analyses and beta regression models.

The analyses of spatially varying predictor variables has shown an association between speeding and the assigned speed limit of a road, with a higher proportion of speeding on roads with a 30km/h speed limit. Further analyses of temporally and spatio-temporally varying predictor variables are still ongoing.

Keywords: Speed limit; Low-cost sensor · Citizen science

1 Introduction

1.1 Background and Motivation

Vehicles driving at speeds exceeding the legal speed limit of a road is a common problem worldwide. A survey of road users' attitudes in 20 European countries found that on average 56.3% of respondents drove faster than the speed limit inside built-up areas at least once in the previous 30 days [1]. When analysing responses by country this percentage ranged from 40.5% in Italy to 72.9% in Iceland, with a speeding prevalence of 45.1% in Ireland [1].

Driving above the speed limit increases the risk of a crash scenario, and poses a safety risk to the driver, to passengers and to bystanders. The World Health Organisation

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lists road traffic accidents as the leading cause of death in people aged 5–29 years, and experts estimate that 30% of fatal injury crashes are associated with speeding [2, 3]. The relationship between vehicle speed and risk of an accident is exponential. For example, a 2 km/h increase in speed increases the risk of a fatal accident by 20%, while a 10 km/h increase raises the risk by 120% [2, 4]. Similarly, the risk of death increases exponentially. Research from France has shown that that the risk of death of a pedestrian when hit by a car in a frontal collision increases 2 fold between 30 km/h and 40 km/h, and 6 fold between 30 km/h and 50 km/h [5]. This combination of high prevalence and high risk suggests that speeding should be treated as a major public health concern.

Speeding is influenced by many factors, including factors related to individuals and factors related to the environment. Individual factors can be related to socio-demographic factors, as well as personality traits, social norms and cultural values [6]. For example, age and gender are known to influence individual speeding behaviour, with 16–24 year olds more likely to speed than older age groups, and males more likely to speed than females [7]. Furthermore, drivers with higher household incomes are more likely to speed than drivers from low household incomes. The personality traits of anger-aggression and impulsive-sensation seeking have also been found to be associated with speeding behaviour [8].

Relatively few studies have investigated environmental factors associated with speeding. These studies used driving simulators [9–11], surveys [12], speed cameras [13] and GPS tracking [14–17], and it was found that a range of environmental factors are related to speeding including lane width, shoulder width, number of lanes, posted speed limit, roadside activity.

Speed limit exceedances can be detected using a number of methods, including stationary or mobile cameras, and laser guns. In many countries, the spatial coverage of these methods is limited and only a small fraction of roads can be covered. For example, County Dublin, Ireland, has a road network length of 3950 km, but only 295 camera safety zones. However, citizen science and low-cost sensor networks can help to overcome this limitation by providing additional datasets.

The aim of this study is to analyse the influence of environmental factors on the percentage of cars exceeding the speed limit in Dublin based on data collected during a citizen science campaign in 2021.

2 Materials and Methods

2.1 Data Collection and Preparation

WeCount was an EU H2020 project, which used low-cost traffic sensors to measure traffic and car speeds in five case study areas across Europe (Leuven, Barcelona, Cardiff, Ljubljana, Dublin). In Dublin 147 citizens participated in the project. Participants installed a camera based sensor on a window of their house or flat, which overlooked a road. The sensor recorded the number of cars, heavy vehicles, bikes and pedestrians per hour, and it also recorded the frequency distribution of car speeds per hour. Measurements were only collected during daylight hours. Data collected by the sensor was automatically

uploaded to an open access platform (https://we-count.net/networks/dublin), which displayed hourly counts at the street segment level. Data on this platform is openly accessible and can be downloaded via an API.

We downloaded data collected in the Dublin area between 21/03/2021 and 21/09/2021. The low-cost camera based sensors only collected reliable data during daylight; therefore, only hourly data collected between 6:00 and 18:00 h was used. Initially, we used OpenStreetMap to extract the speed limit of each street segment in the WeCount Dublin dataset. However, spot checks indicated errors in the OpenStreetMap speed limits; therefore, the speed limits on all segments were manually verified against GoogleStreetView images. Using the verified speed limit of each road, we calculated the number and percentage of cars driving above the speed limit for each hour and each segment. This data was the outcome variable in our analysis.

Potential predictor variables were extracted from several sources of open data, including OpenStreetMap and Met Eireann. The predictor variables used in the analyses can be categorized into spatial variables, temporal variables and spatio-temporal variables, as shown in Table 1.

Table 1. Predictor variables used in analyses.

Spatial variables	Temporal variables	Spatio-temporal variables
Speed limit on road, Road width, Presence of bus stops on segment, Presence of traffic lights on segment, Area socio-economic status, Distance to the nearest school	Time of day, Weekday, Weekend, Rain, Sunshine, Visibility	Number of cars per hour, Number of heavy vehicles per hour, Number of bikes per hour, Number of pedestrians per hour

2.2 Statistical Analysis

First, we used standard descriptive analyses to gain an initial understanding of the dataset. This included heat maps of each measured street segment that showed the median percentage of cars above the speed limit by weekday and time of day. To analyse the spatial predictor variables, we calculated the total ratio of speeding for each segment, i.e. the sum of cars driving above the speed limit during the whole study period divided by the total number of cars during the whole study period. Since the outcome variable is a ratio, we used Bayesian beta regression models. To analyse the temporal and spatio—temporal variables, we will test zero one inflated beta models [18] and ordered beta regression models [19], as segments can have hourly speeding ratios of 0 or 1. These analyses are very processing intensive and are still ongoing at the time of writing this paper. All statistical analyses were carried out in in R v4.3.1 [20] and Stan v2.26.1 [21].

3 Results

Using the API, we extracted data from 114 segments in Dublin for the study time period. However, some segments had large amounts of missing data, so after further data cleaning procedures, we used data from 106 segments. Figure 1 shows the spatial variation in the total percentage of cars speeding per segment. No clear spatial trend is apparent; however, the map does suggest some hot-spot areas in Sandymount and near Crumlin. Table 2 shows descriptive statistics of the number and percentage of cars driving above the speed limit per hour and in total.

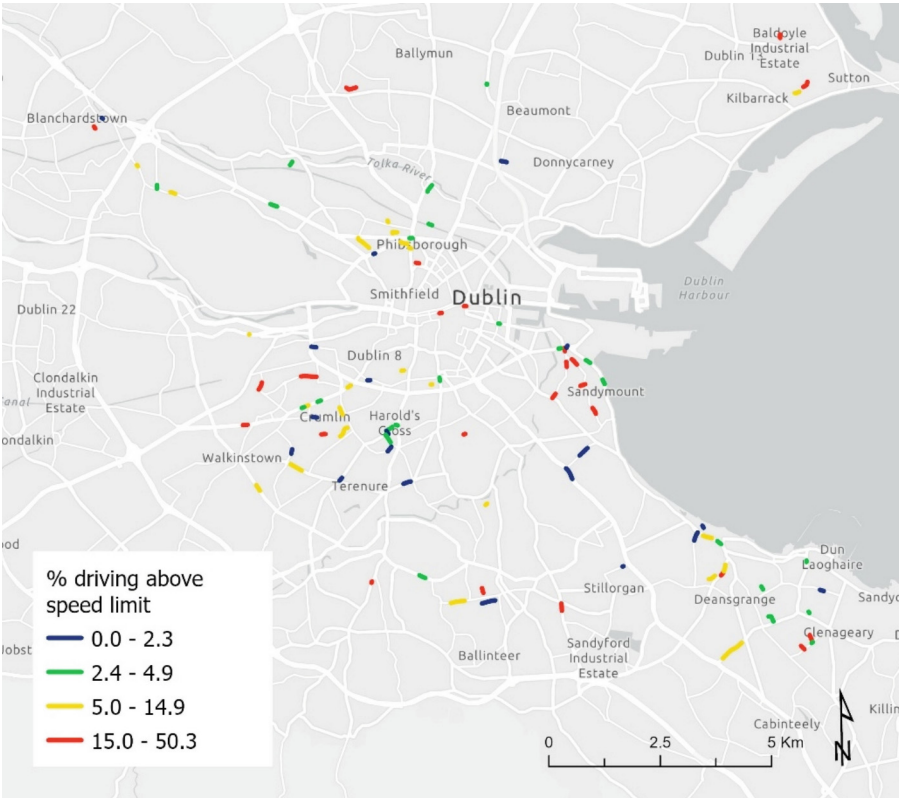

Fig. 1. Street segments in Dublin indicating the total percentage of cars driving above the speed limit during the study period (created with ArcGIS Pro v2.9)

Figure 2 shows examples of the speeding patterns by time of day and weekday from three different street segments. The first example is a street segment with relatively low, but consistent speeding throughout the day and week. The second example shows street segment with high proportions of speeding, but also in a consistent pattern. The third example shows a variable pattern of speeding, with higher speeding in the evenings and on weekends.

Table 2. Descriptive summary statistics of hourly data from 106 street segments.

	N driving above speed limit	% driving above speed limit
Minimum per hour	0	0
Mean per hour	17.2	11.0
Median per hour	5.32	3.86
Maximum per hour	305.6	100
Total	3,062,608	7.4

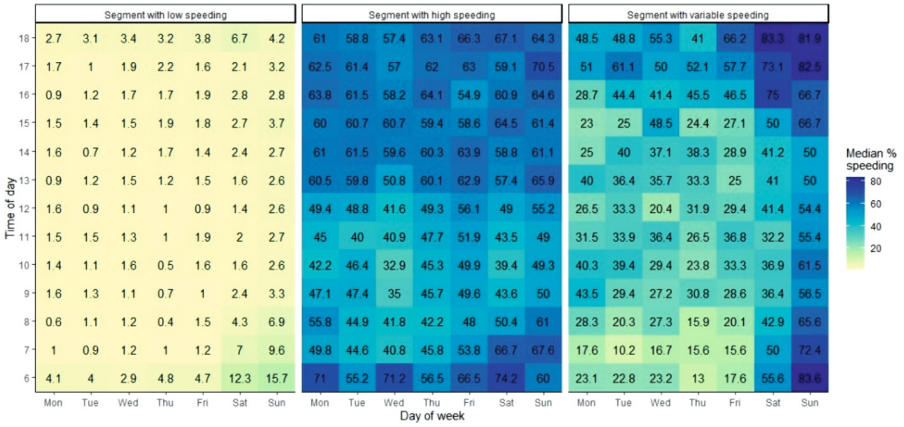

Fig. 2. Heatmaps showing the median percentage of cars driving above the speed limit by Time of day and weekday at three example sites (created with R v4.3.1)

As stated above, the analyses of the temporal and spatio-temporal predictor variables is still ongoing. The analyses of the spatial variables showed an association between the ratio of cars speeding and the posted speed limit, but not with any other of the spatial predictor variables. The posterior average marginal effects of posted speed limits of 50 km/h and 60 km/h compared to 30km/h are shown in Table 3. It can be seen that the proportion of cars speeding on 50 km/h and 60 km/h street segments is significantly lower than on 30 km/h street segments.

Table 3. Posterior average marginal effects.

	Estimate	95% Highest Posterior Density Interval	
50km/h vs 30km/h speed limit	-0.112	-0.161	-0.071
60km/h vs 30km/h speed limit	-0.140	-0.188	-0.080

4 Discussion and Conclusion

This paper presents findings from a study of the percentage of cars speeding in Dublin based on data collected during a citizen science campaign of 106 street segments. Preliminary analyses of potential predictor variables that only vary spatially indicate that the assigned speed limit of a road is associated with speeding. The proportion of cars speeding is significantly higher on street segments with a 30km/h speed limit than on street segments with a 50km/h or 60km/h speed limit. This is an important finding, because streets with a 30km/h speed limit are often found in residential area, near schools and near shopping areas. These types of streets are likely to have more pedestrians on or near them, which means a larger population is exposed to a higher proportion of speeding cars. In contrast, streets with a speed limit of 50km/h or 60km/h are often larger arterial roads, which pedestrians are more likely to avoid. An association between speeding and the assigned speed limit of a road was also found in a study by Ambros et al. (2020) [14], who found a higher proportion of speeding on roads with a 50km/h limit, compared to roads with a 70km/h or 80km/h limit.

We did not find an association between speeding and road features, such as the presence of bus stops or traffic lights, or the road width. Other studies have found that roadside features, such as bus stops, trees, or buildings can reduce speeding [9, 10, 12, 14], and road width in particular has been found to have an influence on speeding [11–13]. A possible reason for a lack of association in our study could be the quality the predictor variables, as they were extracted from OpenStreetMap data. If a more accurate and detailed dataset was available of the street layout at each segment, these analytical results may change.

The total number of cars exceeding the speed limit during the six month time period was 3,062,608 (Table 2). The current fixed penalty charge in Ireland for exceeding the speed limit is €160 and 3 points on the driver's license. Therefore, the speed limit exceedances measured during this study would have been equivalent to penalty charges of €490 million and 9.2 million points. On 4th September 2023 the Irish police (An Garda Síochána) held a National Slow Down Day with speed checks by both Garda members and GoSafe Safety Cameras. Over 24 h the speeds of 149,488 vehicles were checked, and 865 cars were recorded as speeding [22], which is equivalent to 0.6%. Our study measured a much higher proportion of speeding (7.4%), and given the data from previous road users' surveys [1], we would expect that 7.4% underestimates the true value. Based on newspaper reports, the National Slow Down Day seemed to focus on motorways, national roads and regional roads with high speed limits, which may explain the low percentage of speeding.

Based on the preliminary findings of our research, we would recommend to deploy more speed cameras on local roads with low speed limits as the proportion of speeding is higher on these roads and a larger population is at risk.

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Investigating the Influence of Mobile Phone Use on Driving Behaviour with Machine Learning Analysis

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Abstract. This paper aims to investigate the impact of mobile phone use on driving behaviour and more specifically the sizes of the speed, acceleration and lead time through statistical analysis of imbalanced data using Machine Learning techniques. For classification and regression of mobile phone usage, telematics data from the OSeven, collected from naturalistic measurements, were used. Mobile phone use was defined as an indicator of risky behaviour and classification was performed on two levels of driving behaviour (risky and not risky). Variables related to travel speed were found to be the most significant independent variables, while according to the classification evaluation metrics, the most appropriate model was considered to be that of Linear Discriminant Analysis. Furthermore, a significant proportion of the drivers, about 25% of those recorded, used a mobile phone during driving without being aware of the activity for which they were using their mobile telephone.

Keywords: Machine Learning · road behaviour analysis · road safety · naturalistic driving · mobile phone usage · classification · regression

1 Introduction

According to the World Health Organization (WHO), every year about 1.3 million people lose their lives in road crashes and 20 to 50 million people are seriously injured as a result of the crash. The mobile phone usage is a main factor of driver distraction. Using a handheld cell phone while driving places drivers under the burden of three distinct tasks: first, the act of locating and glancing at the phone diverts their gaze away from the road; second, reaching for the phone and dialing impairs their control over the vehicle; and third, engaging in conversation via the phone distracts their attention from driving. Dialing a handheld cell phone, in particular, is an especially perilous activity, as it necessitates diverting one's eyes from the road, significantly elevating the risk of accidents and near-miss situations (Yannis et al., 2014; Ziakopoulos et al., 2023). The high prevalence of cell phone use during driving has led to its recognition as a primary contributing factor in automobile accidents, a topic extensively researched and discussed by the National Highway Traffic Safety Administration.

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2 Data Collection

In this study, data were collected concerning 356.162 road trips in the year 2020 in Greece. The data was collected during the period of the COVID-19 pandemic outbreak (Michelaraki et al., 2023). Indicators related to the drivers' rating (Stars) were extracted, as well as indicators related to the scores achieved by the drivers during the road trip (total_score, speeding_score, mu_score, hb_score, ha_score), in order to protect personal data. Finally, indicators were also removed, which have a direct dependence on each other and therefore might lead to unreliable subsequent analysis (Table 1).

Table 1. Data Description

Variable Name	Measurement unit	Variable Description
Duration	sec	Total trip duration
total_distance	km	Total trip distance
risky_hours	km	Distance driven in risky hours (00:00–05:00)
ha/100 km	-	Number of harsh accelerations per 100 km
hb/100 km	-	Number of harsh breakings per 100 km
sum_speeding	sec	Total duration of speeding in a trip, i.e. driving over the "Speed Limit and Tolerance"
av_speeding_kmh	km/h	Average speed over the speed limit in a trip, i.e. driving over the "Speed Limit + Tolerance"
avg speed	km/h	Average speed in a trip
avg_driving_speed	km/h	Average driving speed
time_mobile_usage	sec	Total duration of mobile usage in a trip
driving_duration	sec	Total duration of driving, i.e. duration of stops has been excluded
time_mobile_usage/driving_duration	sec/sec	Total duration of mobile usage in a trip per total duration of driving
sum_speeding/ driving_duration	sec/sec	Total duration of speeding in a trip per total duration of driving

Using the available seaborn library in a Python programming environment, the following triangular heat map was drawn. Positive correlation between independent variables is denoted by shades of blue, while negative correlation is denoted by shades of brown Scikit-learn: Machine Learning in Python WWWDocument (2022); Seaborn: statistical data visualization [WWW Document] (2022). There is a high correlation between different descriptive statistics of the same variable. The above high correlation is logical since it concerns the relationship between different manifestations of the same item. For example, the independent variable driving duration and the independent variable duration have a very strong correlation ($r = 0.98$) because both are manifestations of the magnitude of driving duration.

Total_distance shows a strong correlation with the variable total driving duration either with or without stops (duration and driving_duration respectively), which follows logically from the equation of the speed definition, where driving duration and total distance travelled are proportional amounts. There is very little negative correlation between the independent variables, which demonstrates that increasing one independent variable does not decrease the magnitude of another.

Using a mobile phone while driving generally increases driving time, while it also slightly increases the average driving speed. This is due to the distraction of the driver when using a mobile phone, which leads to longer reaction times and larger speed variations. Mobile phone use has almost no effect on harsh accelerations and decelerations per 100 km.

3 Methodology

3.1 Oversampling Technique

The most important problem with unbalanced data is the high misclassification rate for the minority class because the classifier favours the majority class. For this reason, balancing is required to continue the classification process. In particular, in this research project the data belonging to non-use of mobile phones is much more than those of use. Out of the three methods of resampling and balancing the data, the Oversampling method through the Synthetic Minority Oversampling (SMOTE) technique was finally chosen. In particular, the Undersampling method was not preferred in this research project for fear of losing important information, as the variation in variable values is strong.

3.2 Classification Analysis

In this subsection, data analysis is performed with mobile phone use as the dependent variable. More specifically, from the initial data provided by OSeven Telematics (Kontaxi et al., 2022; Khan et al., 2021) the requirement arose to create a binary variable, which will be the dependent variable for the classification. This continuous variable is the duration of mobile phone usage, which was transformed into the binary variable of mobile phone usage with the following values: i.e. value 0: For no mobile phone use during driving, value 1: For using a mobile phone while driving (Fig. 1).

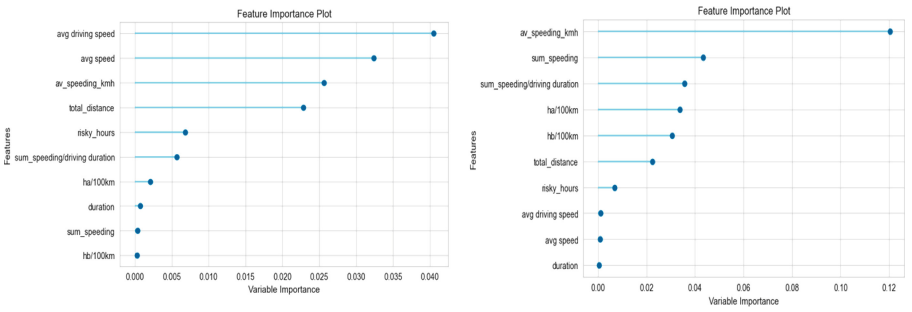

Fig. 1. Variable importance with dependent variable time_mobile_usage with Linear Discriminant Analysis and Logistic Regression

3.3 Regression Analysis

From the Figures below, the 5 most important independent variables were selected for further phe data was collected during the processing and analysis and the regression analysis was repeated only with these variables (Fig. 2).

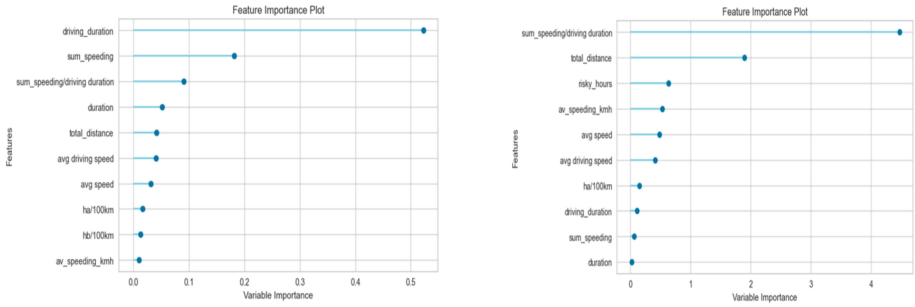

Fig. 2. Variable importance with dependent variable time_mobile_usage with AdaBoost Regressor and Linear Regression

Table 2. Summary table of classification models.

Classification		Linear Discriminant Analysis	Logistic Regression
With all independent variables	Accuracy	84.4%	83.4%
	Precision	73.3%	67.4%
	Recall	65.1%	72.4%
	FNR	34.6%	26.4%
	F1-Score	68.8%	70.0%
	AUC Score	89.5%	89.1%
With most signifcant variables	Accuracy	83.5%	98.2%
	Precision	72.0%	99.8%
	Recall	62.4%	93.5%
	FNR	37.2%	6.4%
	F1-Score	66.9%	96.6%
	AUC Score	87.7%	99.9%

4 Results

Tables 2 and 3 summarise the results of the classification and regression algorithms obtained through the statistical analysis of the data.

According to Table 2, the most suitable algorithms for the prediction of driving behaviour was the Linear Discriminant Analysis model with all the variables under consideration, which showed a high and realistic accuracy rate (realistic accuracy values range from 70% to 90% according to the international literature), as well as a moderate rate of False Negatives.

From Table 3 it can be noted that the Adaptive Empowerment model is the optimal regression model as it has a very satisfactory R2 coefficient of determination value both with all the variables under consideration as well as with the most significant ones. In

Table 3. Summary table of regression models.

Regression R2	AdaBoost	Linear Regression
With all independent variables	0.842	0.497
With the most significant variables	0.840	0.422

general, satisfactory R2 values are considered to be those in the range from 0.8 to 0.9, because higher values may indicate overfitting and for values less than 0.8 the model becomes less reliable. It is worth mentioning that the coefficient of determination R2 becomes the most informative simple metric in the evaluation of regression analyses (Chicco et al., 2021).

5 Conclusions

The main influencing parameter of mobile phone use according to the classification models turned out to be speed (km/h). This makes sense, as the duration of mobile phone use transformed into the binary variable of mobile phone use leads to driver distraction and indirectly influences driver speed either by increasing it by exceeding its limit or by decreasing it, confirming the international literature.

The main parameters influencing the duration of mobile phone use according to the regression models were both the total driving time with exceeding the speed limit and tolerance per unit of non-stop road trip duration (sec/sec) and the non-stop road trip duration (sec). The duration of mobile phone use increases as a road trip increases. Furthermore, there is a dependence between the duration of mobile phone use and the duration of driving above the speed limit, as it has been observed that drivers whose attention is distracted by their mobile phone increase their reaction time and lead to more abrupt driving behaviour and thus to speeding.

In this study, two classification algorithms and two regression algorithms were trained with all the variables under consideration as well as with the most important ones. The best algorithm for the classification models was the Linear Discriminant Analysis model, while for the regression the AdaBoost Regressor model gave more reliable results. The total distance driven affects the duration of mobile phone use, as evidenced by the Pearson's triangular matrix combined with the significance of the variables, and this is explained by the fact that the greater the road distance driven, the more time the driver has to use his/her mobile phone. In addition, by distracting the driver with the mobile phone, he can take a longer route to reach his destination. It was observed that mobile phone use had almost no effect on sudden incidents and more specifically harsh accelerations and decelerations in drivers using a mobile phone. This may be due to the fact that being preoccupied with the mobile phone sometimes causes a reduction in speed, as confirmed by the international literature (Gazder & Assi, 2022).

Dangerous driving hours, i.e. between 00:00 and 05:00, do not seem to have much effect on mobile phone use. Despite the general occurrence of symptoms of dangerous driving behaviour during this period, drivers do not seem to be particularly concerned with their mobile phone, so it is not practically responsible for causing serious crashes

during this period. Lastly, it was observed that the regression algorithms with the most appropriate variables showed a lower coefficient of determination R^2 compared to the same algorithms considering all the independent variables under consideration. This conclusion lies in the fact that the R^2 coefficient indicates the predictive ability of the model with the more independent variables.

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Public Road Tests of Automated Lane Keeping Systems Under UN Regulation No. 157

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Abstract. UN Regulation No. 157 was the first to establish worldwide uniform provisions for the type-approval of SAE Level 3 (L3) Automated Driving Systems (ADS) called Automated Lane Keeping Systems (ALKS). To ensure the safety of the systems, detailed test provisions were introduced, which include mandatory public road tests. The present work is focusing on public road testing and safety assessment of ALKS systems and reports on the methodology, challenges and lessons learned from a proof-of-concept experimental campaign. In line with the regulatory requirements concerning the minimum duration of system verification on public roads, various traffic circumstances and mandatory traffic scenarios were all considered in carrying out the experimental campaign. Since there was no suitable ADS on the market, a vehicle equipped with an SAE L2 system was used instead. The effort was aimed at providing a practical proof of concept for the regulatory provisions and not verifying the compliance of the vehicle under test. By carefully planning test execution, the authors managed to encounter the required traffic density conditions in all needed traffic scenarios with their necessary repetition number, within four testing days. In conclusion, the experimental campaign put in place under UN R157 proved to be a feasible exercise.

Keywords: Automated Vehicles Testing · Motorway Driving · Measurement Campaign · Policy Support · UN Regulation No. 157

1 Introduction

Driving automation is witnessing a progressive transition from a dream to reality, featuring different systems being type-approved across the world [1]. A major step forward was undertaken with the United Nations Economic Commission for Europe (UNECE) Regulation No. 157 (UN R157, [2]). UN R157 was the first regulation to establish worldwide harmonized provisions for the type-approval of an Automated Driving System (ADS) named Automated Lane Keeping System (ALKS).

According to the scope of the regulation, the system can only be activated on highways. The maximum operational speed is restricted to 130 km/h and automated

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lane changes are allowed. When it is active, the responsibility of vehicle control and monitoring the environment is entirely on the ADS.

Test provisions were introduced to reflect the level of risks associated with the usual speeds of highway driving, creating dedicated parts for track testing (Annex 5 of the regulation) and public road testing (Annex 6). According to the latter, a minimum duration of 15 operating hours shall be recorded on public roads with the system activated. From these 15 h, at least 5 h should be devoted to heavily congested traffic conditions. The residual 10 h should cover free-flow traffic conditions, if applicable according to the vehicle's Operational Design Domain (ODD). An important exemption mentioned in the annex is regarding measurement time. According to this, if the testing exercise was continued for at least 16 h, i.e. 2 working days of testing (not to be confused with the requirement for 15 recorded operational hours), the authority may decide to abandon the tests. In this case, the manufacturer should provide the remaining test scenarios from internal system validation results. Nonetheless, a set of test scenarios should be recorded during public road operation, the list of these is included in Annex 6.

It has to be pointed out that within 15 h of road driving it is unlikely to meet critical traffic scenes. The public road tests can only provide an indication that the behavior of the vehicle under test (VUT) is acceptable under typical traffic conditions.

The current contribution summarizes the preliminary findings of a public road test carried out according to UN R157. The goal is to provide guidance and recommendations for obtaining valid, significant and traceable results as well as suitable equipment for such type approval tests.

2 Methodology and Case Study

Public road testing is the final step in the type approval process. The safety assurance process of the manufacturer has first been evaluated by the safety audit, while the general performance of safety-relevant functions has been demonstrated in the documentation by simulations and internal validation tests performed by the manufacturer. In addition, safety-critical reference scenarios have been verified in proving ground tests. The purpose of the real-road test is to provide evidence concerning the driving behavior of the ADS in real traffic and under changing environmental conditions.

To support the assessment of an ADS, the present contribution summarizes how the road test concept has been designed and performed.

2.1 Experimental Campaign

The experimental campaign was planned to suit regulation requirements as effectively as possible from the perspective of the needed duration. The test drive routes were selected based on usual traffic conditions on a given section of road at a given time. Three days of tests were foreseen to cover the required heavily congested and free flow traffic. Time of day was also considered during the planning, e.g. traffic jam measurements were performed during early morning rush-hours. By the end of the three-day measurement campaign additional heavily congested driving recordings still had to be taken. The missing amount of measurements were performed, by an additional half-day test drive.

There was no suitable automated vehicle on the market at the time of the test campaign. Therefore, the authors decided to carry out the assessment using a vehicle equipped with Advanced Driver Assistance Systems (ADAS), i.e. Adaptive Cruise Control (ACC) and Lane Keeping System (LKS). This fact did not have effects on the results, since the focus of the current work is on the validation of the technical feasibility of the test provisions and not on the compliance of the vehicle itself. The ADAS functionalities were used to simulate ALKS capabilities for all in-lane driving. Necessary lane changes (including overtakes, entering and exiting highways, merging, etc.) and speed settings according to the speed limit signs were the task of the human driver.

The campaign was carried out using a wide range of measurement tools. The instrumentation included a high accuracy positioning system together with four cameras facing in the four directions and three LiDARs for the detection of traffic participants.

Most of the perception algorithms used to generate the metadata are low-level fusion algorithms. In this type of fusion, more accurate and robust information can be extracted by combining sensor data. Some of the applied algorithms use only camera images incorporating homography or only LiDAR point clouds with various machine learning algorithms. Perception algorithms included traffic rule recognition (e.g. traffic sign identification), road parameter determination (e.g. lane width, road curvature radii, lane marking) and detection of other road users.

2.2 Requirements of UN R157

UN R157 reports provisions for the ALKS vehicle to maintain a safe following distance with respect to the vehicle ahead. This should be tested with different types of lead vehicles, including passenger cars and heavy-duty vehicles. For speeds up to 60 km/h explicit threshold are defined, above this speed local traffic rules shall be considered.

Lane keeping functionality should be tested with different curvature radii and speeds to ensure that the ALKS vehicle maintains a stable position within the lane in various circumstances.

UN R157 includes explicit requirements for lane changes. These ensure that the ALKS does not disrupt traffic and that the maneuver is sufficiently smooth and properly signaled to the other traffic participants.

Critical cut-in scenarios are statistically unlikely to happen within 15 h highway driving, therefore public road tests of UN R157 require to include only scenarios similar to cut-ins: different merging situations or another vehicle changing lane close in front of the ALKS vehicle. Repetition of certain merging scenarios is required.

Additional scenarios that should be encountered during the testing include: system override by the driver, traffic rule compliance and different road events (e.g. tunnels, work zones, changing environmental conditions, etc.).

3 Results

During the measurement campaign, approximately 2.2 TB of data was collected. The recording covered data from approximately 11 h of free-flow and lightly congested traffic, and 5 h of stop-and-go style driving in congested traffic. This preliminary analysis

contains a 46 min highway drive. Considering the length restrictions of this paper, only a small selection of the data analysis is presented below.

Figure 1 depicts the histogram of VUT speed during the 46 min subset. The cumulative distance travelled was equal to 90.7 km for an average speed of 32.5 m/s (117 km/h).

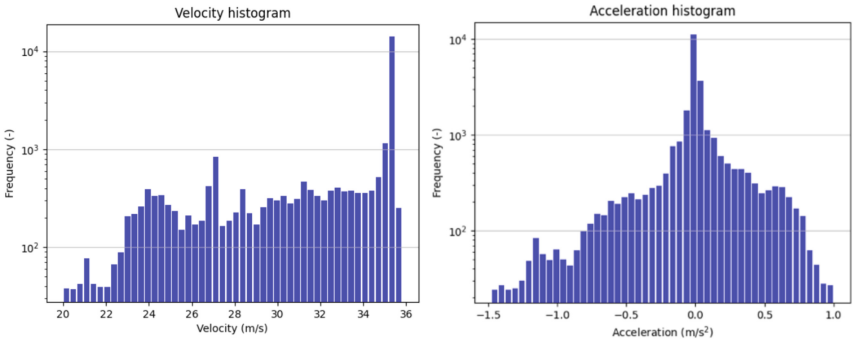

Fig. 1. Histograms of velocity and acceleration during the test drive.

In the sub-sample of data, the VUT has been driving without interaction with other road users 58% of the time, meaning that either no traffic participant was in front of the VUT or cases where a vehicle was more than 3 s ahead of the VUT. This corresponds to the definition in Annex 6 of the regulation. No instance of heavily congested traffic was recorded in the considered subsample and the VUT was travelling under lightly congested conditions for 5% of the time. These considerations find a graphical evidence in Fig. 1, where a clear spike indicates that the VUT travelled at the ACC set speed for the relative majority of the time.

The following distance requirement was evaluated by extracting cases where the VUT speed was stationary for 5 s and during which a lead vehicle affected the behavior of the VUT. The stationarity requirement is needed to ensure that only a stable car-following regime is part of the analysis.

The resultant sample points are shown in Fig. 2 together with the 1 s and 2 s following rules. Overall, the ACC uses a lower headway than recommended by the national traffic law in Hungary. Here it has to be noted that the ACC is a driver assistance system, where the driver can set the following time-gap and also the target speed. The following time-gap policy of the VUT was similar to the time-gap applied by other road users and the VUT occupants also judged it to be sufficiently safe. The ACC of the VUT during the whole measurement campaign was set to “medium” following time-gap.

4 Lessons Learned

Testing automated vehicles with substantial ODD limitations requires careful preparations in order to meet the prescribed traffic conditions. As an example, selecting busy highways during the morning or evening rush hour enabled the recording of the 5 h

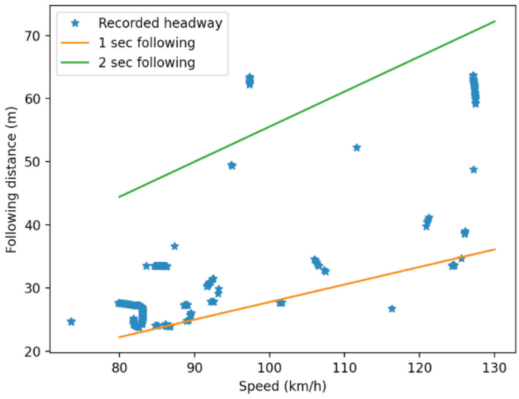

Fig. 2. Following distance versus 1 s and 2 s rules.

of congested traffic situations. On the other hand, selecting highways known to be less busy, and executing the test drive during the day made the collection of free-flow hours relatively easy. The data collection for the 15 h of operation took altogether 3.5 days, including all preparatory works (starting up the systems, cleaning sensors, filling up the VUT, etc.) and data handling activities after returning from the tests. During the test campaign, more than 1500 km were covered and all the mandatory scenario types were encountered with the necessary repetition number. No inclement weather was met, and light conditions were limited only to daylight circumstances. Depending on the ODD of a given ALKS system, these have to be considered as additional factors for the planning of the measurements.

The measurement equipment of the VUT is a complex and expensive system. Such a system needs to be operated and evaluated by skilled personnel. Vehicle adaption, calibration, and evaluation of the traffic scene in total require a considerable amount of time, expertise and a substantial financial effort. The result of the entire exercise is a dataset with the traffic situations as seen by the independent reference system mounted on the vehicle. As such, the collected data does not contain the information used by the ADS for the operation, therefore one cannot easily assess the environment-sensing system of the VUT. This is enough to evaluate compliance with the regulation but does not allow for a deep safety assessment of the system. For the evaluation, it is not necessary to have an independent perception system, more effective would be to use the vehicle's own perception system.

Eventually, we have to note that the amount of raw data generated by the cameras and LiDARs is several orders higher than the metadata derived from it and used for the safety assessment. Recording only the necessary signals calculated by the VUT is a considerably easier task.

5 Conclusion

A test campaign was aimed at investigating the feasibility of the requirements mandated by UN R157 for the type-approval of ALKS: the first road-legal ADS. The experimental contribution leveraged a vehicle with ADAS due to the unavailability of an ALKS-featured vehicle. The VUT was equipped with a state-of-the-art measurement system to provide the lists of signals mandated by the regulation and to assess the vehicle's technical requirements compliance with respect to the provisions. The measurement system used is capable of providing the necessary signals but requires a substantial financial and time investment, calibration and data extraction effort. A more efficient candidate with further advantages would be to use the perception system of the VUT itself provided that the system has been validated beforehand.

The preliminary findings suggest that UN R157 requirements can be reliably verified if the data collection procedure is accurately planned and the measurements are sufficiently robust. Selection of the routes according to the usual traffic density on different calendar days (e.g. weekdays or weekends) and time of day substantially contributed to covering all necessary scenarios and time provisions of the regulation within 4 days. The non-compliances reported from our test campaign shall not be interpreted as deficiencies of the VUT's set of ADAS. Instead, they are representative of the measurement system's capability to grasp the failure to achieve compliance with the technical requirements.

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Unveiling Driving Behavior Patterns During a Naturalistic Driving Experiment

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Abstract. This paper aims to provide a detailed overview of driving behaviour indicators during the implementation of the H2020 project i-DREAMS interventions in Greece. To fulfil this aim, a robust methodology utilizing a k-means clustering approach was employed to detect meaningful driving behaviour patterns within a dataset comprising 11,731 trips from 56 Greek car drivers. This exploratory analysis was complemented by an unsupervised pattern recognition algorithm, which aimed at identifying clusters based on safe or dangerous driving behaviour of the users. The assessment of driving behaviour encompassed indicators such as speeding events, harsh braking and accelerating events, and distraction events (phone in hand). This analysis provides valuable insights into the risky driving behaviour among the i-DREAMS naturalistic driving experiment Phases in Greece.

Keywords: i-DREAMS · cluster analysis · risky driving · safety interventions · naturalistic driving experiment

1 Introduction

Road safety is a major public health issue that requires immediate coordinated efforts and effective prevention. Although several efforts are being made to improve road safety, at a global level the death toll remains very high, estimated at 1.3 million per year [1]. The three main factors contributing to road crashes are the road user, the road environment, and the vehicle, with driver behavior being the main cause of 95% of road crashes [2].

In recent years, advancements in technology have revolutionized the monitoring and analysis of driving behavior. Automotive telematics and driver monitoring systems utilize connected technologies and big data to provide safety interventions and feedback to drivers. These systems leverage sensors in smartphones or On-Board Diagnostics devices to evaluate driver behavior. The primary goal of these interventions is to improve driving behavior and promote road safety and sustainable mobility [3].

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The i-DREAMS project, funded by the European Union's Horizon 2020 program, focuses on establishing a platform and system for timely safety interventions, specifically aiming to create a context-aware 'Safety Tolerance Zone' framework for driving.

This paper provides a comprehensive overview of driving behavior indicators observed during the implementation of i-DREAMS safety interventions in Greece, with the objective of identifying significant driving behavior patterns and understanding factors contributing to safe or dangerous driving. The analysis utilized a robust methodology, including a k-means clustering approach, on a dataset comprising 11,731 trips from 56 Greek car drivers. It also employed an unsupervised pattern recognition algorithm to identify clusters based on safe or dangerous driving behavior. Key indicators assessed included speeding events, harsh braking and accelerating events, and distractions like phone usage while driving. These indicators are widely recognized as significant contributors to road accidents and are crucial for evaluating the effectiveness of interventions aimed at improving road safety [4].

2 Methodology

2.1 The i-DREAMS Naturalistic Driving Experiment in Greece

The purpose of the i-DREAMS interventions is to effectively increase driver safety by supporting drivers in their driving task. The experimental design of the i-DREAMS on-road study in Greece consisted of three Phases.

Phase 1 served as the baseline phase, where driving behavior was monitored without interventions for risky driving events. This phase aimed to establish a comparison between driving behavior with and without safety interventions. The baseline measurements were conducted over a 4-week duration. Phase 2 spanned four weeks and involved post-trip interventions. The i-DREAMS post-trip interventions can be qualified as digital-or internet-based interventions via app and are to be understood as combining e-coaching with virtual coaching. Finally, in Phase 3, which lasted six weeks, gamification features were introduced to the drivers. Unlike the previous phase, drivers were rewarded or received benefits for practicing safe driving behavior. A competitive element was introduced through the leader board function.

The system employed flexible thresholds to determine the STZ status, which defines three risk levels: low (crash risk is minimal), medium (risk of crash increases as internal/external events occur), and high (crash risk is further increased if no preventative action taken by driver). In the framework of this paper, it must be noted that events are presented in the following two severity levels 'medium', and 'high', which correspond to the 'Danger' and 'Avoidable crash' driving phases of the STZ. The overall objective of the i-DREAMS platform was to keep drivers in the low STZ level for as long as possible and prevent their transition from the medium to the high STZ level.

2.2 Methodological Background

Cluster analysis is a powerful statistical technique used to group similar data points based on certain features or characteristics [4]. In driving behavior analysis, cluster analysis

helps identify patterns and understand road safety implications. A widely used algorithm for clustering is K-means clustering [5]. It partitions data into 'k' clusters and minimizes the within-cluster sum of squares (WCSS) [5]. Each data point is assigned to the nearest centroid iteratively until the centroids stabilize.

K-means clustering has been applied extensively in transportation and road safety research [6, 7]. Various customized methods have also been developed [8, 9]. Determining the optimal number of clusters ('k') is crucial, and methods like the Silhouette Coefficient can help [10, 11].

3 Results and Discussion

Table 1 provides a comprehensive overview of the descriptive statistics for various driving events per 100 km (km) during each of the three Phases. Those numbers offer valuable insights into how driving behavior evolved in response to safety interventions and gamification features.

In Phase 1, the baseline phase, the trip distance traveled shows considerable variability, with a relatively wide standard deviation (Std) of 15 km. As for total speeding events per 100 km, the high Std of 37 indicates considerable dispersion in these events. Acceleration, deceleration, and distraction events also demonstrate substantial variability, indicating a wide spectrum of driving styles within the baseline phase. Moving to Phase 2, we observe a decrease in the mean trip distance, possibly suggesting a preference for shorter trips. Notably, the reduction in speeding events, indicates the initial effectiveness of post-trip interventions in promoting safer driving. In Phase 3, the mean distance traveled increases to 10 km, implying greater variability in trip lengths. Most significantly, the continued decline in speeding events, with a mean of 27, underscores a sustained shift towards safer driving. The improvements in other examined events further validate the positive impact of combined safety interventions in road safety.

Before starting the analysis, data was cleaned removing trips that were 'outside phase', excluding drivers who did not have trip data in all phases, removing the trips that were outliers (defined as the mean $\pm$ three standard deviations), and excluding the trips with less than 1 km.

Based on the analysis of the Silhouette method, Fig. 1, developed using R, indicates that the optimal number of clusters is two for Phase 1 and 3 while for Phase 2 is three. The overall models' quality is considered good (av. Silhouette width > 0.4) (Table 2).

In the baseline Phase, where no safety interventions or gamification features were introduced to the drivers, the K-means clustering resulted in two distinct clusters. Cluster $1_{,1}$ was characterized by mostly normal driving behavior within longer trip distances and more frequent speeding events compared to Cluster $2_{,1}$, which displayed distracted driving behavior during shorter trips. Cluster $1_{,1}$ represented most total trips (95%) during Phase 1.

Moving on to Phase 2, where post-trip interventions were introduced via a smartphone app, K-means clustering identified an additional cluster. Comparing Cluster $1_{,1}$ with Cluster $2_{,2}$, we observed an improvement in driving behavior in terms of the number of dangerous driving events per 100 km. This improvement characterized Cluster $2_{,2}$ relatively safer driving behavior, and it still represents most of the trips (69%). Notably,

Table 1. Descriptives of events per 100 km for each Phase

	Phase 1 - baseline				Phase 2				Phase 3			
	Min	Mean	Max	Std	Min	Mean	Max	Std	Min	Mean	Max	Std
distance_km	1	9	278	15	1	8	230	15	1	10	222	18
duration_min	1	17	193	15	1	17	151	14	1	18	185	15
speeding_total	0	32	625	37	0	30	286	34	0	27	400	33
speeding_H	0	25	625	33	0	24	286	32	0	21	400	29
speeding_M	0	7	200	15	0	6	167	14	0	6	125	13
acceleration_total	0	5	375	16	0	6	250	18	0	4	174	14
acceleration_M	0	3	143	10	0	4	250	13	0	2	119	9
acceleration_H	0	2	375	11	0	2	167	9	0	2	167	9
deceleration_total	0	9	375	20	0	9	222	19	0	8	167	17
deceleration_M	0	6	250	15	0	6	222	14	0	5	167	13
deceleration_H	0	3	167	11	0	3	200	11	0	3	125	9
distraction	0	23	875	60	0	23	667	57	0	17	417	48

* H = STZ high level, M = STZ medium level, total = M + H.

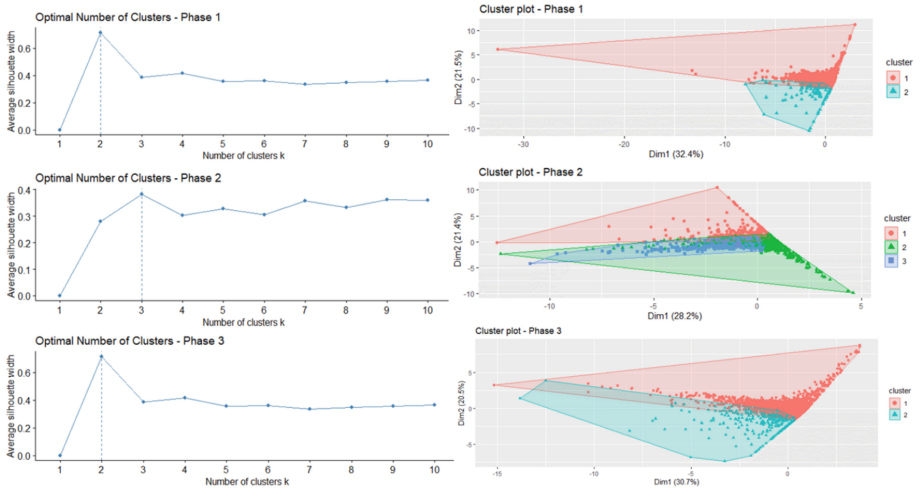

Fig. 1. Optimal number of clusters and the cluster plots for each Phase.

Cluster $1_{,2}$ displayed a significant number of mobile use events, yet it demonstrated a substantial reduction in these events (−23%) compared to Cluster $2_{,1}$. This reduction implies a positive trend towards decreased distracted driving behavior within Cluster $1_{,2}$. Furthermore, a new cluster emerged in Phase 2, comprising drivers with a tendency for speeding behavior, representing 24% of the total trips.

Table 2. Centroid centers and types for driving behavior clusters for each Phase.

Cluster		trip_ distance	speeding total	acceleration _total	deceleration _total	distraction	Cluster_size	
							trips	%
Nr	Behavior	Phase 1						
$1_{,1}$	normal	9	33	4	9	12	2827	95%
$2_{,1}$	distracted	3	24	11	11	231	143	5%
		Phase2						
$1_{,2}$	distracted	4	27	8	11	179	310	8%
$2_{,2}$	low risk	10	16	3	7	10	2822	69%
$3_{,2}$	speeding	7	79	10	14	17	964	24%
		Phase3						
$1_{,3}$	normal	11	30	4	8	10	4334	93%
$2_{,3}$	distracted	4	32	9	12	160	331	7%

In the final Phase, where drivers received post-trip interventions and were introduced to gamification features, K-means clustering identified two clusters. Cluster $1_{,3}$ demonstrated significant improvements in driving behavior compared to both Phase 1 and Phase 2. Drivers in this cluster exhibited fewer speeding events, fewer aggressive accelerations and decelerations, and reduced distraction events. Cluster $1_{,3}$ can be characterized as relatively normal driving behavior and represented the vast majority of the total trips. Cluster $2_{,3}$ also showed improvements in driving behavior, although distraction events remained relatively frequent but lower compared to Phases 1 and 2.

4 Conclusion

The analysis of driver behavior plays a crucial role in enhancing road safety and reducing crashes. To that end, a cluster analysis of Greek car driver trips made for each Phase of i-DREAMS experiment using k-means clustering approach to understand the impact of post-trip safety interventions and gamification features on driving behavior. The optimal number of driving behavior clusters was found to be two during both the baseline Phase and the final Phase, which introduced gamification features alongside post-trip interventions. In contrast, Phase 2, which solely featured post-trip interventions, revealed three distinct driving behavior patterns.

The analysis revealed that the clusters differed in terms of distances traveled and various driving behavior indicators such as speeding events, harsh acceleration and deceleration events, and distraction events. Across the three phases of this study, distinct patterns in driving behavior emerged. In the baseline Phase (Phase1) with no safety interventions, two primary profiles emerged. One exhibited normal driving with longer trips and relatively more frequent speeding events, while the other displayed distracted driving, especially during shorter trips. In Phase 2, post-trip interventions led to safer driving habits, marked by fewer risky driving events like speeding and mobile phone use. A new speeding behavior cluster also emerged. Moving to final Phase 3, where gamification elements were incorporated with post-trip interventions, saw substantial

improvements in driving behavior, with reduced speeding, harsh events, and distraction, highlighting the effectiveness of tailored interventions in promoting road safety.

In summary, the three Phases of the i-DREAMS experiment in Greece demonstrated a clear progression in driving behavior improvement as safety interventions and gamification features were introduced. Future research should focus on longitudinal analyses to understand how driving behavior evolves over time. Exploring the relationship between driver characteristics and behavior can inform personalized interventions. Evaluating intervention effectiveness and leveraging advanced technologies can further enhance road safety.

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Effects of Rear Lights on Cars by Daylight

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Abstract. Effects of rear-light usage by daylight were examined. A field experiment measured passing vehicles' lateral distance to a stationary car, as an effect of rear-light status. A questionnaire survey measured car drivers' perceptions regarding safety and visibility depending on rear-light usage, and their experiences, preferences, and beliefs about own usage of rear lights in daylight. An observational study measured percentages of cars with lit and unlit rear lights, respectively, in sunshine during summer. Results show that rear lights give greater lateral distance when being passed by. A car with lit rear lights is interpreted as more likely to start driving. Lit rear lights are preferred and estimated to give better visibility and traffic safety. Only a small proportion of drivers know that they drive with unlit rear lights in daylight, whilst the majority actually drive with unlit rear lights. Conclusion: lit rear lights in daylight improves traffic safety. It is therefore recommended that rear lights with sufficient brightness to be seen even in sunshine should be legally required.

Keywords: Rear light · taillight · tail light · vehicle lighting · daytime running lights · traffic safety · visibility · detectability · road user behaviour · driver behaviour

1 Introduction

This study investigated the effects of car rear lights by daylight, dawn and dusk – in light conditions when cars should be clearly visible even without lit headlights and rear lights. In daylight, lit rear lights should not contribute much and significantly to whether cars are detected, or how early or at what distance they are detected. However, it is conceivable that if a car does not have its rear lights visibly lit, it may be more difficult for other drivers to identify if it is running, and if it can therefore make a sudden change in position. A car with lit rear lights is reasonably more likely to have a person in the driver's seat, and its engine should be more likely to be running. To avoid collisions, it can be time-critical to detect vehicles in traffic, where they are, in which direction they are traveling, and what their drivers intend to do. A vehicle must have the lights and headlights that are prescribed for the vehicle lit, however, if prescribed warning lights are used on a car in daylight, the rear or side lights do not need to be lit [1].

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In 2011, the European Union introduced requirements for automatic daytime running lights at the front of all new cars, but in order to reduce carbon dioxide emissions, this did not apply to the rear lights [2]. A requirement was introduced in August 2016 that new passenger cars and trucks must also have automatic rear lights, at minimum when the ambient brightness falls below 1000 lx, for example in darkness or when driving in tunnels [2, 3].

It has been claimed that rear lights can be unlit without impairing road safety and that unlit rear lights are a way to save energy and for the car industry to work towards more sustainable driving (e.g., [4]), and that there are no studies that indicate that unlit rear lights during the day would reduce road safety and that lit rear lights rather impedes the visibility of the brake lights (e.g., [3], citing [5]). However, [5] is both 20 years old and lacks reference to such empirical evidence. Rear lights on cars also vary widely in brightness, and many newer versions are dimly lit. When the sun shines on a newer car, it can therefore be very difficult to see if its rear lights are lit. At the same time, it is quite clearly visible if the same car's headlights are on, because the headlights shine significantly brighter. Previous Swedish large-scale observational surveys showed that 15% of vehicles had unlit rear lights in the dark in 2018, and that 5% had unlit rear lights in the dark while 21% had unlit rear lights in daylight in 2021 [6, 7].

The overall aim was to investigate the effects of rear-light status (i.e., whether the rear lights are lit or unlit) on driver behavior in surrounding traffic; and drivers' attitudes and experiences of visibility and road safety as an effect of rear-light status. In addition, the agreement between Swedish drivers' awareness of whether they have their rear lights lit or unlit in daylight, and the actual use of rear lights in daylight was also investigated. The study was conducted as a field experiment, a questionnaire survey, and an observational study.

2 Field Experiment

The *purpose* was to investigate whether a stationary vehicle's rear-light status (lit/unlit) affects how much lateral distance passing vehicles keep. A further aim was to investigate what percentage of Swedish passenger cars have unlit rear lights at sunrise, sunset and during the day.

Method. Data was collected on five different occasions in April 2023 on a country road with single lanes in both directions. The speed limit is 70 km/h, lane width 3.5 m, dashed center line (3 m long, 9 m interval), and dashed edge line (1 m long, 1.5 m interval). Two occasions were at dawn, two at dusk, and one was a gray overcast morning. A grey Toyota Avensis station wagon, 2010 model, rear lights with bulbs, filament, was parked in the road clearing, 1 dm to the right of the dashed border. Inside were three cameras, two of which were directed backwards, and one forward. The rear lights were lit and unlit approximately every four minutes, whenever possible when no vehicle was approaching and could see the lights being switched on or off. $N = 850$ passing vehicles were videotaped, $n = 765$ related to their own rear-light status (on or off). Neither drivers nor license plates can be identified on the video recordings. The lateral position on the road surface (the position of the vehicle on the road surface laterally) was measured

from video recordings of the lateral position of the vehicle's right front tire on the road approximately 5 m before it passed the test car.

Results. When the stationary test car had its rear lights lit, the average lateral position of the passing vehicles was $M = 5.48$ cm ($SD = 1.46$ cm); with rear lights unlit, the average lateral position was $M = 5.20$ cm ($SD = 1.46$ cm), $t(848) = 2.33$, $p < .05$, $d = 0.16$. Converted from measurement on the monitor to reality (on the road surface), the average lateral position was about 9 cm further to the left when the test car's rear lights were lit. At sunrise, $n = 169$ (28%) of passing vehicles had unlit rear lights, while at sunset, $n = 19$ (23%) had unlit rear lights. During the day, $n = 48$ (59%) had their rear lights off.

3 Questionnaire Survey

The *purpose* was to investigate why passing vehicles pass laterally farther from a stationary vehicle with lit rear lights. In addition, car drivers' attitudes to lit and unlit rear lights in daylight, and the knowledge of current legislation on the use of rear lights, were investigated.

Method. *Participants* for the survey study were recruited via advertisement on social media 11–17 May 2023 and via VTI's own website, aimed at users aged 18 and over, throughout Sweden. In addition, the Swedish Homeowners Association advertised on 22 May 2023 via their monthly member email to approximately 19,000 members. In the opening text of the questionnaire, it was stated that the person who would participate in the study needed to have a valid passenger car driver's license. The social media advertisement reached 52,480 users and was shown an average of 1.87 times per user. N = 9282 respondents aged 18–100 years (M = 60 years 4 months, SD = 12 years 7 months) answered the survey, of which 30.4% women, 69.0% men and 0,5% who did not want to state gender, from all of Sweden's counties.

The respondents were randomly allocated to *the four questionnaire versions* via a web link on VTI's website. For between-group comparisons, video and still images of the test car were shown with either the rear lights lit, or unlit. For within-group comparison, video and still images were shown where the test car had the rear lights both lit and unlit, and in two different presentation orders. In all questionnaire versions, video was shown without sound, filmed from inside a car that passed the test car. The video was recorded on a test track without other traffic, in a right curve so that the test car was not visible from the beginning. The purpose of the design was to first examine how the respondents pay attention to and estimate overtaking when they were unaware that the study is about a difference between lit and unlit rear lights, and to also (with within-group comparison) examine how they assess the difference depending on whether the rear lights were on or not. The purpose of the final block of questions was to investigate attitudes, how they think they use their rear lights themselves, and the level of knowledge regarding the use of rear lights. For all estimates of visibility, clarity, and risk, 101-point (0–100) visual analog scales were used, with 50 as the midpoint (e.g., no difference between video clips). The direction of the rating scales was consistent with the order of the video clips, so that the order of presentation with rear light lit and unlit was reflected in the rating

scales. Before the analyses, these rating scales were therefore inverted for those who received the On–Off presentation order, in order to align all rating scales.

Results. It was judged to be slightly but significantly more likely that the stationary car would swerve out if it had its rear lights lit, see Table 1. This explains why the passing vehicles in the field experiment kept farther from the stationary test car when it had its rear lights lit. In contrast, rear-light status does not seem to make a difference to how clearly visible an observer thinks the car is – when there is no other car, with contrasting rear-light status, to compare with.

Table 1. Between-group comparison of car drivers' estimates as an effect of rear-light status.

	Lit rear lights			Unlit rear lights				
Survey question	*n*	*M*	*SD*	*n*	*M*	*SD*	*t*	*d*
After video with one passage (on *or* off)								
8. How *visible* do you think the stationary car was?	2202	59.74	24.06	2146	59.91	25.33	0.23	
9. How *clearly* could the car be seen?	2202	59.40	24.29	2142	59.93	25.09	0.71	
10. How likely was it that the car would *swerve out*?	2202	45.10	21.63	2146	40.43	22.18	7.03***	0.21

***$p < .001$.

As seen in Table 2, the mean values of all estimates differed significantly from the midpoint of the scale, meaning that rear-light status difference consistently had an effect. Passing the test car was judged to be safer when the rear lights were unlit. This is also consistent with the fact that lit rear lights was estimated to entail a greater risk for swerving out, and the greater lateral-position difference in the field experiment. Lit rear lights were also estimated to provide better visibility and safety – even though the vehicle passage in the video clip was judged to be somewhat safer when the rear lights were switched off.

Are you aware if you yourself drive with your rear lights on or off during the day when the light conditions do not require it by law? Of the $n = 3{,}279$ respondents, 76.2% stated that they drive with their rear lights on, while 16.8% stated that they drive with their rear lights off, and 7.0% stated that they do not know if they have their rear lights on or off during day time.

Do you prefer cars that have their rear lights on or off during the day? Of the $n = 3{,}279$ respondents, 84.4% indicated that they prefer on, while 1.6% indicated that they prefer off, 12.3% indicated that they think there is no difference, and 1.7% indicated that they don't know what they think on the matter.

Which lighting configuration do you think is safest during the day? Of the $n = 3{,}271$ respondents, 87.0% stated that they think that switching on the rear lights is safest during the day; 1.5% indicated that they think rear lights switched off are safest during the day;

Table 2. Car drivers' estimated differences of rear-light status (Unlit–Lit) against the null hypothesis that there is no difference (which corresponds to $\mu = 50$).

Survey question	*n*	*M*	*SD*	*t*	*d*
After video with both passages (on–off; off–on)					
8. Which overtaking was the *safest*? (1–2)	3756	45.04	27.28	11.15***	0.18
9. In which clip was the car most *visible*? (1–2)	3748	64.19	31.53	27.55***	0.45
10. In which clip… Risk that the car would *swerve out*? (1–2)	3737	64.30	32.78	26.67***	0.44
After text about rear-light status, with still image of the difference					
12. Which rear-light configuration was *safest*? (off–on)	3381	52.14	40.21	3.09**	.05
13. Which rear-light configuration was *most visible*? (off–on)	3376	84.98	22.17	91.67***	1.58
14. Which rear-light configuration was *clearest*? (off–on)	3377	72.63	32.07	41.01***	0.71

**$p < .01$ ***$p < .001$.

8.7% that they think lit and unlit rear lights are equally safe; while 2.8% stated that they do not know what they think about the matter.

Do you know what the law says about daytime running lights? Of the $n = 3{,}276$ respondents, 60.5% answered yes, while 39.5% answered no. This shows that a large percentage of Swedish drivers consider that they do not know the law on the use of rear lights.

4 Observational Study

In order to map more exhaustively the proportion of passenger cars and trucks in categories M1 and N1 that are driven without visibly lit rear lights in daylight, and in sunny weather during summertime, surrounding traffic was observed during car journeys in southern Sweden on 18 July 2023 and 22 July 2023 on the E4 motorway between Mantorp and Ljungby, and 28 July 2023 on the E22 between Kristianstad and Sölvesborg. Of the N = 794 cars, n = 143 (18%) clearly had lit rear lights, while for n = 49 cars (6%) it could not be judged whether the rear lights were on or whether it was the lamp glass that retroreflected the sunlight, and n = 602 cars (76%) clearly appeared to have unlit rear lights. The percentage of cars that did not have rear lights clearly switched on was thus 82% (n = 651 cars).

5 Discussion

The majority of Swedish drivers do not have lit rear lights by daylight, although they think they do. A large percentage stated that they do not know what the law says about rear lights during the day. The vast majority also prefer that surrounding traffic should have their rear lights on, because they think that the vehicles are then more clearly visible, that it is safer, and that it is easier to determine whether the vehicles are moving – which, for example, increases the perceived likelihood that a vehicle may suddenly start driving when you are about to pass it. This is also reflected in that drivers keep a greater distance laterally when passing a stationary car with lit rear lights.

Lit rear lights on vehicles, in daylight, is therefore highly desirable from a traffic-safety point of view. The recommendation is that the current EU legislation on the use of rear lights be reviewed and revised, to make it mandatory to have lit rear lights with sufficient brightness to be seen even in sunny weather.

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Can Safe Driving Patterns Be Identified? An Exploratory Analysis

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Abstract. In order to improve road safety, recent studies suggest that it is important to study and identify the optimal driving benchmarks that reflect the safest driving behaviour that may be observed by human drivers. The objective of this paper is to identify boundaries of risky and typical driving by studying the car-following driving behaviour. The data used in this study was collected by TNO in a recent naturalistic driving study. The distributions of driving metrics related to the following and leading vehicle were illustrated to understand their shapes and outliers. The safety-related car-following driving metrics of Time to Collision (TTC), Deceleration Rate to Avoid the Crash (DRAC), Crash Index (CI) and over-speeding were calculated, with risky thresholds obtained from the literature, and typical driving thresholds based expert assessors' ratings. Principal Component Analysis (PCA) was applied to these metrics and showed that 'optimal driving' can be represented by one linear component that represents over 95% of the total dataset's variance.

Keywords: Car-following · driving metrics · Principal Component Analysis

1 Introduction and Literature Review

Driving is a complex task that necessitates a blend of motor and cognitive skills. Drivers must adeptly manage their vehicles in traffic while sustaining critical cognitive functions such as attention, visuospatial coordination, and executive functions (1). Amid this dynamic landscape, drivers engage with their environment and other road users, applying their skills and experience (2). Although most interactions occur successfully, there are sporadic instances of traffic conflicts, near-miss situations, or actual collisions. Over recent decades, extensive research has been conducted on preventing and mitigating these critical moments of increased traffic risk (3). Notably, in recent years, surrogate safety measures have emerged as a valuable tool, enabling proactive assessment of risk before actual accidents occur. This proactive approach to safety management holds potential for averting safety critical events before they happen and permits a proactive strategy based on early risk evaluation (4).

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Nonetheless, in the broader field of safety science, it has been proposed that solely concentrating on negative outcomes offers only a partial comprehension of a system's safety (5). As systems, especially complex ones, continue to evolve, new collision mechanisms may surface, and decomposing the role of individual risk factors becomes more difficult. Conversely, there is valuable knowledge to be gained from closely observing the 'typical' functioning of the system and how users/operators handle inherent risks as part of their everyday activities (6). In order to improve road safety specifically, recent studies suggest that it is important to study and identify the optimal driving benchmarks that reflect the most successful driving behaviour, in terms of safety, that may be observed by human drivers (7). The initial step to achieve this is by defining the boundaries of risky and typical driving in a multivariate framework. This paper aims to identify these boundaries by studying the car-following driving behaviour.

2 Data Collection and Methodology

TNO (Dutch Organisation of Applied Research) recently conducted a driving study (the reader is referred to (8) for more details) where the kinematic variables of the ego (test) vehicle (longitudinal and lateral positioning, speed, acceleration, etc.) were recorded, together with the surrounding traffic variables (using a combination of Mobileye, front radars and cameras) of an instrumented vehicle. Fifteen drivers participated in the study, who had more than 7 years of driving experience and drive at least 10.000 km per year. Each driver drove twice in the same location, the stretch of the A2 highway between Best and Boxtel in the Netherlands between exits 25 and 27. Each driver drove for approximately 40 min, given the speed limit (100kph).

One expert driving assessor from the Centraal Bureau Rijvaardigheidsbewijzen (the Dutch agency in charge of awarding driver licenses) accompanied and assessed in real time each driver. The assessors (two in total), were requested to annotate whether driving was "competent", "neutral" or "not competent" by pressing one of three buttons at least once every 30 s. The kinematic data, together with the button presses, were recorded at a 20Hz frequency by the same storage device, the StreetLive box, in ROS format, which was then post-processed into Matlab files. These files were processed in Python for modeling and visualization purposes.

In order to understand the shapes of the driving metrics' distributions and identify the outliers, those were visualized. These distributions included metrics of both the following and leading vehicle as well as their interaction. Metrics encompassed factors like speed, acceleration, Time to Collision (TTC), distance from the leading vehicle, lane positioning, and relative velocity. Subsequently, after excluding lateral movements within a 30-s window around lane changes, safety-oriented car-following metrics were computed. These included TTC, Deceleration Rate to Avoid the Crash (DRAC), Crash Index (CI), and instances of over-speeding. Thresholds denoting risk levels for each of these metrics were determined through prior literature examination and the time spent within the risky area was calculated for each metric.

Having excluded the risky areas from the data, the 'typical driving' area was defined by further filtering the data to identify the proportions of non-risky driving that corresponded to the "competent" button presses by the expert assessor for each metric. In

order to reduce the dimension of "typical" driving to one principal component, Principal Component Analysis (PCA) was applied, which is a statistical technique employed to reduce the dimensionality of data while preserving its essential information. It identifies orthogonal axes (principal components) that capture the maximum variance within the dataset. PCA aids in simplifying complex data, enhancing interpretability, and revealing patterns. It is extensively utilized in various fields, including transport safety for the purposes of data compression, feature selection, and visualization, enabling researchers to discern underlying structures and reduce data complexity for further analysis (9).

3 Results

3.1 Descriptive Analysis of Safety Metrics

Figure 1 shows the distributions of the ego vehicle's speed, acceleration, and lateral position, i.e. the distance of the vehicle's central axis from the lane's right border. The average speed is found to be around 95 kph. It is also observed that slightly more people drive between 95–100 than 90–95 kph. A longer tail can be noticed on the left side of the distribution, which mainly captures driving behaviour while entering or exiting the highway. Regarding the acceleration, which is converted to kph per second, it averages around 0 kph/s. Finally, the positive values present slightly higher frequency than the negative values. With regards to the lane positioning shown in the right panel, the distribution is observed to be symmetric and centered around 1.60 m.

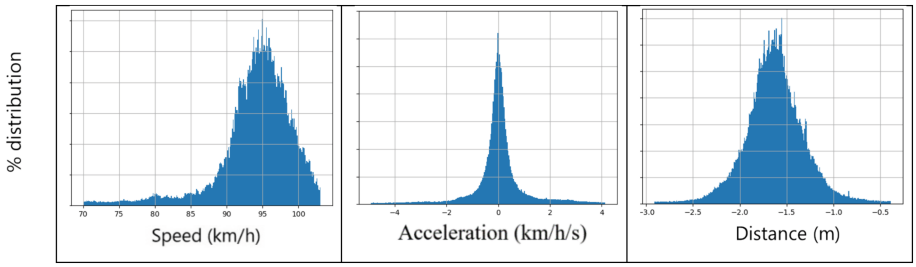

Fig. 1. Distribution of speed (left panel), acceleration (middle panel) and lane positioning (right panel) of the ego vehicle of the experiment

Figure 2 shows the distributions of the relative speed between the ego and the leading vehicle, the TTC between the two vehicles, as well as the distance from the leading vehicle. The fact that the right tail of the relative speed distribution is longer and has higher frequency than the left tail, shows a tendency of the following vehicles to approach the leading vehicle. Additionally, the distribution of TTC in the middle panel is negatively skewed with mean value around 6 s. It is observed that a share of critical interactions are recorded with TTC less than 2 s, which according to literature corresponds to critical conflicts. At the same time, a share of interactions with TTC less than 4 s may be considered to reflect the "successful" interactions, while the right part of the distribution may be considered to reflect the "undisturbed" interactions (7). Regarding distance from

the vehicle ahead, it can be observed that the distribution is lognormal and positively skewed.

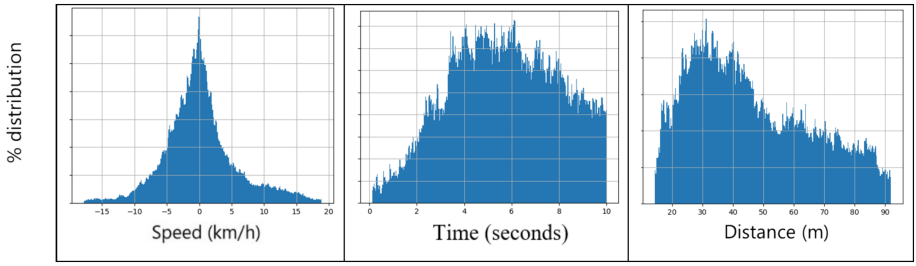

Fig. 2. Distribution of relative speed (left panel), TTC (middle panel) and distance to the leading vehicle (right panel) of the ego vehicle of the experiment

Figure 3 shows the breakdown of the relative speed and lane positioning distributions with respect to the button presses of the assessors. It can be seen that the vast majority of small relative speeds between the leading and the ego vehicles are rated as "competent" or "neutral", whereas a small share of large speed difference is rated as "competent", possibly because it would be acceptable due to contextual factors. Similarly in the distance distribution, the vast majority of very low distances were given a "non-competent" rating, and the vast majority of high distances were given a "competent" rating; a small share of close interactions were given a "competent" or "neutral" rating, probably reflecting situations where the ego vehicle engaged in these interactions in a safe way. This descriptive analysis shows that examining a single driving metric may not provide a full understanding of driver's performance. Additionally, the assessment by an experienced evaluator can contribute valuable insights into the safety aspects in each case.

Following the above, it was decided to focus on longitudinal driving and exclude lateral movements occurring 30 s before and after lane changes. The car-following metrics were calculated from the experimental data and their risky thresholds were adopted from the literature (10), as follows: 1.6 s for TTC, 16.95 for CI, 3.35 for DRAC and 100kph for Speed. It is noted that the CI threshold was specified on the basis of the boundary conditions of the formula provided in (10) on the basis of the risky thresholds of the included metrics, i.e. by considering 100 kph speed limit for both the leading and the following vehicle, 0.6 m/s^2 acceleration for the following vehicle and 1.6 s TTC for the following vehicle.

3.2 Principal Component Analysis for Typical Driving

A PCA model estimated 4 components (based on the 4 metrics). The 1st component represents 99.6% of the total variance of the dataset, meaning that the data can be adequately represented without using the rest of the components. In order to define the 'typical' driving period, the values lying within the 10% and 90% percentiles of this component were retained.

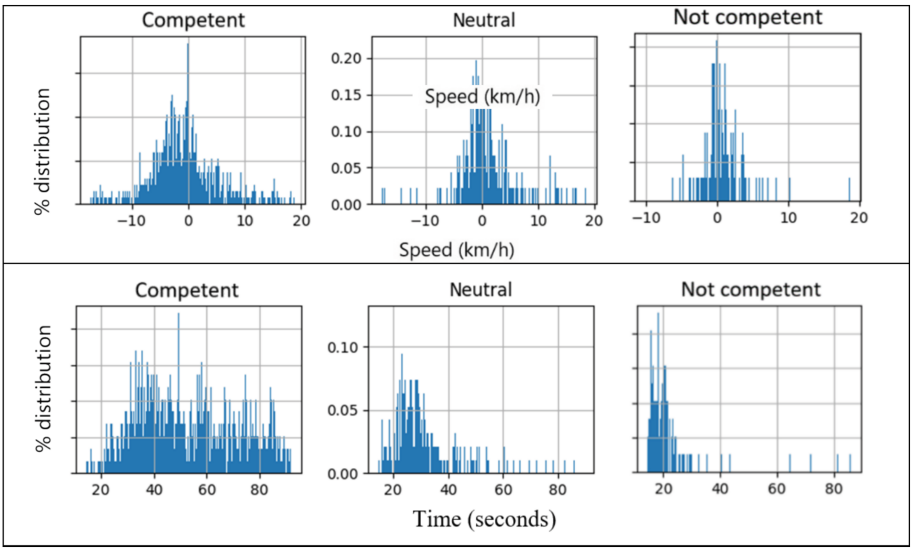

Fig. 3. Breakdown of the distribution of relative speed (upper panel), and TTC (lower panel) of the ego vehicle per assessor ratings (competent, neutral, not competent)

4 Discussion and Conclusions

The 4 driving metrics used were found to be relevant for distinguishing both safe and typical driving segments. The methodology involved creating a latent construct to define typical driving and applying three criteria: staying within non-risky thresholds, having a 'competent driving' button pressing by an expert assessor, and excluding extreme percentiles. This resulted in a concise representation of typical driving, which may potentially serve as an optimization input. PCA revealed that these driving metrics can be formed into a single linear component of typical driving.

This research has some limitations. The analysis was limited to car-following conditions, and lateral movements were excluded, due to difficulty in estimating appropriate metrics of lateral movement (e.g. gaps, lateral acceleration) from the available data.

The determination of typical driving behavior was founded on a blend of data-driven (non-risky driving time) and expert-based (assessor's "competent" rating) criteria. We acknowledge that neither of these criteria is flawless individually, nor is their combination. Obviously, there may be some subjectiveness in assessors' ratings. On the other hand, the fact that the proposed methodology lies on the existence of expert-based ratings, it is not directly transferable to other existing naturalistic driving datasets.

These results may be useful to researchers on road safety and human factors, as they offer insights into the skills used by drivers to navigate real-world driving and manage risks. Moreover, these findings have may practical implications for developing better Advanced Driver Assistance Systems (ADAS), by learning from the whole spectrum of driver behaviour and developing automation and support strategies that are recognizable and trustworthy by human drivers. Future research may study optimal driving as an

optimisation process, in which the "typical" driving performance is maximised, and any risky driving situations is minimised.

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Measures for Reducing Risky Behaviour of Motorcycle Riders on Curvy Mountain Roads

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Abstract. Motorcycle riders exceeding speed limits and driving on the opposite traffic lane in curves has been identified as an acute traffic safety issue on many scenic mountain roads in Slovenia. The Slovenian Road Agency initiated a programme to research the possibilities of preventing such behaviour on these roads by innovative approach. Different types of visual velocity reducing measures have been implemented on nine selected curves on two roads frequently used by motorcycle riders. The measures consist of different patterns of horizontal road markings and other visual clues in form of vertical signalisation. The study compares the behaviour of the motorcycle riders before and after the implementation of the measures on the same test locations, each time during a period of three days including a sample of several hundred single motorcycle rides. The measured variables are the velocity, the distance from the road edge and the lean angle of the riders. They are determined by means of image analysis from calibrated video recordings. The analysis of the results has been done for each location to determine the correlation between the implemented measure and the change in the parameter variable values. The paper presents the data acquisition, the research and analysis methodology, and the results. The discussion evaluates the efficiency of the implemented measures, the possibilities of their seamless integration into the traffic legislation, as well as the requirements and the plans for further research.

Keywords: traffic safety · motorcycle rider · velocity reducing measure · road markings · traffic legislation · image analysis

1 Introduction

The curvy mountain roads are often used by motorcycle riders for recreational rides. Some of those riders tend to disrespect the lane divisions and speed limits, putting themselves and other traffic participants in danger [1–3]. The aim of the research was to analyse the behaviour of a representative sample of motorcycle riders on nine locations on two scenic mountain roads in Slovenia. The first one (referred to as Road 1) was on the Jezersko mountain pass, the second one (referred to as Road 2) on the road between Mozirje and Trbovlje, near Marija Reka. The geographical locations are shown in Figs. 1, and 2. Based on the results, we proposed the measures for preventing dangerous behaviour on those road sections. After the measures are realised another behaviour analysis will be performed on the same locations to assess the efficiency of the measures.

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Fig. 1. Location of Road 1 and Road 2 on the map of Slovenia (Source: Image created with map of traffic collisions by Slovenian Traffic Safety Agency).

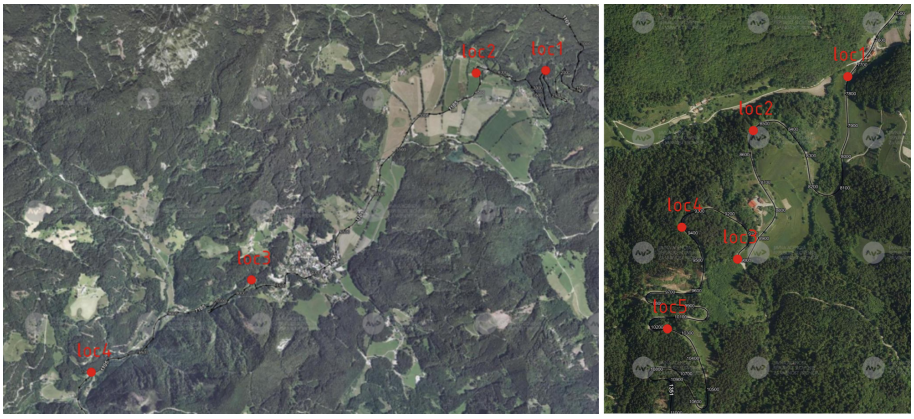

Fig. 2. Monitoring locations on Road 1 (left) and Road 2 (right) on an orthophotographic image (Source: Image created with map of traffic collisions by Slovenian Traffic Safety Agency).

2 Methods

2.1 Location Selection and Preparation

The roads and the locations were selected based on previous accident data. The analysed locations are on curves with different radii and different road configurations. The analysis was done in the direction where the motorcycle riders are likely to veer over the road centre line. The study required data acquisition to be hidden from the test subjects, so a special care was taken to assure the equipment was hidden from the riders approaching the locations. The markings on the road surface were kept to a minimum and only included four calibration points (red dots on the road edges in Fig. 3).

Fig. 3. Sample frame from Road 1, loc2, with visible calibration markings (bright red dots on the side of the roadway) (Source: Faculty of Mechanical Engineering).

The recording was done separately on each location during summer 2021 for minimum of 48 h, spanning from Friday afternoon to Sunday afternoon. Care was taken that the road conditions were suitable for motorcycle riding (i. e. dry road, no precipitation, ambient temperature over 20 °C). The number of sampled motorcyclists on each location thus varied and is presented in Table 1.

2.2 Equipment and Data Acquisition

The acquired data included motorcycle rider images and their velocity. A TOPO system by RTB [4] was used for data acquisition. The equipment was attached to a stand, which was placed in a covered position next to the road on each location. The images of the vehicles passing were captured by a camera, triggered by a radar sensor, concealed in a standard guide-post. This ensured that the images of all vehicles were captured on approximately the same location on the road. The radar sensor also measured the velocity of each captured vehicle. The images of all captured vehicles together with the velocity data files were transferred to a remote system for analysis.

The captured images were processed by an image recognition algorithm to filter out the images of the vehicles that were not motorcycles with riders. This procedure yielded the initial dataset for the analysis. The final dataset was obtained by performing a manual check on the initial dataset to remove any falsely recognised images.

2.3 Data Analysis

The acquired motorcycle rider images, as schematically displayed in Fig. 4, were analysed by using the image analysis software [5]. The following parameters were extracted from every captured image:

- position of the motorcycle rear or front wheel contact point (BOTTOM) relative to the lane dividing line,
- position of the top point of the motorcycle rider head (TOP).

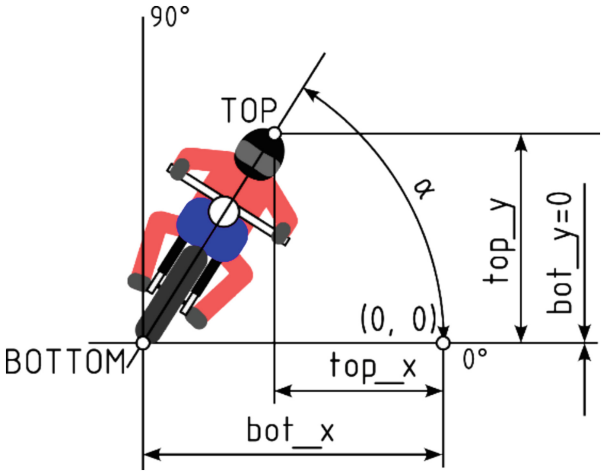

Fig. 4. Geometry of the motorcycle rider in a curve on a captured image

The coordinates of these points allowed us to calculate the approximate motorcycle rider lean angle α, expressed as the inclination of the rider in the captured image. The point coordinates, the calculated lean angle, and the measured velocity of each captured motorcycle rider were combined into a single data record. Each individual data record was then entered into a spreadsheet file that was used for data analysis.

The data analysis was done for each location separately. The values of each parameter were divided in seven bins spreading through the entire range of the parameter values. The basic statistical parameters for each parameter were calculated for each location and then aggregated per-road and per-study to be compared to the corresponding values acquired after the velocity-reducing measures are implemented. The before-after-analysis afterwards will yield the correlation between the parameter values and provide an assessment of the efficiency of each implemented measure.

3 Results

For each location the width of the roadway was divided into three areas: further than 0.5 m right from centre line (green), closer than 0.5 m right from the centre line (yellow) and left from the centre line (red). The motorcyclists riding in the yellow area present the border case as their head and upper body may protrude into the oncoming traffic lane due to their inclination. The percentages of motorcycle riders in each area at each of the 9 locations are presented Fig. 5.

The numerical values for average velocity and inclination at each location are shown in Table 1.

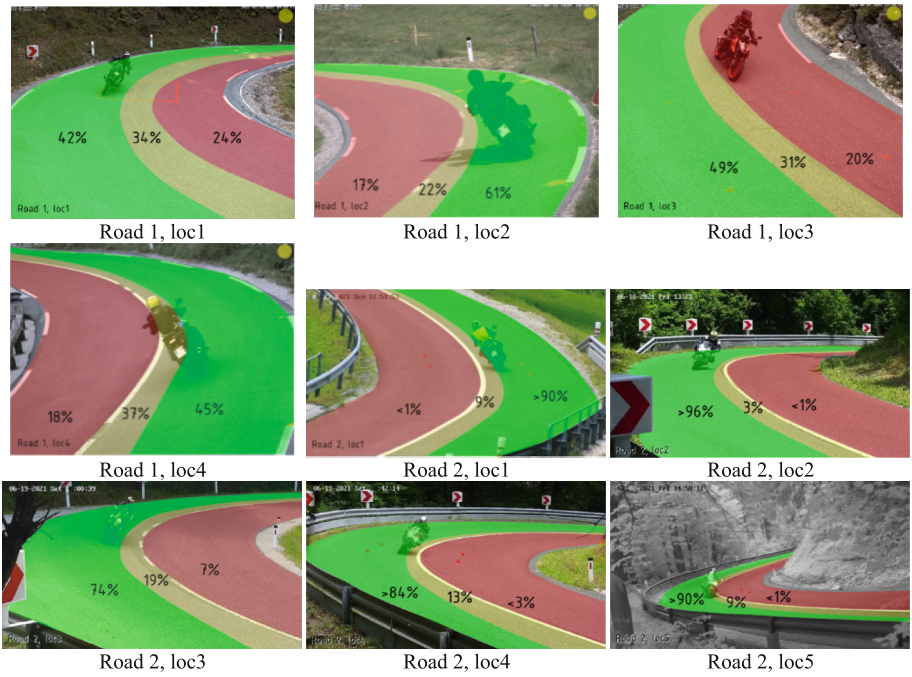

Fig. 5. Results of lateral distribution of motorcycle riders on all monitored locations

Table 1. Sample size, average measured velocity and inclination at each location.

Location	No. of motorcycle riders	Average velocity v_{avg} [km/h]	Average inclination from horizontal α [°]
Road 1, loc1	155	29.32	59.62
Road 1, loc2	334	56.32	60.34
Road 1, loc3	455	37.11	63.07
Road 1, loc4	493	58.20	57.24
Road 2, loc1	274	65.73	69.64
Road 2, loc2	265	66.03	69.20
Road 2, loc3	221	37.41	65.77
Road 2, loc4	362	48.48	60.75
Road 2, loc5	311	51.88	63.00

4 Discussion and Conclusions

The preliminary results on locations before implementing the velocity reducing measures show that the values of the measured parameters depend on the terrain configuration. On tighter curves with shorter line of sight (Road 2, loc1, loc2 and loc5) the percentage of

motorcyclists riding and leaning far into the opposite lane is small. On curves with longer line of sight (all other locations), this percentage is significantly higher. Expectedly, the average velocities also depend on the radius of the curve.

Based on the results we have proposed the measures [6, 7] to reduce the velocities and to help keep the motorcycle riders out of the space above the opposite lane. Figure 6 schematically shows the two types of proposed road markings. The elliptical pattern (left) is more suitable for implementation in thermo-transfer materials, the "zigzag" pattern (right) is more suitable for conventional painting.

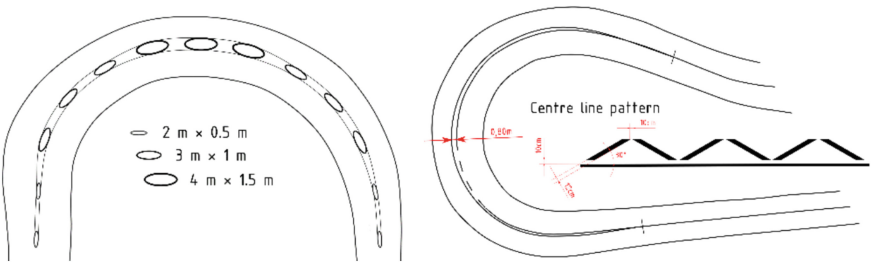

Fig. 6. Proposed road markings as the measures of velocity reduction

The markings are expected to be fully implemented on the all the locations by spring and the field analysis of the situation after implementation by summer 2024. Afterwards, another set of measurements with the same parameters as in the described analysis will be performed on all locations to assess the efficiency of the proposed measures.

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Safety Relevant Behaviour-Based Driving Dynamics Indicators of E-Scooter Usage in Parcours Situations

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Abstract. E-Scooters provide a fast, easily available, easy to use means of transportation for a broad range of users in urban traffic. Apart from adjustments of rules and policies of E-scooter use, increasing safety for these vulnerable road users is challenging, given driven speeds, handling of e-scooters and the lack of physical protection for E-scooter riders. One approach to understanding the needs of E-scooter users is to study their driving behaviours in everyday and specific challenging situations.

The project SEED (Safe E-Scooter Driving) aims to provide and discuss such data, which was collected from more than 80 subjects during an extensive three-day test trial. Three different E-scooters have been used, each equipped with measurement devices to precisely collect data of their motion states. Voluntary test subjects were instructed to pass a diverse driving parcours, including braking manoeuvres. We study the effects of different scooter types on manoeuvrability (indicated by measures such as standard deviation of steering speed and roll-rate or decelerations realized in real conditions), whilst correcting for influences of age, sex and several other parameters on measured driving behaviours. This yields conclusions on what E-Scooter types require which behavioural adjustments to drive safely.

Keywords: E-Scooter · Vulnerable Road Users · Driving Dynamics · Urban Mobility

1 Introduction

E-Scooters provide easy to use micromobility that has been considered to be a potential facilitator of combining public transport with a last mile solution for individual target destinations (see [1]). Though the usage statistics on whether car trips or other public transport trips are being replaced do not always support this (see [2, 3]) nevertheless individually owned E-Scooters as well as floating systems have become an important part of urban transport and therefore, provisions for safe use have to be made, in particular policy recommendations (see [4, 5]). Basic properties of the handling and braking dynamics of E-scooters are analyzed in [6].

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We present here outcomes of the project SEED (Safe E-Scooter Driving) within which an essential task concerned the study of driving behaviours of a subject population for a given set of tasks on a parcours. We interpret the findings and discuss effects of E-scooter models in combination with different user populations.

2 Methods and Data

2.1 Experimental Parcours

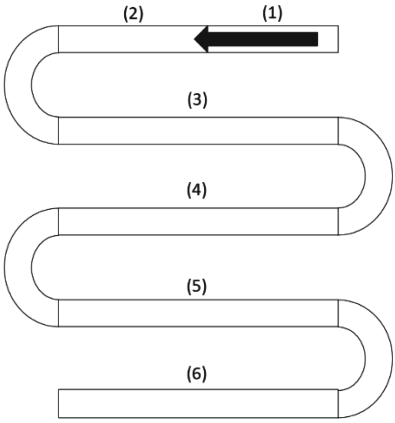

Fig. 1. Representation of the sections used to evaluate subjects' driving behaviour. The black arrow depicts the driving direction.

The parcours consisted of six basic driving tasks as indicated in Fig. 1: a narrow driving section (1), a section in which a hand-signal had to be performed whilst continuing driving (2), a section in which a slalom had to be performed (3), a section in which a lane change maneuver had to be performed (4) and finally two braking exercises, the first of which required the participants to break suddenly upon a given signal (5) and the second required them to brake as close as possible to a given line (6). Before entering in the parcours subject performed several everyday driving tasks (braking, reaccelerating, curves), that are not in the focus of this analysis.

2.2 Scooter Types and Instrumentation

Three types of e-scooter were included in the experiment: A cheap model with an intermediate footboard width (wheelbase 83 cm, weight 16.3 kg, steering head angle 14°) (Type 1), a more costly model for private use with multiple braking systems and a narrow footboard (wheelbase 91 cm, weight 15.2 kg, steering head angle 9°) (Type 2) and a relatively heavy floating-use type model with left and right brake handles similar to a bicycle and a wider steering handle than the other types (wheelbase 101 cm, weight 29.0 kg, steering head angle 15°) (Type 3). The given weight of the e-Scooters each

include measurement devices, which basically consist of: a GPS sensor to capture the position and forward speed of the vehicles, an inertial measurement unit (IMUs) to obtain accelerations (in X-, Y- and Z-direction) and rotational velocities (Yaw-, Roll- and Pitch-rates) with high frequency (100 Hz). Additionally, steering angles were tracked on all three e-scooters.

2.3 Subject Population

We recruited subjects to take part in a monitored driving experience on the parcours outlined in Sect. 2.1 using the E-scooters described in Sect. 2.2. Full data was acquired from 82 subjects, along with their self-reports on age, body height, weight, sex and driving experience (in 3 discrete categories). Their performance in each task was noted (successful/not successful) in order to structure analyses based on successful trials only. In addition, their standing position on the footboard of the E-scooter (front, centered, rear) was gathered by measuring (static) wheel loads.

2.4 Obtained Data and Regression Models

From measurement systems on all 3 e-scooters we obtained accelerations (X-, Y- and Z-directions), rotational velocities (Yaw-, Roll- and Pitch-rates), steering angles, GPS localization and forward speeds. Analysis was based on average effects i.e. we calculated an average value Y of all the valid rides of a subject and regressed against their age (in years) *Age*, their sex (self-report) *Sex*, their previous driving experience level (3 categorical values, "no experience", "1–3 times", "more often") *Experience_levels*, their height *Height*, the distribution of their measured weight (between 0 and 1, 0 meaning all weight lying on the back wheel) *Weight_dist*, their total measured weight (in kilograms) *Total_Weight* and the type of scooter used (3 categorical values) *Type*, with a normal distributed error ϵ:

$$\begin{aligned} Y \sim\ & a\,Age + \mathrm{s}Sex + t\,Type + h\,Height + wd\,Weight_dist + \\ & tw\,Total_Weight + \mathrm{e}Experience_levels + \in \end{aligned} \tag{1}$$

From the model Eq. (1) we obtained the regression coefficients (*a,s,t,h,wd,tw,e*) to evaluate the effects of various personal parameters and retrieve effects of the E-scooter types after correcting for their influence in the form of the estimated t regression coefficient, which can be tested for the significance of its effect and investigated for the size of its influence.

This model was implemented in the software R ([7]). The relevant segments were found by subdividing the data according to GPS localization on the beginning and end of a task area. This alignment approach failed for the data of one subject, leading to the exclusion of data from the analysis.

3 Results

For this analysis, we will focus on the results regarding the e-scooter types, after correcting for the influence of the variables mentioned above. We find significant effects of scooter types on all six stations of our driving parcours.

Figure 2a shows effects found on roll rate standard deviation in the narrow driving lane segment. Scooter Type 1 shows significantly ($p = 0.0013$) lower roll rate standard deviation of Type 1 ($t = -1.4$) compared to Type 2 (baseline) and Type 3 ($t = -0.49$). Figure 2b shows the effect on the steering rate standard deviation, as a measure of rebalancing attempts during giving a hand sign. During the hand sign segment, the heavy Type 3 scooter contributed the least to steering angle speed standard deviation ($t = -0.05$, $p = 0.037$), while the difference Type 2 to Type 1 was not found to be significant.

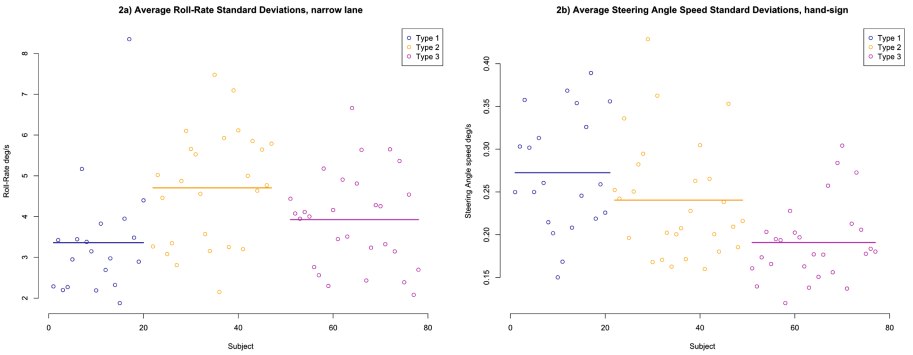

Fig. 2. 2a) Average roll-rate standard deviation during narrow lane maneuver. 2b) Average steering speed standard deviation during the hand sign segment, both by subject.

Figure 3a shows the sum of the total differences of steering angle maxima during the slalom as a measure of the steering effort in the slalom. The Type 2 E-scooter required notably less steering overall to perform the maneuver ($t = 31.6$, $p = 0.01$ for Type 1, $t = 27.3$, $p = 0.01$ for Type 3, Type 2 baseline). Figure 3b shows the max vs min Lateral-acc during the lane change maneuver by type. A significantly higher average is found in the peaks of Type 1 ($t = 0.43$, $p = 0.005$).

Figure 4a shows the negative horizontal accelerations (X-direction) during the braking maneuver. The riders of the Type 3 E-scooter reached substantially higher decelerations ($t = 0.95$, $p = 0.0002$). Figure 4b shows the same during the targeted braking. Again, the Type 3 E-scooter achieved substantially higher average decelerations ($t = 1$, $p = 0.00003$).

4 Discussion

We performed an experiment with 82 subjects on a parcours involving multiple driving tasks, employing E-scooters equipped with measurement devices (GPS, IMU, steering angle sensor) to precisely track their motion and driving states. Subjects were instructed and then rated during these tasks. Subject's personal data (height, weight and age) was obtained from all subjects. Successful performances were averaged for a set of prespecified variables of interest and regression against the personal data of the subjects and the type of E-scooter they were using was carried out. The resulting effects of E-scooter

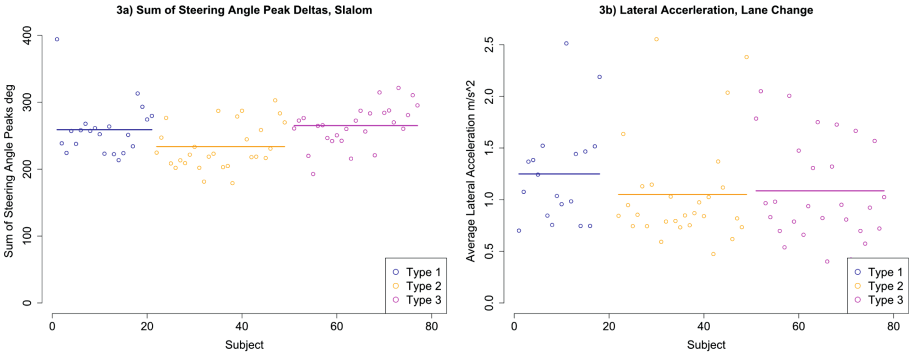

Fig. 3. 3a) Sum of difference for peak positive and peak negative steering angle changes, for six slalom curves. 3b) Average lateral acceleration during lane-change, both by subject.

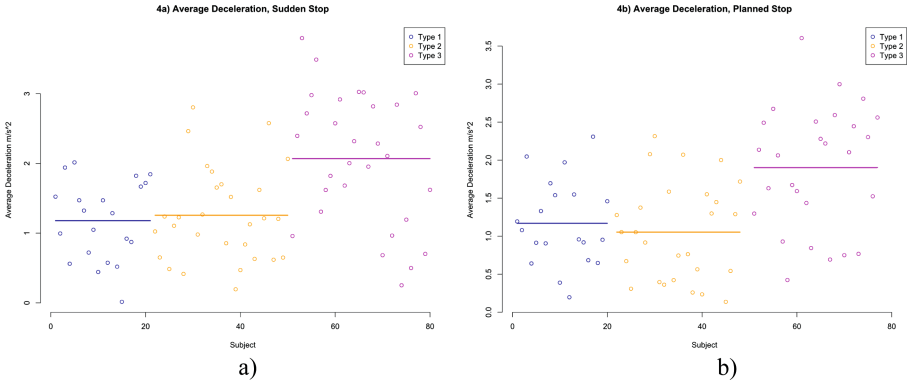

Fig. 4. 4a) Average deceleration during braking upon a given signal. 4b) Average deceleration during planned braking maneuver, both by subject.

types were obtained from a statistical model, correcting for the influences of personal data.

We find that E-scooter Type 1 shows desirable features (lower roll-rate standard deviation) in the narrow segment task as well as high lateral acceleration in the lane change maneuver. The reported findings support the notion that such an E-scooter supports maneuverability and driving in difficult spatial conditions. The E-scooter Type 1 appears to be best suited for users driving at moderate speeds and valuing maneuverability i.e. less experienced users driving at moderate to low speeds.

E-scooter Type 2 shows good all-round performance, with very responsive steering seen in the slalom, while assumedly not being as quick on following lateral movements as Type 1 and not contributing much to user stability. That makes this type best suited for more experienced users, that have less need for small corrections and might go slightly faster on average.

E-scooter Type 3 shows the largest stability w.r.t. steering and the highest braking capacity. The high braking capability and the steering stability go well with floating system use that needs to be amenable to users of all experience levels.

To conclude, we find that a vehicle like Type 1 might be a good starting machine for inexperienced users, acting responsibly with regards to speed, while Type 2 is more demanding in user control and Type 3 offers the most steering stability and braking power, but is quite heavy compared to typical models for private use. We would not rank the 3 types in terms of being safer or less safe in general, as this depends on the requirements of the rider and could differ substantially.

Further research will report the effects of the personal variables omitted here and show how these findings relate to simulations of the mechanical properties of these e-scooters. Ultimately, a risk model methodology devised previously ([8]) will be transferred to the situation of e-scooters in an urban environment.

We note as a clear limitation, that this study was exploratory and thus future research will have to reproduce these findings.

Acknowledgements. The project SEED gratefully acknowledges funding by the Austrian Road Safety Fund ("Verkehrsicherheitsfonds", VSF) under grant number GZ: 2021–0.053.053.

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Influence of Contrasting Colors on the Drivers' Ability to Detect E-Scooter Riders

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Abstract. E-scooter riders are particularly vulnerable regarding car drivers. Therefore, this study aims to investigate the potential of contrasting colors to make e-scooter riders more visible to car drivers during daylight. Two visibility aids were designed: Patterned Jacket (including jacket and backpack composed of alternation of yellow and black squares) and Wheels-Backpack (including yellow stripes on black e-scooter wheels and yellow triangles on black panels of the dark backpack).

Volunteers were invited to detect e-scooter riders from images while completing a secondary task. They detected riders wearing the Wheels-Backpack significantly sooner than riders wearing the Patterned Jacket or those without any visibility aid. Moreover, their visual strategies were more effective while detecting riders from the Wheels-Backpack condition. The Patterned Jacket did not show any significant improvement of riders' conspicuity relative to the Control. However, participants judged that both aids provided e-scooter riders the same visibility benefits.

It seems that merely adding contrasting colors in visibility aids might not always make e-scooter riders more visible to drivers. Instead, the distribution of contrasting colors across the key points of the e-scooter and the rider could be a better technique.

Keywords: e-scooter riders' safety · daylight visibility · contrasting colors · driving · detection · eye fixations

1 Introduction

In France, accidents between e-scooters and motor vehicles have become more prevalent over recent years after the appearance of multiple shared e-scooter services. Between 2018 and 2019, the number of injured e-scooter riders was multiplied by 7.3 [1]. A recent French report suggests that in 2022 the micromobility-related injuries (including e-scooters) were expanded by 261%, and the fatalities were expanded by 240% compared to 2019 [2]. An American research on e-scooter fatalities reported that 86% of them involved motor vehicles, suggesting that e-scooter riders are particularly vulnerable on the road, as much as pedestrians or cyclists [3].

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Increasing the saliency (visibility) of vulnerable road users to drivers may prevent collision with motor vehicles [4, 5]. Saliency refers to the sensory conspicuity describing the capacity of an object to grab one's attention due to several physical characteristics such as brightness, color contrast, shape and angular size [6, 7].

To our knowledge, no research has explored the e-scooters' conspicuity for car drivers. Fortunately, numerous studies have demonstrated that the use of visibility aids implementing contrasting colors could significantly enhance the conspicuity of pedestrians and cyclists on the road [8, 9]. Thus, a study based on self-reported accidents in Denmark found that cyclists wearing yellow safety vests were less likely to be involved in an accident with a motor vehicle [10]. A study in a driving simulator found that yellow vests helped cyclists to be detected by drivers at significantly greater distance in several situations in an urban environment during daylight [11]. Several on-road night studies uncovered that retroreflective elements attached to major joints of standing pedestrians may be more beneficial for their conspicuity, than when attached to their torso, as it facilitates the perception of a human form [12, 13]. Alternatively, positioning contrasting colors directly on mechanical components of a device (e.g. bicycle) might also enhance the conspicuity of its owner. Thus, a video-based study found that under several lighting conditions the bicycle tire featuring an alternation of colors increased the distance at which drivers detected cyclists, compared to when the tire was colored on a solid black [14].

Given these encouraging findings, the current study aims to explore the benefits of contrasting colors for e-scooter riders' visibility to car drivers. Precisely, the visibility aids producing an inner color contrast (centered within the e-scooter and the rider) and featuring different configurations were assessed during the experiment under controlled lab settings. According to the studies mentioned above, it is reasonable to believe that strategically configurated contrasting colors across the e-scooter and the rider could help him to stand out conspicuously and thereby to be detected faster by drivers. The drivers' detection time, several ocular intervals and subjective conspicuity judgements were examined to test this working assumption.

2 Method

2.1 Participants

The data for this study was obtained from 39 volunteers (26 women and 13 men) aged 24.6 years on average (SD = 2.4). They have had their driving license (M = 5.6 years, SD = 3.2) and most of all (N = 36) occasionally used an e-scooter (trips per year: M = 2.4, SD = 1.02). In addition, all participants reported having a vision that does not require any optical correction (eyeglasses or lenses).

2.2 Apparatus

Participants observed a set of 54 images (1,44 m long x 0,84 m high) each lasting 6 s, that were displayed on a wall projection (Epson EMP-TW1000) at a distance of 1,45 m from them. Images were generated by a driving simulator from the perspective of a driver, representing an urban road under daylight.

Half of the images contained an e-scooter rider from one of three Visibility Aid conditions: Control, Patterned Jacket and Wheels-Backpack. In Control condition riders were wearing grey clothes and a grey backpack. For the Patterned Jacket condition, the riders wearing grey were provided with a jacket and backpack, both with a black and yellow checkerboard pattern [15]. The Wheels-Backpack visibility aid was provided with the same yellow color, but it was attached to three distinct points. Precisely, the dark riders' backpack integrated black panels with yellow triangles, oriented toward the riding direction, and stripes of the same color were placed on the black e-scooter tires. The riders from these three visibility aid conditions are illustrated in Fig. 1. The e-scooters in the images could be entirely visible or partly hidden on different locations of the roadway (road, bicycle path, sidewalk).

Fig. 1. The three visibility conditions, from left to right: Control, Patterned Jacket and Wheels-Backpack. Image generated using the OSGSim2 car driving simulator of Gustave Eiffel University.

Participants' eye movements were recorded using a head-mounted Pupil Labs eye-tracker offering an accuracy of 0.6 degree of visual angle and a sampling rate of 30-Hz for the world camera and 200-Hz for two eye-cameras [16].

2.3 Procedure

While the images were being displayed, participants were instructed to complete the N-back task with "1-back" level of difficulty [17], requiring them to listen to a series of random numbers from 1 to 9 every 2.5 s and to repeat out loud the number they had heard just before the current one. At the same time, they were told to press a button on a keypad indicating they had seen an e-scooter rider in the images. The1-back task was stopped every time participants pressed the button, so they could evaluate the rider's visibility (conspicuity) through a Likert 10-point scale, where 1 equals low visibility and 10 equals high visibility. Once the answers were provided, the entire procedure was restarted. During the experimental session that lasted around 2h, each participant saw the full set of images.

2.4 Data Analysis

37 participants out of 39 provided sufficient high-quality eye-tracking data and were included for further analyses. The repeated measures ANOVA (Visibility Aid conditions: Control, Patterned Jacket and Wheels-Backpack) were conducted for detection time,

ocular intervals and conspicuity ratings, following a post-hoc Fishers LSD test every time any significant differences appeared ($p < .05$ were considered significant).

The Pupil Labs software provided information about ocular fixations within a 1° dispersion and 80 ms duration. A zone of 5,5° visual angle around the fixation point was considered, corresponding to the area of central visual field [18]. The AOIs (areas of interest) were created around each e-scooter rider, including both rider and e-scooter. The following ocular intervals were investigated:

- Time to Fixate (s): Time from when the e-scooter rider appeared in the participant's field of view to when the participant first fixated e-scooter rider;
- Fixations Number and Fixation Duration (s): Total number of fixations and their duration on AOI prior to pressing a button;
- Time to Identify (s): The time spent from the end of the first fixation on AOI prior to pressing a button;

3 Results

3.1 Detection Time

The Visibility Aid condition had a significant effect on detection time, $F(2,72) = 8.356$, $p < 0.001$, $\eta 2 = 0.188$. Participants detected e-scooter riders from the Wheels-backpack condition (Mean = 1.994 s, SD = 0.378 s) significantly faster than e-scooter riders from the Patterned Jacket (Mean = 2.237 s, SD = 0.404 s) and the Control (Mean = 2.251 s, SD = 0.471 s) conditions. The mean detection times for the Control and the Patterned Jacket were not significantly different from each other.

3.2 Ocular Intervals

The effect of Visibility Aid condition on the Time to Fixate $F(2,72) = 0.823$, $p = 0.44$) and on the Number of Fixations ($F(2,72) = 2.411$, $p = 0.09$) was not significant. However, a significant effect was found for the Fixation Duration ($F(2,72) = 3.357$, $p = 0.04$, $\eta 2 = 0.085$) and the Time to Identify ($F(2,72) = 4.152$, $p = 0.01$, $\eta 2 = 0.103$). Their means and standard deviations are illustrated in Figs. 2 and 3.

3.3 Conspicuity Ratings

A significant effect of Visibility Aid condition was revealed for the Conspicuity ratings, $F(2,72) = 11.796$, $p < 0.001$, $\eta 2 = 0.247$. Both visibility aids (Wheels-Backpack: M = 5.81, SD = 1.34; Patterned Jacket: M = 5.96, SD = 1.34) produced higher ratings than the Control (M = 5.02, SD = 1.73), but there was no significant difference between Patterned Jacket and Wheels-Backpack.

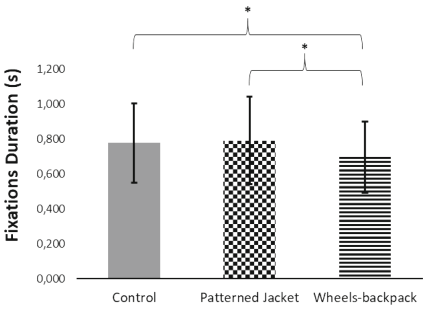

Fig. 2. Mean duration of fixations (s) spent on the e-scooter rider as a function of visibility condition (Control, Patterned Jacket and Wheels-backpack). Legend: *, $p < 0.05$.

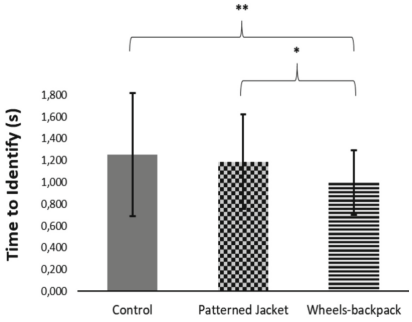

Fig. 3. Mean time to identity (s) as a function of visibility condition (Control, Patterned Jacket and Wheels-backpack). Legend: *, $p < 0.05$; **, $p < 0.01$.

4 Discussion

This study investigated the daytime conspicuity benefits of contrasting colors for e-scooter riders and provided insight into two visibility aids: Patterned Jacket and Wheels-Backpack. Therefore, it seems that participants required less time to detect e-scooter riders provided with the Wheels-backpack visibility aid, but they spent an equal time detecting riders wearing the Patterned Jacket, as well as those who were not wearing any visibility aid at all. This is an important result indicating that adding a contrasting color on the rider's torso might not make them more visible to drivers, contrary to the same color placed on several key points of the rider and the e-scooter.

The findings from the ocular data uncovered the mechanisms underlying the effectiveness of the Wheels-Backpack. Specifically, the results from Fixation Duration and Time to Identify data suggest that participants needed less time to collect and process the relevant information in order to be confident to have seen the e-scooter riders in the images, when the riders were provided with the Wheels-Backpack visibility aid.

Collectively, these findings point out that the effectiveness of Wheels-Backpack consists rather in facilitating the identification of the e-scooter rider. Given that, it is tempting to assume that similarly to the studies with pedestrians mentioned above [12, 13], there are parts of e-scooters that are most likely to have a salient shape and location.

The highlighted wheels, as well as the riders' height accentuated by distributed yellow markings, provided relevant information about the distinctive features of e-scooter riders, so that the participants could identify them more easily in an urban environment. This assumption refers to the cognitive conspicuity meaning that the visibility of an object does not depend only on its physical qualities, but also on the observer's knowledge and expectations [19].

The subjective conspicuity ratings, however, demonstrate that participants did not realize that Wheels-Backpack provided a greater advantage than Patterned Jacket. Probably, they believed that e-scooter riders should be visible when they wear visibility aid integrating yellow color, due to its wide use for security purposes, like yellow safety vests, traffic cones etc.

There were several limitations in this study. Participants were invited to detect only e-scooter riders from captured images, featuring a static urban road environment, which is not similar to real-world driving. Thus, additional research is warranted in a more ecological environment.

5 Conclusion

This study provides the first insight into e-scooter riders' conspicuity in daylight conditions, examining the benefits of visibility aids implementing the yellow contrasting color. The main finding of this study suggests that optimally configurated contrasting colors effectively enhance the e-scooter rider conspicuity during daylight. Additional research exploring the daylight conspicuity benefits of Wheels-Backpack visibility aid in realistic conditions is ongoing.

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Development of an E-scooter Simulator

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Abstract. This paper introduces the development and validation of an e-scooter simulator at the Transportation and Ambient Mobility Systems (TAMS) Laboratory at "University of Patras". E-scooters are gaining popularity as an eco-friendly mode of transport, but safety issues remain. The simulator allows users to interact with a virtual e-scooter within a Virtual Reality (VR) environment, using sensors for accurate transmission of movements. The chosen e-scooter is integrated into a mechanical structure for safety and efficiency. The virtual environment, designed with Unreal Engine (UE) software, replicates a familiar university campus location. Sensors include a rotary encoder for steering angle, a linear actuator with a potentiometer for surface slope, and a photoelectric sensor for speed measurement. Calibration parameters optimize speed data. Validation trials confirm accurate communication between the virtual e-scooter and the simulator. This innovative tool promises to enhance our understanding of e-scooter behavior and safety in various scenarios, addressing emerging challenges and contributing to safer micromobility solutions in urban areas.

Keywords: micromobility · simulator · e-scooter · virtual reality

1 Introduction

Micromobility is gaining popularity as an affordable and eco-friendly mode of transport serving as a promising transport mode in cities and densely populated areas. According to market analysis report, e-scooter market is expected to annually grow with rate of 9.9% from 2023 to 2030 [1]. Shared e-scooters are emerged as a last-mile solution to transit [2] or short trips [3]. However, the safety of e-scooter users in certain circumstances has not been thoroughly studied. A study conducted in six European countries underlined that police-reported accidents involving micro-vehicles have been increased by 8.2% [4], as well as e-scooter-related injuries have been raised [5]. Consequently, there is a need to address the challenges associated with e-scooters and prioritize the safety of users.

One promising approach to address these challenges is the development of an e-scooter simulator. A simulator can serve as a valuable tool for addressing driving behaviors under targeted risky circumstances and identify the challenges users' face. It can also help to assess the impact of e-scooters on urban infrastructure and safety, as well as

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evaluate the environmental consequences. By creating a virtual environment that replicates real-world scenarios, an e-scooter simulator can contribute to reducing accidents and injuries. More specifically, the collection of information for parameters like speed, steering angle, and scooter direction for a variety of scenarios that in real life would be dangerous for the users, could lead to conclusions (average speed of users, reaction time, driving behavior under different external components) which in turn, could help for the design of new infrastructure, the optimization of the existing infrastructure in order to be safer for the users and also, the implementation of updated guidelines regarding the driving of e-scooters, which aims to protect their users. Furthermore, these conclusions could be used as feedback to the developers of the electric scooters in order to validate the characteristics of the electric scooters such as the maximum speed and the steering angle, but also it can eventually help to change the giving measures of protection for the users. Similar bicycle simulators have been developed to address challenges, identify risky driving behaviors, and finally enhance road safety [6–8].

A simulator provides a valuable tool for further studies on e-scooter behavior and mobility in different scenarios, allowing for a more comprehensive understanding of e-scooter safety. This paper is an introductory step to an e-scooter simulator development and validation.

2 Methodology

2.1 Development of the Simulator

The simulator was developed at the Transportation and Ambient Mobility Systems (TAMS) Laboratory at the department of Civil Engineering in University of Patras. The fundamental idea of a simulator is the accurate communication between the user and the vehicle as well as the vehicle with the Virtual Reality (VR) environment, and vice versa. Following this, the VR environment presents outcomes via an image display device, and the user responses to visual stimuli. The simulator interacts with the VR environment with the aid of sensors such as ARDUINO. The visualization of the e-scooter's movements within the simulated environment is achieved with the aid of a high-resolution projector or Virtual Reality headsets (Fig. 2). The travelling environment was designed with the use of the Unreal Engine (UE) Software and concerns a specific location at the university campus. The selection of the location was based on the familiarity of the users to it, in order to capture the exact geometrical design features in the virtual reality environment and to conduct further research on the overall users' experience, in the subsequent time.

On the first place, a commercial e-scooter with 8.5" wheel was selected in order to stay close to the technical specifications of popular vehicles widely used on the road. The only specific requirement was that the motor had to be in the rear wheel. This rule was set because it helps not only to keep the measurements for steering angle and speed separate for both wheels, but also to make the equipment adaptable to future changes and adjustments for other small vehicles, like e-bikes. The e-scooter was established on a mechanical structure basis that ensures its efficiency and the safety of the user.

Figures 1, 2, 3, 4, 5 and 6 presented below were captured at the "Transportation and Ambient Mobility Systems (TAMS) Laboratory" at the University of Patras.

Fig. 1. E-scooter's overview

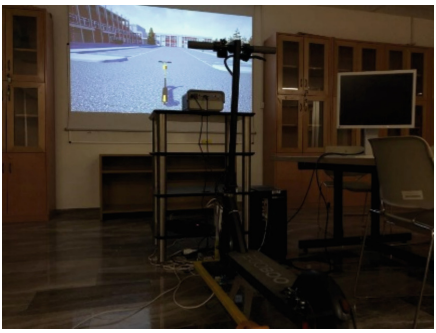

Fig. 2. E-scooter's overview

As mentioned before, the interaction between the virtual e-scooter and the simulator is achieved with sensors to accomplish accurate transmission of the movement. The choice of these sensors was made based on different bicycle simulators such as the "PICSL-L" bicycle simulator, which is located at the "Gustave Eiffel" university in France and the bicycle simulator which has been developed at the "Technical university of Delft" in Holland. In addition, this kind of sensors are widely used in cases it is needed to measure parameters like circular speed and rotation. Furthermore, a mechanism is also established as a starter point to acquire the initial speed that is required from the e-scooter to start moving (Fig. 3). The steering angle is measured with rotary encoder (Fig. 6) and the slope of the surface is achieved with a linear actuator with a potentiometer (Fig. 4). Lastly, the speed is measured with the aid of a circular disk with holes (Fig. 5). A photoelectric sensor measures the speed by counting the number of holes passing per time interval.

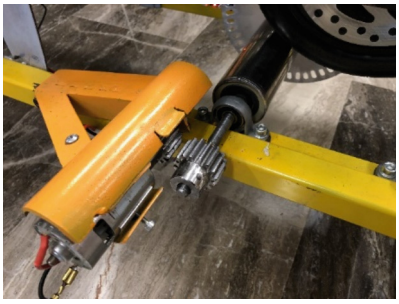

Fig. 3. Electromechanical equipment: Speed up mechanism

Fig. 4. Electromechanical equipment: Linear actuator

2.2 Validation of the Hardware

The validation procedure of velocity and angle was conducted through a series of trials. To achieve more accurate results, calibration parameters for the speed were employed within the software. The outcomes of this optimization process are presented in Fig. 7

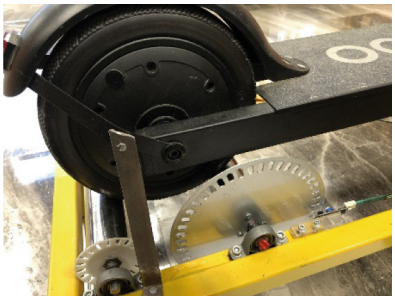

Fig. 5. Electromechanical equipment: Circular disk

Fig. 6. Electromechanical equipment: Rotary encoder

and Fig. 8. The sensor's measurement speed from the VR-rig scooter and the resulting speed of the virtual e-scooter are displayed in Fig. 7. As can be seen, there are two regions, acceleration and deceleration. In the case of the VR-rig wheel, acceleration is nearly instantaneous, whereas in the virtual e-scooter, there is an acceleration value of approximately 170 cm/s^2.

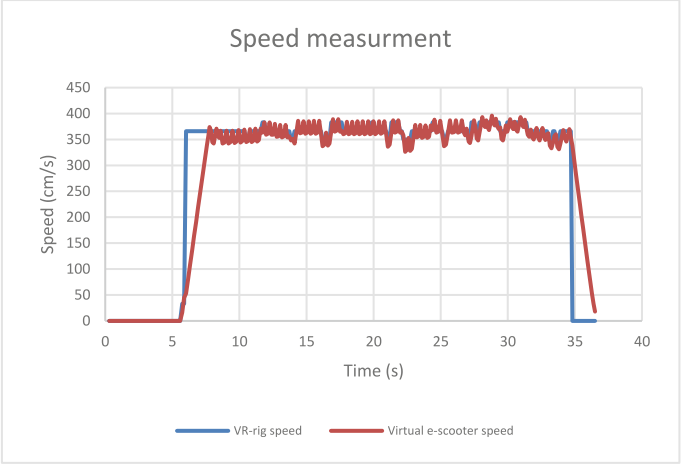

Fig. 7. Speed measurement feedback

Figure 8 shows the VR rig angle (controlled by the user), the final virtual e-scooter direction and the value of virtual e-scooter speed (right axis). It is observed that when the steering angle is stable, the e-scooter direction changes linearly and in fact due to different angle values the rates of e-scooter direction change are 15.3, 8.8 and -2.3 respectively. Finally, as shown in the right end of the diagram below, while the virtual e-scooter has zero speed, its direction remains constant even when the VR rig angle is not zero. This means, that in order to change the direction of the virtual e-scooter, users must develop a certain amount of speed in the virtual environment. In conclusion, the

measurement of the steering angle consistently offers consistent and reliable feedback to the Virtual Reality E-scooter.

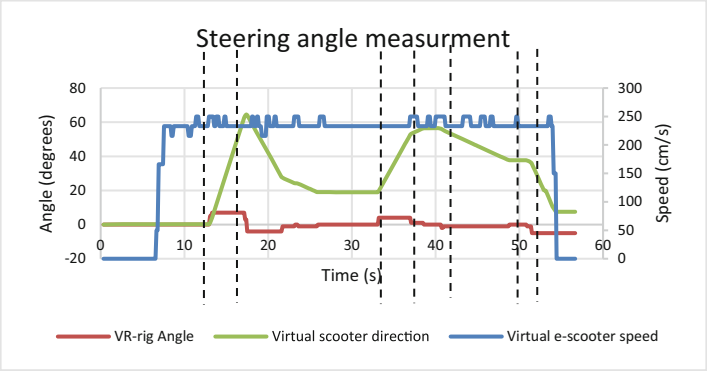

Fig. 8. Steering angle and scooter direction relation

3 Future Work and Recommendations

E-scooters is an emerging mode of transport in many cities and areas worldwide. Their affordability, eco-friendly impact and convenience makes them as a basic mode of transport for small and last-mile trips. Although, safety issues and driving behavior gaps have not been thoroughly addressed and solved. This paper introduces an e-scooter simulator that was totally developed in TAMS Lab, which will be a mean to identify and understand the rising problems of e-scooters and their potential. The foundational concept of a simulator is based on the interaction between the user and the vehicle, as well as the interaction between the vehicle and the Virtual Reality environment. The validation of the e-scooter simulator showed promising results.

Further studies should be focused on the optimization of the sensor's communication as well as, the enhancement of the realism of the e-scooter simulator, in terms of the overall user's experience. This can be achieved by optimizing the infrastructure of the e-scooter and the virtual environment to make it even more interactive and dynamic. Furthermore, the simulator should be expanded to include bike and e-bike models to accommodate diverse experiences of micromobility. This will facilitate a more comprehensive understanding of how different e-vehicles designs impact user's safety and behavior.

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COFACY: From Behaviour to Cycling Accident Factor

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Abstract. For several years, an increase in bicycle routes has been observed in France and is accompanied by a significant number of deaths and injuries. Financed by the DSR (Road Safety Department), the COFACY project aims to describe profiles, uses and behaviours of cyclists and to identify the risky situations they encountered and their determinants. This project was prompted by a joint evolution of cycling mobility and data accidents. A naturalistic study was conducted in France in the regions of Ile de France (April to June 2022) and Auvergne-Rhône-Alpes (September to November 2022). A total of 78 volunteer cyclists were monitored for 4 weeks with a camera attached to the helmet. A logbook was completed after each route and weekly self-confrontation interviews were carried out to detail and review their critical situations. A particular attention was paid to the occurrence and environment of the situations (urban or rural areas). Cyclists completed 2152 routes and reported 779 risky situations. Results showed that the exposure to risky situations was twice as high in urban areas (1 situation every 80 min) than in rural areas (1 situation every 160 min). The main scenarios encountered were: "Non-compliance with lateral distances", "Presence of an obstacle" and "Refusal of priority with signs" in both environments. Cars were the road users involved in the majority of situations both in urban and rural areas. These results will allow a better understanding of practice, uses and dangers encountered by cyclists according to the environment in order to direct further public decisions.

Keywords: Cyclists · Naturalistic study · Risky situation

1 Introduction

Ecological, health and economic issues as well as recent Covid-19 issues have highlighted soft mobility such as bicycles. In France, between 2019 and 2021, cycle routes have increased by 34% in urban areas and 18% in rural areas. At the same time, in 2021 the number of cyclists killed has increased by 16% in urban areas compared to 2019 (107 killed). In rural areas the increase is 47% (137 killed). In addition to the significant increase, recent road accident data shows that the severity of cycling injuries is six times higher in rural areas than in urban areas [1].

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Numerous studies focused on accidents data of cyclists. For instance, Knowles et al. (2009) [2], observed (in the UK) that in 83% of situations where a cyclist was killed or seriously injured, it was due to a collision with another vehicle. While many studies have been carried out on cyclists' injuries, few have analysed the behaviour and risky situations encountered by cyclists on real roads. We can note the study of Johnson et al. (2014) [3] in Australia involving cyclists equipped with cameras, and in France, the DSR COCY project (2018–2020) [4] where 75 cyclists were monitored for a month with cameras and took parts to weekly interviews in order to review their critical situations.

Mixed "accidentality"/"incidentality" studies putting typical accident and incident into perspective would be relevant in order to have an exhaustive knowledge of risky situations. This mixed approach has been set up in the COFACY project. This study is part of an original conceptual approach initiated by the Ergocentre team. It is based on progressive conceptual developments carried out over the last 20 years of natural studies carried out with various users. This approach lies at the intersection of three initially distant theoretical frameworks. First, the French-language ergonomics give tools for data collection and analysis of human activity in natural situations [5]. Then, the critical incident method where the subject has to recall an incident in which he was involved and then a series of questions are asked to help him to go deeper in the course his behaviour [6]. Finally, the third framework refers to the concept of "error" in transport psychology [7] following the works of Van Eslande (2001) [8]: human mistakes can be broken down in a series of successive functional stages. This approach aims to identify the cognitive stage during which a failure appeared in the cognitive processing of information.

The objective of the COFACY project was to describe profiles and behaviours of cyclists, and to identify the risky situations they encountered. This paper presents the methodology we used to carried out this naturalistic study and the main results.

2 Data Collection

2.1 Population

A total of 78 volunteer cyclists were recruited for the naturalistic study: 38 in the Paris Region and 40 in the Lyon region. For each region, half of the cyclists mainly ride in urban areas ("Urban" group) and the other half make trips both in rural and urban areas ("Mixed" group). The Agglomeration group was composed by 19 men and 20 women with an average age of 38 (min: 23 and max: 64). The most frequent socio professional category is 'Executives and higher intellectual professions' (74,4%). In this group, 53,8% of the cyclists had more than 10 years of practice experience. In the Mixt group, 30 men and 9 women were recruited. The average age is 41 (min: 19 and max: 65). The 'Executives and higher intellectual professions' socio professional category is the most important one in the group (48,7%). Nearly 85% of them had more than 10 years of cycling experience.

2.2 Methods

The study was conducted in the same way for all the participants during the 4 weeks of experimentation. Three data collection methods were combined: 1) recordings of all

their journeys with a camera installed on the participant's helmets and a remote control fixed on the handlebar (Fig. 1), 2) completion of a logbook to report their journeys and their risky situations, and 3) interviews at the begin and at the end of the study in order to draw up a cyclist profile and a weekly interview to review the risky situations encountered during the week. By pushing on the remote control, the cyclists could signal a risky situation during their trip.

Fig. 1. Instrumentation for the cyclists. Photographs courtesy of Ergocentre, reproduced with permission.

2.3 Analysis

In order to have an overview of the participant's verbal data, a data collection grid was built: interviews were transcribed and data from the logbooks exported. All replies were then summarised in a processing grid with different analysis categories (e.g. trigger factors, actors involved). For each category, different response possibilities were associated and based on the participant's responses (e.g. actor involved: 1. Car, 2. Pedestrian, etc.). All the data were then coded to facilitate the subsequent statistical analyses. Before the coding, inter-judge concordance was carried out between the study staff to ensure the homogeneity and reliability of the coded data.

3 Results

3.1 Bike Use

The Urban group did 1197 trips whereas the Mixed group did 955 trips. Cyclists in the Mixed group made fewer trips than the Urban group (ie. 5 trips on average). However, the average duration of Mixed trips was significantly longer ($t(1792) = 11.8$, $p < 0.001$) than the Urban group (50 min against 26 min, respectively).

During the study, 1761 trips were carried out in urban areas (UA) and 391 in rural areas (RA). Cyclists of the Urban group ridded exclusively in urban areas (99% of their trips) while cyclists of the Mixed group ridded in both urban (60.2% of their trips) and rural areas (30.8% of their trips).

In UA, most trips were done on weekdays (86.5%, n = 1524) in the time slots "[6am – 10am[" and "[5pm – 8pm[" (47.4%, n = 835). These routes were mainly used for commuting journeys (58.9%, n = 1083) (Fig. 2) with an average duration of 26 min.

In RA, 75.3% of trips were done on weekdays. Twice as many routes were done during weekends than in UA. Overall, 20% of the trips were done during the "[5pm – 8pm[" period. If we cluster the routes used for leisure/fun and sports routes, they represented 41.9% of usage in RA (Fig. 2), with an average duration of 114 min. We can note also that commuting (which represents 28.9% of the overall trips for RA), is largely much longer than in UA ($t(938) = -9.1$, $p < 0.001$) (59 min against 28 min).

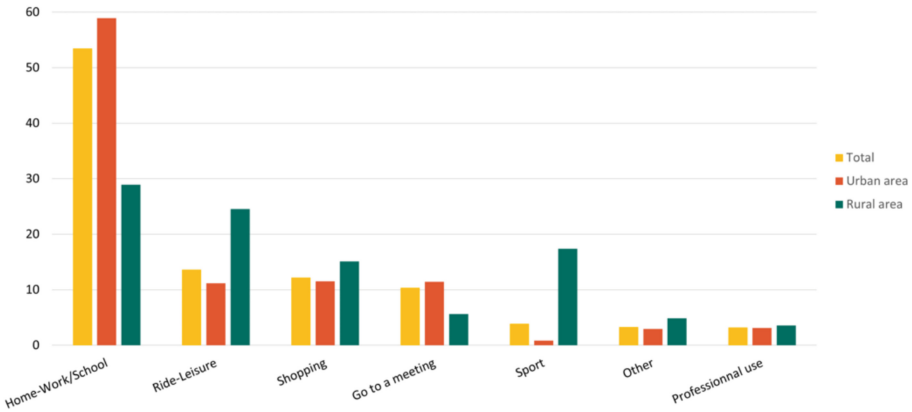

Fig. 2. Routes made during the study according to their localization in percentage

3.2 Risky Situations

A total of 779 risky situations were reported by cyclists. In UA, 573 risky situations were reported, i.e. every 3.1 trips, and 206 in RA, i.e. every 1.9 trips. In other terms, studied cyclists have identified one risky event every 80 min in UA, compared with one every 160 min in RA. The risk of encountering a dangerous situation is therefore twice as high when riding in UA than in RA.

Trigger factor depended on the environment. Failure to give way by other road users was the main factor reported in UA (38.4%), whereas it is voluntary risk-taking which is the main factor in RA (57.4%). The presence of an obstacle was an important factor both in UA (24.2%) and RA (16.3%), but the nature of this obstacle differs according to the environment: parked vehicles, pedestrians or bins in UA and tree roots, sign posts or animals in RA.

The risky situations where clustered in nine categories of scenarios (Fig. 3). Some differences according to the cycling environment were observed. The three most risky scenarios were the same in both areas but in different proportions: 'Non-Compliance with lateral/longitudinal distances' (UA: 24.3% / RA: 45.1%); 'Presence of an obstacle or pedestrian' (UA: 31.1% / RA: 26.2%) and; 'Failure to give way' (UA: 16.2% / RA: 10.2%).

Cyclists reported that another road user was responsible for the situation in 78.9% of cases. The main other road users that are declared as "responsible" in UA were car drivers (51%), pedestrians (15.1%) and cyclists (9.8%). In RU, the "responsible" main users were drivers (61.8%), vans (13.3%) and heavy goods vehicles (6%).

City centre roads were the type of road on which cyclists reported the most risky situations, both in UA (49.2%) and RA (51%). However, the proportion of situations reported on cycling facilities differs according to the environment: 48.7% in UA against 24.7% in RA.

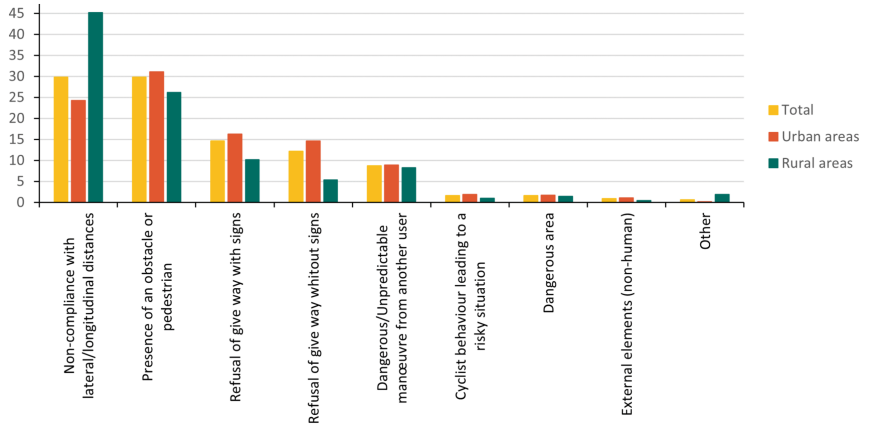

Fig. 3. Risky situations scenarios report by cyclists during the study according to their localization in percentage

3.3 Cognitive Failure

Cyclists reported being responsible for 6.8%, (n = 53) of risky situations they reported with slightly more situations in UA (7.5%) than RA (4.9%).

In almost three quarters of these situations, the cause was a failure of 'perception' (40.8%) or 'decision-making' (32.7%). It was therefore at these stages that the cyclist was unable to manage the difficulties he was facing. These failures relate to a problem of information detectability, whether due to masking, distraction or information detectability. A decision failure concerns the undertaking of a manoeuvre whether the decision is voluntary or forced.

4 Discussion

Overall, many similarities between the two groups of cyclists were observed during this study. We can identify three sub-profiles: 'Commuters cyclists' who use the bicycle exclusively to go to work; 'Fun cyclists' who use bicycles for leisure or sport competition, and 'Mixed cyclists' that cyclists who achieve both.

Results showed that the risk of encountering a dangerous situation is twice as high during an urban route than during a rural route. This difference can be explained by the greater complexity of the environment in urban areas.

This study highlights three kinds of risky scenarios: 'non-compliance with lateral/longitudinal distances', 'presence of an obstacle or pedestrian' and 'failure to give way'. These risky situations are the same as those observed during our other team projects in France. The users mainly involved in incidents are also the same: car drivers. The presence of vans and HGVs among the mainly involved users in rural areas could be explained by a greater danger due to their size and speed outside built-up areas.

In majority, another user was declared by the interviewed cyclist to be 'responsible' for the risky situation. Concerning situations in which the cyclists declared themselves to be responsible, the cause was a failure to 'perception' or to 'decision-making' like in the study of Van Eslande and al. (2004) [9].

The incident data collected during the naturalistic study will be cross-referenced with the "Accidentality" part conducted by other partners in this project to obtain a complete analysis.

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Examining the Impact of Driver Distraction on Speeding Through the Exploitation of Smartphone Sensor Data

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Abstract. Road safety is a complex phenomenon which is affected by several factors, with the most significant one being the driver behavior. The aim of the current research is to identify the impact of driver distraction on speeding using data obtained from smartphone sensors. To fulfil this objective, a naturalistic driving experiment was carried out in Greece and data collected from 100 drivers (18–65 aged) over a period of six months were analyzed. Four statistical lognormal regression models forecasting the percentage of exceeding the speed limits were developed: one overall model and one per road type (i.e. highway, rural, urban).Results demonstrated that driver distraction significantly affected driving behavior and, especially, speeding. Lastly, a stronger correlation had emerged between harsh accelerations and speeding, but also distance travelled, risky hours driving during night and demographic characteristics had a direct impact on speeding.

Keywords: road safety · driver distraction · mobile phone use · speeding · lognormal regression

1 Introduction

Mobile phone use and engagement while driving consists one of the most crucial factors affecting road safety and one of the leading cause of road crashes. Over the last years, driver distraction through mobile phone use while driving has been extensively studied. Iio et al. (2021) analyzed the effect of mobile phone use on driving behavior and findings revealed that driving speed and phone handling rate had a strong negative correlation. Similarly, Papantoniou (2018) claimed that mobile phone use had a negative effect on driving performance.

Another study conducted by Yannis et al. (2016) who examined the impact of texting on drivers' behavior and road safety. Results demonstrated that average driving speed was decreased and headway was shorter while texting. Although mobile phone use while driving was linked to lower driving speeds, it was found to quadruple the crash risk probability (McEvoy et al., 2007), probably due to slower reaction times (Caird et al., 2008) or inappropriate handling in case of unforeseen events (Papantoniou, 2015).

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Based on the aforementioned, this study aims to examine the impact of driver distraction on speeding through the exploitation of data from smartphone sensors. Moreover, the analyses were extended to determine the influence of road type (i.e. highway, rural and urban) in the percentage of speeding as well as any underlying correlations with other factors (e.g. harsh events, distance travelled, etc.).

2 Methodology

2.1 Data Collection

For the purpose of this research, 100 drivers, aged 18–65, participated in a naturalistic driving experiment during a 6-month timeframe and a large database of thousands trips was produced. In particular, an innovative data collection system using a smartphone application developed by OSeven was exploited. More specifically, OSeven has developed an integrated system with personalized interactive tools for recording, collecting, storing, evaluating and presenting driving behavior data. The most advanced Machine Learning algorithms and reliable metrics have been implemented in order to detect speeding events, mobile phone use, harsh accelerations or brakings, recognize whether the user is driver or passenger and identify the trip transport mode.

Prior to completion of each trip, the app uses an appropriate communication tool, transmitted through WiFi or cellular network and valuable information, such as features, driving scores, metrics and highlights is produced to evaluate driving profile and performance. It should be highlighted that OSeven platform has very clear privacy policy statements and cutting-edge encryption regarding the type of data collected. To that end, data security procedures are in accordance with the national legislations and the European Union's General Data Protection Regulation (GDPR) rules.

2.2 Questionnaire

In advance of initiating the driving experiment, participants completed a questionnaire, which was divided into three distinct sections: a) perspectives towards road safety, b) driving performance and c) socio-demographic characteristics. More precisely, drivers provided useful information with respect to their habits and attitudes toward road safety (e.g. compliance to speed limits, crash history), driving behavior characteristics(e.g. mobile phone use, aggressiveness) and demographic features (e.g. gender, age).

2.3 Model Overview

Statistical analyses were applied using multiple lognormal regression techniques in order to determine whether driving performance indicators, such as mobile phone use while driving, affect and can therefore predict speeding.

The basic equation of the multiple lognormal regression model is the following:

$$\log(y_i) = b_0 + b_1 \times x_{1_i} + b_2 \times x_{2_i} + \cdots + b_n \times x_{n_i} + e_i \tag{1}$$

- y_i: the dependent variable

- $b_0, b_1, b_2, \ldots, b_n$: the partial regression coefficients
- $x_{1_i}, x_{2_i}, \ldots, x_{n_i}$: the independent variables
- e_i: the regression error

During the statistical processing, four statistical regression models were formulated: an overall model and three models for each different road type (highway, rural and urban road). It is worth noting that an attempt was made to use exactly the same variables in each one in order to make comparisons across models. Then, it was determined for each model individually if the numerical results, which quantified relationships among variables, did satisfy the models' quality requirements. Firstly, the signs and values of the lognormal regression coefficients bi need to be logically explainable. Secondly, the statistical significance level along with the values of the t-statistic control, for the confidence level used, should be satisfactory and acceptable. Thirdly, the constant coefficient of the equation, which considers all the parameters that have not been taken into consideration, must be as low as possible. Lastly, the correlation coefficient R^2, which represents the proportion of the dependent variable that can be explained by the independent variables, should reach the highest value possible.

Finally, the elasticity (ei) that depicts how responsive one variable is to a change in another as well as the relevant influence elasticity (ei*) used for quantifying the influence of each individual variable are examined.

3 Results and Discussion

In order to accomplish the goal of this study, several driving performance indicators along with demographic characteristics were chosen as independent variables. For each model, the dependent variable was the logarithm of the speeding and the independent variables were the following: mobile phone use while driving (yes/no), harsh acceleration, average deceleration, distance travelled, risky hours distance, gender and age.

Table 1 provides a description of the parameters that were found to be significant in the multiple lognormal regression models.

Table 1. Description of the independent variables used in the analyses

Independent Variables	Description
Mbu/yes-no	Mobile phone use (0: no use of mobile phone, 1: use of mobile phone)
Harsh accelerations	Number of harsh acceleration events occurred (absolute value)
Avg. Deceleration	Average number of deceleration events (km/h/s)
Distance travelled	Total distance travelled (km)
Risky hours driving	Risky hours distance from 22:00 pm to 05:00 am (km)
Gender	Gender of participants (1: male, 2: female)
Age	Age of participants (1: 18–24, 2: 25–34, 3: 35–44, 4: 45–54, 5: 55–65)

The final multiple lognormal regression models are presented in Table 2; overall model and highway, rural and urban models, respectively.

Based on the results, in three (overall, highway, rural) out of four models, the mobile phone use while driving was associated with increased speeding percentage. This was probably due to the fact that in highways and rural areas, distracted drivers were focused more on their smartphone and less on the driving task, which led them to drive more nervously, pushing the accelerator gas pedal intensively without realizing it, resulting in speeding increase. The high impact of mobile phone use to speeding was an impressive finding which revealed a quite dangerous driving behavior style. A probable explanation might be that the driver who does not comply with the forbiddance of the use of the mobile phone while driving, does not comply with the speed limits. On the other hand, in urban environment, speeding was negatively correlated with the distraction from mobile phone use. This result can be probably explained by the fact that the existence of crossings and signaling in urban network forced drivers to reduce the average speed.

Moreover, the parameters of distance travelled, the number of harsh accelerations and driving during risky hours had all been determined as statistically significant and positively correlated with the percentage of speeding. For instance, participants who were driving at risky hours from 22:00 pm to 05:00 am, revealed a more dangerous driving behavior, performing more harsh accelerations and exceeding the speed limits, which was probably caused by low traffic load. What's more, results indicated that the higher the number of harsh accelerations and distance travelled is, the higher the speeding percentage occurs. In the opposite context, average deceleration was associated with decreased percentage of speeding. A probable explanation might be that a vehicle slows down when there are obstructions in front of it, such a red light or heavy traffic, making it impossible to exceed the speed limits.

Regarding the variables collected from the questionnaire filled in by the participants, this study revealed that the vast majority of male drivers displayed less cautious behavior during their trips and exceeding more the speed limits than female drivers. The negative value of the "Gender" coefficient in all models implied that as the value of the variable increased (males coded as 1, females as 2), the speeding percentage got lower.

It is also remarkable that older drivers and most experienced road users adopted a more conservative driving behavior and complied with the speed limits due to their driving skills and driving experience. The negative value of the "Age" coefficient in all models implied that as the value of the variable increased (higher value indicates increased age and, therefore, increased years of participant's experience), the speeding percentage was lower.

Table 3 displays the comparison of the lognormal regression mathematical models applied for speeding. It becomes easily perceived which of the independent variable had the greatest impact on each model and can affect speeding.

In accordance with the results of Table 3, in the overall model, the variable of "distance travelled" had the greatest impact among all the independent variables on speeding. In particular, it had 20.91 times greater impact than the variable "Age", which had the least significant impact on speeding (by absolute value).

Table 2. Multiple lognormal regression models developed for speeding

Independent Variables	Model 1 (Overall)			Model 2 (Highway)			Model 3 (Rural)			Model 4 (Urban)		
	b_i	t	e_i	b_i	t	e_i	b_i	t	e_i	b_i	t	e_i
Constant	1,493	57,351		1,690	30,019		1,654	54,509		3,033	187,263	
Mobile phone use	1,007	100,984	0,847	0,763	26,025	0,242	0,546	31,813	0,164	–1,039	–118,139	–0,231
Harsh accelerations	0,014	4,496	0,245	0,039	4,909	0,050	0,059	13,743	0,306	0,027	6,97	0,400
Avg. Deceleration	–0,066	–5,439	–0,574	–0,097	–8,005	–0,064	–0,043	–4,906	–0,145	–0,027	–4,131	–0,294
Distance travelled	0,003	10,03	1,004	–0,003	–15,439	0,201	0,001	3,294	0,361	0,005	25,942	1,074
Risky hours driving	0,007	4,478	0,654	0,009	4,393	0,428	0,007	4,675	0,245	0,005	4,023	0,407
Gender	–0,58	–58,866	–0,116	–0,733	–25,412	–0,156	–0,471	–28,683	–0,105	–0,614	–79,272	–0,078
Age	–0,123	–24,775	–0,048	–0,051	–8,918	–0,017	–0,181	–26,857	–0,044	–0,291	–70,157	–0,039
R^2	**0,491**			**0,728**			**0,569**			**0,562**		

Table 3. Relative influence of the independent variables in each model

Independent Variables	Model 1 (Overall)	Model 2 (Highway)	Model 3 (Rural)	Model 4 (Urban)
Mobile phone use	17,650	14,188	3,686	5,995
Harsh accelerations	5,106	2,956	6,876	10,366
Avg. Deceleration	11,954	3,747	3,253	7,616
Distance travelled	20,906	11,801	8,106	27,811
Risky hours driving	13,626	25,125	5,515	10,552
Gender	2,412	9,136	2,350	2,024
Age	1,000	1,000	1,000	1,000

4 Conclusions

The current study aimed to investigate the impact of driver distraction on speeding through the exploitation of smartphone sensor data. For that purpose, data collected from 100 drivers who participated in a naturalistic driving experiment for six months were collected and analyzed, combined with respective questionnaire answers.

Results indicated that driver distraction and mobile phone use while driving had a significant effect on speeding, as it was estimated that drivers had a reduced perception of what was happening around them. Furthermore, distracted drivers were not able to develop high speeds in urban areas, due to the presence of signaling and intersections. This finding is in agreement with the international literature that have proven that drivers who used their mobile phones while driving showed lower rates of speeding, especially in urban areas (Papadimitriou et al., 2019).

Additionally, distance travelled appeared to have the greatest influence in all models predicting speeding. It was revealed that drivers who traveled longer distances were those who showed an aggressive driving style and consequently exceed more often the speed limits. This conclusion is also confirmed by Tseng (2013) who found that the more driving kilometers are carried out daily, the higher the rate of exceeding the speed limit.

It should be mentioned that harsh accelerations seemed to affect the percentage of speeding while driving in a positive way, as the higher the number of harsh accelerations, the higher the speeding percentage while driving. Similarly, driving during risky hours (22:00–05:00) led to increased speeding events for all road types. For instance, participants who drove during risky hours were more likely to have a nervous and aggressive behavior that may be triggered by the low traffic volumes.

Finally, the driver's character and driving style had a great impact on speeding. This work demonstrated that male drivers exceeded more the speed limits than female drivers. What's more, young-age drivers were more prone to perform riskier driving behavior, detect fewer problems in the road network and exceed the speed limits as compared to experienced drivers. These conclusion is in accordance with international literature that have highlighted young male drivers' have a more aggressive behavior and exceed the speed limits in a great extent (Teo and Gan, 2016).

In conclusion, it is expected that this research can provide considerable gains to the society, since the stakeholders including policy makers and industry could rely on the results and recommendations regarding risk factors that appear to be critical for safe driving. As for further research, the examination of additional methods of analysis are proposed, such as factor analysis. Moreover, microscopic data analysis of the database collected could be implemented through econometric techniques, such as time-series analysis.

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Acceleration Behaviour on Commercial Vehicles to Validate Existing Norms and Guidelines for Load Securing

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Abstract. Safe, secure, and timely goods transport is the backbone of the global economy. Commercial vehicles carry an array of goods, necessitating diverse vehicle bodies and varying demands on securing cargo. Cargo securing ensures that cargo movement or, even worse, the falling out of cargo from the vehicle is avoided. Therefore, cargo security is relevant for the safety of both the goods and traffic. It is anchored in norms and guidelines, which help standardize specifications for vehicle body manufacturers, makers of securing equipment, and fleet operators. Typically, these specifications are given in the form of lateral and longitudinal accelerations in pre-defined driving maneuvers. Since accidents in which a commercial vehicle has lost cargo is not uncommon, the authors believe that possibly higher accelerations are encountered in real driving than those specified by today's norms and regulations. In this project "CargoSec" funded by the German Federal government, different classes of vehicle were tested under varying load conditions on different road surfaces in driving maneuvers, representative of real world driving. It was determined that N1 and N2 classes of commercial vehicles produce acceleration values much beyond those set by norms and regulations. The authors have therefore proposed changes to relevant norms and guidelines.

Keywords: Cargo Safety · Norms · Commercial Vehicles

1 Introduction

Commercial vehicles form the single most important mode of goods transport in Germany. In 2022 commercial vehicles were responsible for 72.1% of the total transport performance [1]. It is expected that this number is not very different for the rest of Europe. The safe and secure transport of goods is essential from an economic as well as social point of view, ensuring running of local and global economies. Norms and guidelines have been laid down in the past, defining the forces and accelerations that act on the body of a commercial vehicle and on the securing equipment. They, thus, form the foundation for the design of the vehicle body and cargo securing equipment like straps.

In project, CargoSec, funded by the Federal Ministry of Economic Affairs and Climate Action, the project premise was that the lateral accelerations which are experienced by a commercial vehicle on the road are higher than those specified by the relevant norms

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and regulations. This could explain some of the accidents in which the sidewalls of a commercial vehicle have failed, leading to loss of cargo onto the road. Hitherto, it has generally been attributed to human error on the part of the driver or the personnel in charge of loading the cargo and securing it. The goal of the project was to determine if the norms and guidelines required an update.

2 Relevant Norms and Guidelines

Firstly, the norms and guidelines relevant for the project were researched and identified. The following Table 1 shows an overview of the lateral accelerations as defined by the norm DIN 12195-1 and the VDI 2700 Part 16 for different classes of vehicles.

Table 1. Lateral acceleration limits for different vehicles classes [2–4].

Vehicle Class	Gross Vehicle Weight (GVW)	Relevant Norm/Guideline	Lateral Acceleration Limit
N1	$\leq$2t	VDI 2700 Part 16	0.7 g
	2t < GVW $\leq$ 3.5t	VDI 2700 Part 16	0.6 g
N2	3.5t < GVW $\leq$ 12t	DIN 12195-1	0.5 g
		VDI 2700 Part 16	
N3	>12t	DIN 12195-1	0.5 g
		VDI 2700 Part 16	

It is seen that the DIN 12195-1, which is used for the calculation of cargo securing forces does not distinguish between the size or class of the vehicle. A lateral acceleration limit of 0.5g is applicable across the board. On the other hand, the VDI 2700 Part 16 distinguishes between vehicles below 2t and those between 2t and 3.5t. For the former category, a limit of 0.7g is applicable, whereas for the latter category, the limit is 0.6g.

3 Vehicles and Cargo Loading

It was the aim of the project to verify the validity of the current acceleration limits of the norms and guidelines for all commercial vehicle classes. Therefore, N1, N2 and N3 vehicles were included for the tests. Figure 1 shows the test vehicles, which were used during the course of the project. The N1 vehicle chosen was a Mercedes Sprinter, which was equipped with training wheels. The training wheels prevent tip-over of the vehicle under very high lateral accelerations. An Iveco Daily box body was selected as the N2 class vehicle, whereas a Mercedes Actros with a swing wall body was the N3 class vehicle. The Actros was equipped with training wheels as well. All the vehicles used in an “as is” condition from a driving assistance point of view. The vehicle stability in the tests performed, therefore, reflect real world vehicle performance very well.

Fig. 1. Test vehicles used in the project [photos by authors].

The vehicle cargo load condition was varied for the tests. This was done to determine the influence of the amount and height of the cargo load on the lateral acceleration. In the case of the Mercedes Sprinter (N1 vehicle class), adjustable weights were available, whose height could be altered (refer Fig. 2).

Fig. 2. Test vehicles used in the project [photos by authors].

For the N2 and N3 vehicles, drinks crates were used to simulate a cargo load with a relatively high center of gravity. With an increase in the height of the center of gravity, the vehicle would tend tip-over at lower lateral accelerations. This therefore represents a worst-case scenario, since if an exceedance of norm limit value occurs at a high center of gravity, it would also happen at a lower center of gravity.

4 Test Methodology

For the lateral acceleration measurement, triaxial MEM acceleration sensors were used. The sensor signal was passed through an amplifier before being recorded at a sample frequency of 100 Hz. The sensors were calibrated prior to testing and their positions are shown in Fig. 3. The positions are defined in DIN EN 12642. One acceleration sensor was in the middle of the front of the vehicle body, whereas another sensor was positioned in the middle of the overhang at the rear of the vehicle.

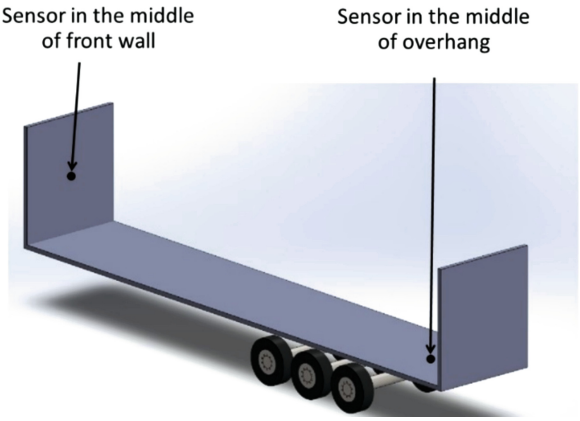

Fig. 3. Position of acceleration sensors based on DIN EN 12642 [CAD model by authors].

The acceleration data measured is subject to noise, which was then filtered using a low pass filter. The filter frequency is specified at 25 Hz, so that a sufficient capture of dynamic behavior is ensured. Further, the acceleration values were averaged in a time window of 80 ms as prescribed by the norm DIN EN 12642 (refer Fig. 4).

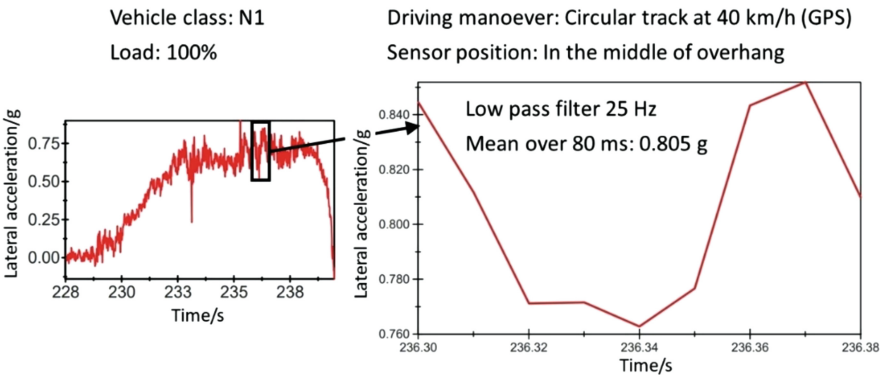

Fig. 4. Post processing of the measured lateral acceleration signal.

For the tests, all the vehicles were tested in a circular track as defined in the norm DIN EN 12642. This involves a constant speed driving maneuver in a circular track with a radius of 25 m (tolerance is $\pm$ 2 m). Tests were repeated in order to eliminate outliers and to ensure reproducibility.

5 Results

The test results of all the vehicle classes are shown in Fig. 5. On the left side of Fig. 5, the lateral acceleration in g is shown, along with the range of variation measured across the test repetitions. On the right hand side of Fig. 5, the percentage these accelerations

represent compared to the limits defined by the norms and guidelines (refer Table 1) are shown.

The highest lateral accelerations, with an average of 0.85g, were measured with the N1 class of vehicles, namely with the Mercedes Sprinter. The gross vehicle weight (GVW) of the Mercedes Sprinter under the tested conditions was 3.5t, which according to the guideline VDI 2700 Part 16 has a limit value of 0.6g. This leads to a limit exceedance of more than 40%.

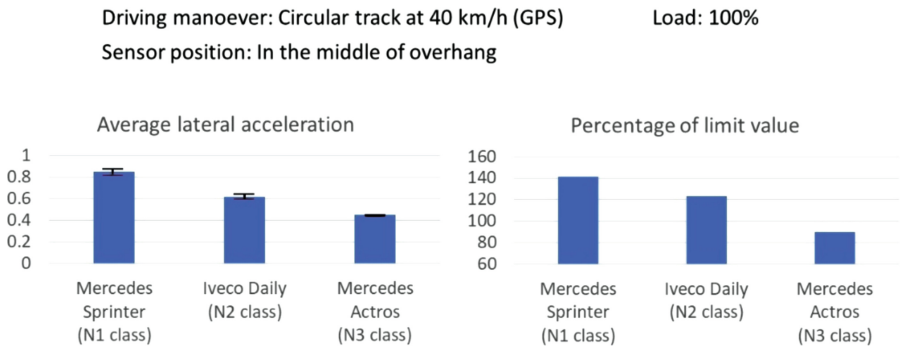

Fig. 5. Lateral accelerations and comparison with limit values for all vehicle classes.

The N2 vehicle class, represented by the Iveco Daily also exceeds the acceleration limit as prescribed by the norm. An average lateral acceleration of 0.61g was measured with it, which leads to an exceedance of more than 20%. On the other hand, no consistent exceedance of the norm was detected with the Mercedes Actros (N3 vehicle class).

6 Conclusion

Lateral acceleration tests were performed on the commercial vehicle N1, N2 and N3 as prescribed by the norm under reproducible test conditions. The vehicles were equipped with calibrated acceleration sensors to ensure accuracy of measurement. The test results show that N1 and N2 vehicle classes exceed the norm and guideline limits for lateral acceleration by a significant amount. The N3 vehicle class however is within limit, as the stability assistance systems do not permit a speed through a turn, which could be large enough to cause a limit exceedance. While implementing similar speed restrictions in the N1 and N2 could be one solution, the authors believe it would negatively affect the drivability of the vehicles. It is the recommendation of the authors, therefore, that a differentiation between the vehicle classes is introduced in the norm DIN EN 12195-1, as well as for the limit values in the norm DIN EN 12195-1 and guideline VDI 2700 Part 16 to be increased.

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Enhancing Passive Safety in N1 Vehicles: From State-of-the-Art N1 to Urbanized

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Abstract. Urbanization trends in European countries have driven a notable increase in the utilization of light commercial vehicles (N1) within urban areas. However, safety standards for N1 vehicles have lagged those for passenger cars. This paper examines accident data to reveal that N1 vehicles contribute to approximately 8% of all accidents. Recent regulations aimed at enhancing N1 vehicle safety have been introduced, aligning them with certain passenger car standards. This research delves into the performance and safety implications for state-of-the-art N1 vehicles under challenging load cases, mirroring Euro NCAP protocols, and explores ways to attain a best-in-class safety rating. The EU-funded project URBANIZED follows a strategic safety approach aligned with Euro NCAP protocols for heavy quadricycles, aiming to elevate N1 vehicle safety and spark discussions on future urban mobility and safety standards. The study focuses on structural integrity and occupant protection, integrating standard restraint systems found in passenger vehicles.

Keywords: N1 vehicle · crashworthiness · safety · best in class

1 Introduction and Motivation

1.1 Introduction

Urbanization is a noticeable trend in European countries driven by population growth and improved living standards associated with educational and occupational opportunities available in cities. Within the European Union (EU), the utilization of light commercial vehicles (N1) is on the rise, particularly in urban areas. These vehicles facilitate flexible manoeuvring in narrow streets and areas with a high density of pedestrians. While passenger vehicles are continuously challenged by new testing protocols by means of consumer testing campaigns, there are notable inadequacies in the safety standards applicable to the N1 vehicle category.

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1.2 Motivation

In the European Union (EU) in the year 2020, the majority of new road vehicle registrations, approximately 86%, were attributed to new passenger cars. Following were light commercial vehicles constituting around 12% of the market share. [1].

A notable proportion of new vehicle registrations comprise N1 vehicles, indicating their equal involvement in road accidents. However, unlike the well-documented accident data for passenger cars, comprehensive accidentology data for accidents involving light commercial vehicles is lacking. An estimated 8% of all accidents in the EU Member States between 2000 and 2008 were attributed to N1 vehicles based on available data. [2] In 2016 and 2021, the regulations R137 Full Width Frontal Impact and R95 Protection of Occupants against Lateral Collision, respectively, came into force for N1 vehicles. These testing protocols have brought N1 vehicles in line with certain legal standards applicable to passenger cars, enhancing the safety of light commercial vehicles. To understand the effect of those regulations on the reduction of fatalities when N1 vehicles are present in the accident, a new accidentology study must be performed to reflect the situation of recent years. While regulations like R137 and R95 address fundamental occupant safety, more stringent load cases such as those outlined by Euro NCAP prove challenging to consistently meet.

The question of what the performance and safety implications for a state-of-the-art N1 vehicle under more challenging load cases are, as proposed by Euro NCAP remains unanswered. The EU-funded URBANIZED project aimed to improve the safety and crashworthiness of N1 vehicles, adhering to Euro NCAP protocols for heavy quadricycles, thereby stimulating discussions on future urban mobility safety standards to benefit EU citizens.

2 Methodology

2.1 Definition of the Load Case

URBANIZED safety approach has been based on a safety performance target for the Euro NCAP Heavy Quadricycle frontal and lateral protocol [3], which consists of full-width frontal testing protocol, collision of the vehicle against a deformable barrier at 50km/h and side impact testing protocol, collision of moving deformable barrier with the speed of 50km/h to a stationary vehicle (Fig. 1).

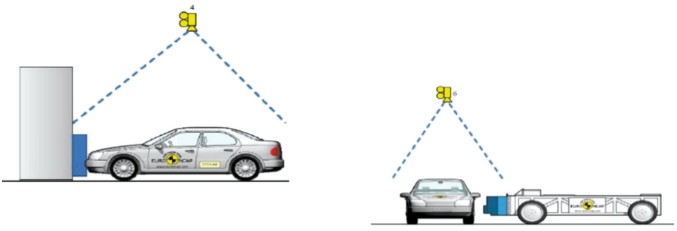

Fig. 1. Euro NCAP Heavy Quadricycle frontal (left) [3] and lateral (right) load case [4]

2.2 Comparison of Biomechanical Values

The occupant protection has been evaluated by the biomechanical values obtained from an anthropomorphic testing device (ATD). The following tables compare the values for legal regulation limits for N1 vehicles and Euro NCAP Heavy quadricycle protocols range limits (from upper to lower performance) for the Hybrid III 50% and ES2 dummy used in frontal and lateral testing protocols, respectively (Tables 1 and 2).

Table 1. Comparison of the selected injury criteria for frontal legal and consumer testing requirements[a] [3, 4]

Load case	Body region	Injury criteria	Euro NCAP	Regulation
Frontal load case	Head	HIC36 / HPC	650–1000	1000
		Res. Acc. 3 ms	72–88	80
	Neck	Extension moment	42 Nm	57 Nm
	Chest	Compression	22–50 mm	42 mm
		Viscous criterion	0.5–1.0 m/s	1.0 m/s
	Knee, Femur and Pelvis	Femur compression	3.8–9.07 kN	9.07 kN
		Knee slider displ	6–15 mm	-

[a] Euro NCAP limits for the frontal load case in the Table 3 are considering with the presence of the driver airbag in the vehicle

Table 2. Comparison of the selected injury criteria for lateral legal and consumer testing requirements [3, 5]

Load case	Body region	Injury criteria	Euro NCAP	Regulation
Lateral load case	Head	HIC36/HPC	650–1000	1000
		Res. Acc. 3 ms	72–88	80
	Chest	Compression	22–42 mm	42 mm
		Viscous criterion	0.32–1.0 m/s	1.0 m/s
	Abdomen	Peak force	1.0–2.5 kN	2.5 kN
	Pelvis	PSPF	3.0–6.0 kN	6.0 kN

A target has been set for biomechanical data based on the vehicle's intended function, placing significant emphasis on ensuring driver safety. Therefore, it has been crucial to consider the driver airbag and seat belt as integral parts of the vehicle's restraint systems.

Following benchmarking analysis, the downgrade of several body regions has been considered acceptable while still achieving best-in-class results. In the frontal load case, the chest and lower extremities have been downgraded by 2 points out of 4. This decision was influenced by the absence of a collapsible steering column, which typically leads to

higher chest deflection, and the minimal distance between the legs and the dashboard, resulting in the downgrade of lower extremity protection.

The final safety target settings can be seen in Table 3.

Table 3. Safety target settings for URBANIZED vehicle

Frontal crash test		Lateral crash test	
Head	4 pts	Head	4 pts
Neck	4 pts	Chest	2 pts (out of 4)
Chest	2 pts (out of 4)	Abdomen	2 pts (out of 4)
Knee & Femur	2 pts (out of 4)	Pelvis	2 pts (out of 4)
Total pts	**12 pts**	**Total pts**	**10 pts**

3 Results

To achieve the expected results, a specific analysis has been covered on the baseline vehicle to identify main points of improvements: wheelbase, size of wheels, frontal structure (crash box), steering wheel position, door side structure. An initial finding indicated that the "Crumple Zone" must be enlarged to effectively absorb frontal impacts and prevent intrusions into the passenger compartment, thereby reducing the stress on the occupant (Fig. 2).

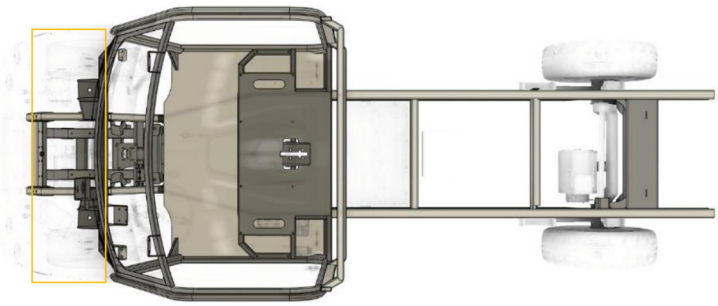

Fig. 2. Crumple zone enlargement to absorb the impact energy (picture from project URBANIZED [5])

The incorporation of the crumple zone, manifested through a crash box, has been securely positioned at the front section of the frame to absorb impact energy. Additionally, a mid-longitudinal member has been introduced to absorb energy during impact. Simultaneously, adjustments have been made to thickness, and perforations have been added to facilitate controlled deformation, aiming to reduce intrusion into the cabin and

mitigate acceleration pulses. These two factors are pivotal for maintaining the stability of the passenger compartment and enhancing the performance of the restraint system.

While severe injuries haven't been observed in the lateral case, structural enhancements have been introduced such as lateral door beams to decrease the intrusion of the barrier and hinges and latched which can withstand the impact severity to ensure the prevention of door opening (Fig. 3).

Fig. 3. Frontal (left – picture taken at IDIADA) and lateral (right – picture from CAE simulation) reinforcements

As previously mentioned, one of the objectives of the project has been to enhance the passive safety performance of the URBANIZED vehicle. In addition to ensuring the structural integrity of the vehicle from a crashworthiness standpoint, the focus have also been on improving occupant protection in the event of a crash. To achieve this goal, given that the baseline vehicle was equipped only with a basic seatbelt and lacked airbags, it was crucial to implement a restraint system countermeasure.

The refinement of restraint systems has been performed by simulation, focusing on variables such as the time to activate the driver airbag and seat belt, the torsion bar of the seat belt, and the venthole size of the driver airbag.

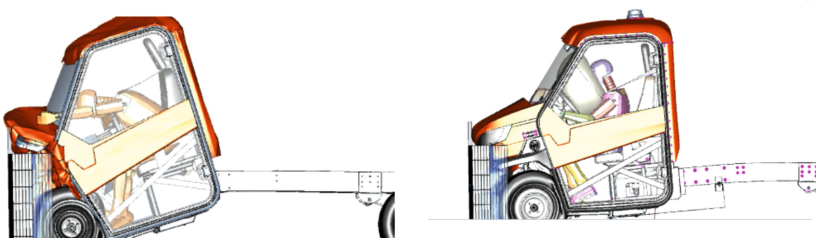

Fig. 4. State-of-the-art vehicle (left) vs. URBANIZED vehicle (right). Pictures from CAE

The newly added safety features include a driver airbag and a seatbelt with a pretensioner. Position of the steering wheel has been adjusted to achieve the optimal position for airbag. The safety belts, retractor, latch plate and buckle has been installed in a position to assure the fulfilment of UN R14.09.

Figure 4 illustrates the enhancements evident between the state-of-the-art (SOTA) vehicle and the URBANIZED model. These include structural enhancements that have

strengthened cabin stability, improved absorption of frontal energy, and reduced vehicle pitching.

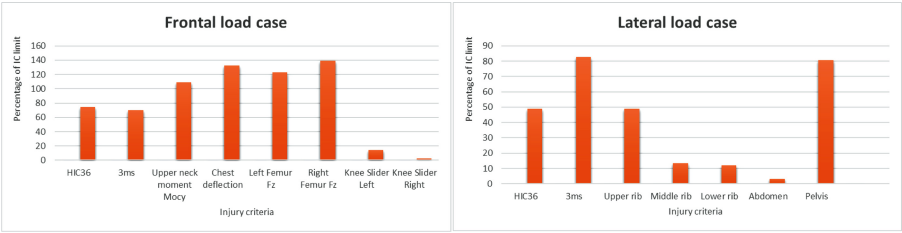

Fig. 5. Preliminary injury results based on the Euro NCAP Heavy Quadricycle protocol. Left – Frontal load case, right – Lateral load case

Figure 5 represents the simulation results of frontal and lateral load case of URBANIZED vehicle compared with the high-performance limit for Euro NCAP Heavy Quadricycle protocol.

4 Discussion, Limitations and Conclusions

Between 2016 and 2021, safety requirements for N1 type vehicles were put in place to ensure the well-being of passengers. However, there is a notable rise in the usage of light commercial vehicles (LCVs), indicating an increasing presence of LCVs in urban areas and a potential rise in accidents involving them. Therefore, either the passenger vehicle testing protocols or newly defined one, taking into consideration urban vehicle speed, could be a way to further improve the safety of this popular mean of transporting goods.

Implementing standard restraint systems, such as frontal airbags can significantly mitigate injuries in frontal crashes. While lateral crashes typically result in fewer injuries due to the vehicle's height, structural enhancements are crucial in this scenario.

Therefore, prioritizing safety measures tailored to the unique challenges posed by urban environments is imperative for mitigating risks associated with the rising usage of light commercial vehicles.

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Stressors and Stress Mitigation for Occupational Road Freight Drivers: A Focus Group Study

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Abstract. European occupational road freight drivers face difficulties such as traffic jams, deadlines and demanding customers during their job. Therefore, they often suffer from stress, a problem that may worsen as traffic increases. Europe has a severe driver shortage, so insight into the issues of occupational drivers is needed to improve their working conditions. Through two online focus group discussions with eleven occupational drivers, this study gathered data on stressors and strategies against stress. The data was analysed through thematic analysis, revealing four different stressor types: stressors related to company operations (e.g. dispatching issues), job tasks (e.g. time-related stressors), client-related factors (e.g. disrespect from the client), and non-work-related stressors (e.g. an ill partner). Strategies against stress include coping strategies (e.g. social contact) and solutions such as an improved attitude towards freight drivers, improved communication between drivers and other parties, better equipment and facilities and changes to the law. The insights of this study about occupational driver stressors could be used for e.g. intervention development.

Keywords: Stress · Focus Group · Occupational Driver · Transport · Road Freight · Well-Being · Working Conditions

1 Introduction

Occupational road freight drivers suffer from stress [1, 2], which can lead to (mental and physical) health issues [3, 4]. If drivers were to quit due to health issues, Europe's truck driver shortage [5] would grow worse. Research into stress and stress prevention for occupational road freight drivers is thus needed.

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1.1 Stress Among Occupational Road Freight Drivers

Factors related to work [6–8] and traffic [9] can cause stress for occupational drivers. Occupational stress can be described by the Effort-Reward Imbalance (ERI) model, which notes that stress is caused by an imbalance between efforts and rewards for said efforts [10], and the Job Demand-Control (JDC) model, which notes that stress is caused by an imbalance between job demands and job control [11]. The Transactional model of driver stress describes driver stress, which is caused by the environment and the driver's personality. These influence the driver's cognitive processes and eventually result in stress symptoms and changes in driving performance [12].

1.2 Causes of Stress

Different traffic factors can cause stress, e.g. congestion [9], the urbanity of the environment [9] and other road users [8]. Road freight drivers may also get stressed due to last-minute tasks [7] and issues at e.g. truck stops [6]. Truck drivers may be more susceptible to stress than public transport drivers, possibly because they often drive new routes (unlike public transport drivers) [13]. Different types of road freight drivers may also encounter different stressors: e.g. long-haul drivers are on the road for several days and short-haul drivers encounter more congestion [7]. Time pressure can also cause stress [6–8, 14, 15]. Regarding sociodemographic variables, their impact on stress is unclear: young car drivers may experience more stress than middle-aged drivers [16] and females may experience less driving stress than males [16], but both for age [17] and for gender [18] there is contrary evidence. Personality traits can also influence stress [13]. Sleep issues [6, 16], loneliness [6], boredom [6], financial issues [7], discrimination and violence [6], image of the profession [6] and expecting some negative events [8] can all cause stress. If a driver experiences stressful life events, there is a positive relation between anxious driving behaviour and accident distress [19].

2 Methods

2.1 Participants

The study's participants were (1) long-haul drivers (LHD), (2) short-haul drivers (SHD) or (3) local delivery drivers (LDD) based in Belgium. They were recruited either via transport companies or by approaching individual drivers. As per earlier focus group research [7], 6–8 participants was the target amount of participants per focus group. All participants signed an informed consent form.

Two focus groups took place in August 2023. Their composition was the following[1]: (1) Focus group one: six drivers (mean age 41.3 years; two females; one LHD, four SHD, one LDD; one national and international driver, four national drivers, one regional driver[2]; five drivers from companies of 50–249 Full-Time Equivalents (FTE), one driver

[1] Company sizes were gathered from [20]. An in-depth questionnaire and a phone call with a participant were used to gather demographic data.

[2] Some drivers also drove internationally.

from a company of 0–49 FTE; (2) Focus group two: five drivers (mean age 56.6 years; one female; four LHD, one SHD; four international drivers, one regional and national driver; one driver from a company of 250–500 FTE, three drivers from companies of 50–249 FTE, one driver of a company with unknown size.

2.2 Focus Groups

The focus groups took place online for flexibility of the participants. After participation, they received €25. Topics of the focus groups included traffic-related stressors, non-traffic work-related stressors and stressors outside of work. Additionally, stress-coping strategies were discussed (including anti-stress solutions that e.g. governments could provide). Presentation slides during the discussion provided discussion prompts if necessary. The discussion was summarized at the end of the focus group and participants could add onto this summary. The first author (BP) was the moderator, JH was the note-taker. Participants provided permission to record the focus groups and the discussions lasted between 1:30 h and 2 h.

2.3 Analysis

The data were analysed by BP through thematic analysis, specifically the semantic inductive approach [21]. The six steps described in [21] were used, namely (1) repeated reading of the data; (2) initial coding of the data; (3) sorting of codes into themes; (4) reviewing of themes; (5) defining of themes; and (6) final analysis and production of the report. The analysis of the data was done with NVivo14 by coding the notes of JH. Quotes were translated from Dutch to English. HD reviewed the codes and themes afterwards.

3 Results and Discussion

3.1 Overview of the Themes

The analysis resulted in five themes, four of which included occupational road freight driver stressors. There were three types of work-related stressors: (1) stress due to company operation, (2) stress due to job tasks and (3) stress due to client-related factors. (4) non-work related stressors were the fourth type of stressor. Lastly, there were (5) stress solutions and strategies which influence the stressors and stress directly. Figure 1 provides a summary of the findings.

3.2 Stress Due to Company Operation

Stress due to company operation included issues with dispatchers and planning (e.g. impossible delivery times, lack of knowledge on the law from dispatchers, unscheduled planning changes); worker interactions (e.g. disrespectful behaviour from warehouse workers, colleague drivers not filling in forms correctly); and equipment issues (e.g. broken equipment, ergonomic issues).

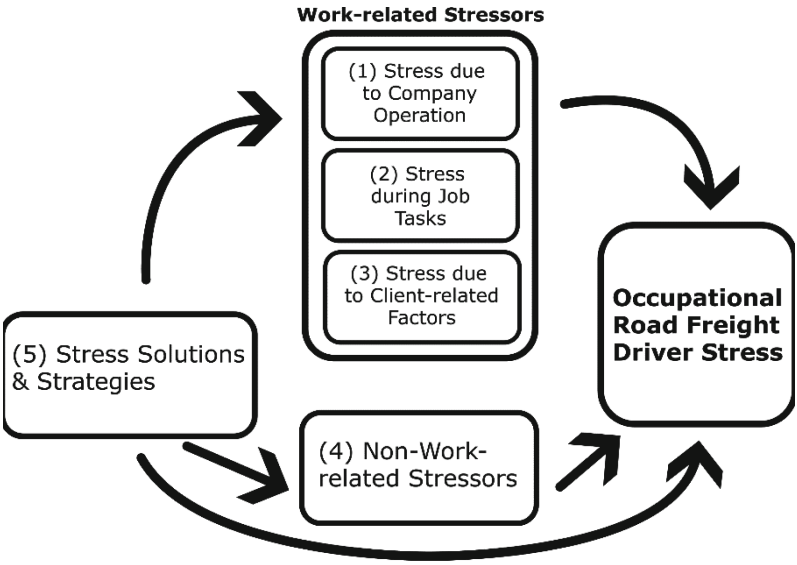

Fig. 1. Schematic overview of the themes

"For example, in our case if a driver does something wrong, you get reprimanded much quicker, and the planning makes errors, okay it's not easy to make that puzzle, but it's like there are no consequences to that there." – Female LDD.

"Very occasionally I have it happen that in the warehouse they really look at you, because I'm a woman and they're like "Oh, she's going to show us how", or the opposite, that I'm not allowed to do anything and that they want to do everything themselves." – Female SHD.

"I had a van in which I didn't have a good seating position, and then I also experienced stress during driving." – Female LHD.

3.3 Stress During Job Tasks

Stress due to job tasks included traffic-related stressors (e.g. disrespectful behaviour of other road users; weight restriction zones when following a route; stressful locations); time-related stressors (e.g. time pressure; traffic jams (though not always); waiting times); facilities (e.g. difficulties to find a parking spot; lacking or dirty sanitary facilities); law and enforcement (e.g. faulty shipping documents). Unsafe or uncivil behaviour of other drivers was also noted as a stressor in [8]. Driving in an urban environment was found to be more stressful than driving on a highway in an on-road experiment with one driver [9], though as seen in the responses in the current study this could differ for different drivers. Routing was also found to be related to stress in previous research [7]. Time pressure being a stressor aligns with previous research as well [6–8]. Traffic jams were the most significant source of stress in [8], though in the current study this was not always the case.

3.4 Stress Due to Client-Related Factors

Frustration due to clients can occur when clients do not provide necessary information (e.g. weight of a load) or services (e.g. administrative work so the driver can enter a weight restriction zone) to the driver. Clients may also showcase disrespectful behaviour, such as ignoring the driver or denying the use of services (e.g.; the bathrooms). This is similar to research in [7]: in that study, while disrespectful clients were not directly mentioned, a lack of respect from e.g. the industry was mentioned.

"If you arrive at the client and they don't look at you for half an hour, so you're just standing there like, do I have to say it… so, I find that, that's what stresses me." – Male LHD.

3.5 Stress Due to Non-work-related Factors

Non-work-related stressors, aside from e.g. delays during a trip causing issues to make a private appointment (which is a time-related stressor cascading into a non-work-related stressor), include for example a lack of support from the driver's partner, the partner suffering from illness or children needing to be brought somewhere.

"Well, all my children do jiu-jitsu, so if they sometimes need to go to the training, it's sometimes difficult, like "Err, I am not going to be home on time!"" – Male SHD.

3.6 Solutions and Coping Strategies Against Stress

The current study revealed the following subthemes about solutions and strategies against stress: (1) coping strategies, (2) education and awareness, (3) communication, (4) equipment and infrastructure and (5) changes to law. Drivers perform coping strategies by themselves, other parties are needed for the other strategies.

Coping Strategies. Experience with the job (e.g. familiarity with the road) may alleviate stress. Alternatively, some stressors (e.g. being away from home) are seen as an inherent part of the job.

"It can seriously get out of hand, that you miss things… If that's going to bother you, then I think you better search for another job!" – Female LHD.

Strategies to deal with stress or prevent it include learning to say "no", taking a break or a day off, and social contact (e.g. with colleagues or their children). Drivers can also use the privacy of the truck cabin to perform some coping strategies, by e.g. thinking through situations or singing.

"At the start of the year, me and my colleague, made a statement: "This will be the year of the no"! And the boss looks at me like, "What do you mean?", that I from now on will say "no" sometimes!" – Male SHD.

"Maybe very cliché, but I sing a lot in the truck too. And that lowers my stress level." – Female SHD.

Education and Awareness. To alleviate disrespect towards freight drivers, drivers noted that the driving school curriculum could be changed by adding information specifically about trucks to it (e.g. the braking distance of trucks). Third parties showing an improved attitude could alleviate the stress of drivers as well, e.g. clients could acknowledge the driver and allow them to use their bathrooms.

"Indeed, if you take your exam for the car, that the braking distance of a truck is shown, but not just say it, but having it actually be shown" – Female SHD.

The driver's company could be more understanding of freight drivers by e.g. giving time off work when needed. A driver mentioned how a planner who had experience as a driver was the best planner she had.

"But we also have one planner who was a driver but due to an accident ended up in [audio noise], so he can't be a driver anymore, and he's one of the best planners we have." – Female SHD.

Communication. Improved communication between all parties may solve various work-related issues. Some drivers wanted to receive positive feedback as well.

"Like [female LDD] says, every few months, every so often, organise a focus group like this one, and putting the problems there are on the table, but also discuss the good things!" – Male SHD.

Equipment and Infrastructure. Proper equipment and infrastructure may make the job of the driver more comfortable.

"Maybe the government needs to start investing in more infrastructure for trucks next to the road." – Female LDD.

Changes to Law. Drivers mentioned some examples of law changes to make their job easier, such as removing non-essential weight restriction zones and adding a right-of-way to trucks similar to buses in some situations.

"[About weight restriction zones] They need to do some major housekeeping there, and actually look like "Okay, that road needs it, that road doesn't need it"" – Female SHD.

3.7 Limitations and Recommendations for Future Research

Most participants in this study were male and at least 50 years old: this is expected, as truck drivers tend to be older males [5]. Participants were also Dutch speakers. It is not known how generalisable the results are to demographics not in this study. The results of this study, however, still provided a deeper understanding of stress and coping strategies of occupational road freight drivers, which can be useful for intervention development.

Future focus group research may focus specifically on demographics such as young or female drivers. Future research could additionally include objective measurements of stress (and its impacts on driving behaviour), either in controlled circumstances (e.g. simulator research) or real-life trips.

4 Conclusions

This research studies stressors and stress mitigation for occupational road freight drivers through two focus groups. Four different stressor types were identified, namely stressors related to company operation (e.g. issues with planning), stressors related to job tasks (e.g. dangerous behaviour from other drivers) and stressors related to client-related factors (e.g. disrespect from clients). Additionally, there are non-work-related stressors (e.g. an ill partner). Several solutions and strategies against stress were mentioned by the participants, such as social contact with others, improved communication with other

parties and education and awareness. The qualitative data from this study provided a deeper understanding of road freight driver stress and coping strategies. These insights can be used as an anchor for future research, e.g. focus groups with other demographic groups and locations and measuring stress itself (during e.g. driving).

List of Abbreviations

- ERI = Effort-Reward Imbalance
- FTE = Full-Time Equivalents
- JDC = Job Demand-Control
- LHD = Long-Haul Driver
- LDD = Local Delivery Driver
- SHD = Short-Haul Driver

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Competing Interests. The authors declare that they have no competing interests.

Authors' Contributions. CRediT authors' contributions statement:

– BP: Methodology, Investigation, Data Curation, Writing – Original Draft, Visualization, Project administration
– AN: Conceptualization, Methodology, Supervision, Project administration, Funding Acquisition
– HD: Methodology, Writing – Review & Editing, Supervision, Project administration
– VR: Writing – Review & Editing
– JV: Conceptualization, Writing – Review & Editing, Supervision, Funding Acquisition
– JMA: Conceptualization, Writing – Review & Editing, Supervision, Funding Acquisition
– FM: Writing – Review & Editing
– AMS: Writing – Review & Editing
– NVO: Writing – Review & Editing
– JH: Investigation
– GW: Conceptualization, Supervision

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Declarations.

Ethics Approval and Consent to Participate. Participants signed an informed consent form to participate in the MILESTONE project, including these focus groups. The MILESTONE project was approved by the Committee for Medical Ethics UZA-UA (Reference: 3126 - Edge n/a - EudraCT - BUN B3002022000096).

Consent for Publication. Not applicable.

Availability of Data and Material. Notes taken during the focus groups can be shared. These notes are in Dutch and are anonymized.

Author's Information. Not applicable.

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Investigating the Effect of Driver-Vehicle-Environment Interaction with Risk Through Naturalistic Driving Data

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Abstract. While mobility and safety of drivers are challenged by behavioral changes, the increasingly complex road environment has placed a higher demand on their adaptability. The ultimate goal of this paper was to identify the impact that the balance between task complexity and coping capacity had on crash risk. Towards that aim, an integrated model for understanding the effect of the interrelationship of task complexity and coping capacity with risk was developed. A vast library of data from a naturalistic driving experiment was created in three countries (i.e., Belgium, UK and Germany) to investigate the most prominent driving behavior indicators available, including speeding, headway, overtaking, duration, distance and harsh events. In order to fulfil the aforementioned objectives, exploratory analysis, such as Generalized Linear Models (GLMs) were developed, and the most appropriate variables associated to the latent variable "task complexity" and "coping capacity" were estimated from the various indicators. Additionally, Structural Equation Models (SEMs) were used to explore how the model variables were inter-related, allowing for both direct and indirect relationships to be modelled. The analyses revealed that higher task complexity levels lead to higher coping capacity by drivers. Additionally, the effect of task complexity on risk was greater than the impact of coping capacity in Belgium and Germany, while mixed results were observed in the UK.

Keywords: driving behavior · road safety · naturalistic driving study; Structural Equation Models; Generalized Linear Models

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1 Introduction

Ensuring road safety is paramount, aiming to reduce crash risk, prevent injuries, and save lives. Every year, a significant number of lives are lost, and many people suffer severe injuries due to road crashes. Multiple factors exert a substantial influence on road safety, potentially leading to crashes and affecting the seriousness of resulting injuries. Human behavior, for example, assumes a pivotal role in road safety. Elements such as speeding, distracted driving, impaired, aggressive driving, and failure to adhere to traffic regulations can elevate crash risk. Moreover, the design, state, and upkeep of roadways and infrastructure also play a role in road safety. Inadequate road design, insufficient signage, the absence of pedestrian crossings, insufficient lighting, and subpar maintenance can all contribute to crashes and injuries.

Simultaneously, the state and safety features of vehicles exert a substantial influence on road safety. Aspects like vehicle upkeep, tire condition, brake performance, and the presence of safety technologies can have a significant impact on the outcomes of crashes. Similarly, environmental conditions can have repercussions on road safety. Elements such as adverse weather conditions (e.g., rain, snow, fog), diminished visibility, and uneven road surfaces can elevate the likelihood of crashes. Additionally, socioeconomic factors, including income level, education, and access to transportation resources, can indirectly shape road safety. Disparities in these factors may give rise to variations in driver behaviors, vehicle conditions, and the quality of road infrastructure.

Based on the above, the overall goal of the i-DREAMS project is to establish a framework for defining, developing, testing, and validating a context-aware safety framework for driving, referred to as the "Safety Tolerance Zone." This framework is integrated within a smart Driver, Vehicle & Environment Assessment and Monitoring System (i-DREAMS). By considering various factors related to the driver's background, real-time risk indicators linked to driving performance, driver condition, and the complexity of the driving task, a continuous, real-time assessment is conducted to determine if a driver is operating within safe parameters.

According to the level of unsafe driving behavior, the STZ is categorized into three levels: 'Normal', 'Dangerous' and 'Avoidable Accident'. Firstly, the 'Normal' level denotes a situation with a minimal crash risk and thus safe driving practices. Secondly, the 'Dangerous' level refers to the chance of a crash increasing, but the crash is not unavoidable. Finally, the 'Avoidable Accident' level denotes a high risk of a potential crash occurring, but there is still enough time for drivers to act and avoid the incident.

Following the i-DREAMS project's goal, this study aims to investigate the interaction between task complexity and coping capacity (i.e., related to both vehicle state and operator state factors). To achieve this goal, a complete Structural Equation Model (SEM) developed and a set of quantitative effects of indicators was created, describing the impacts of vehicle, operator and context characteristics on risk under different conditions. Apart from SEMs, Generalized Linear Models (GLMs) were also used and the goodness-of-fit-metrics for the models were explained.

The paper is structured as follows. At the beginning, a detailed overview of the project and its overall objective is provided. Following that, a comprehensive literature review on the statistical analysis of driving behavior is presented. Furthermore, the data collection process is thoroughly described. The research approach is then outlined, including the

theoretical foundations of the models used. Lastly, the results are provided, followed by substantial conclusions about the relationship between crucial factors such as task complexity and coping capacity on risk.

2 Background

The inter-relationship among task complexity, coping capacity, and crash risk is a multifaceted and crucial area of study in traffic safety research. The assessment of task difficulty and coping ability forms the basis of the i-DREAMS platform.

To begin with, task complexity plays a significant role in influencing crash risk on the roads. The complexity of driving tasks refers to the level of cognitive demand and physical effort required to perform them. Factors contributing to task complexity include traffic density, road infrastructure, weather conditions, presence of distractions, and time pressure, among others. The current state of the real-world environment in which a vehicle is being driven is related to task complexity. The registration of road layout (i.e., highway, rural, urban), time and place, traffic volumes (i.e., high, medium, low), and weather is particularly used to assess job complexity context.

On the other hand, coping capacity refers to an individual driver's ability to effectively manage and adapt to complex driving tasks. It encompasses factors such as experience, skills, perceptual abilities, decision-making processes, and the availability of appropriate coping strategies. Drivers with high coping capacity can better handle complex tasks, maintain situational awareness, and make appropriate decisions to mitigate crash risk. The conceptual foundation for the prediction of risk as a function of coping capacity and task complexity is shown in Fig. 1.

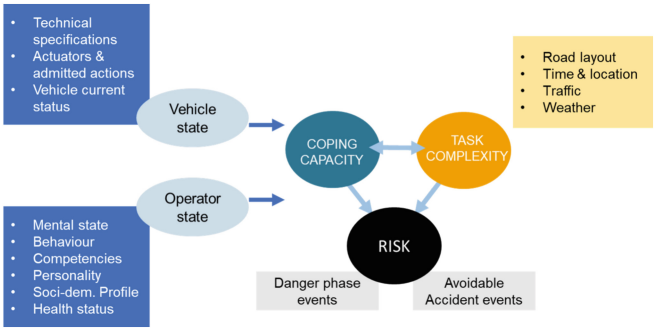

Fig. 1. Post-hoc prediction of risk in function of coping capacity and task complexity.

Road safety is a pressing global concern, with millions of lives lost or impacted by traffic crashes each year. To effectively address this issue, researchers and policymakers have turned to advanced statistical modelling techniques to gain a deeper understanding of the complex relationships between various factors contributing to road crashes.

In particular, SEMs have emerged as a powerful tool for analyzing the intricate interplay between observed variables and latent constructs in road safety research. They

allow researchers to explore the direct and indirect effects of multiple factors on road safety while providing a methodology for direct modelling of latent variable, separating measurement errors from true scores of attributes [1]. This makes SEMs particularly suitable for studying the multifaceted nature of road safety, where numerous factors interact to influence the occurrence and severity of crashes. The application of SEMs in recent road safety research has yielded valuable insights into the underlying factors contributing to crashes and their consequences. By modelling the relationships between various risk factors, SEMs help researchers identify key predictors of road crashes, understand their interrelationships, and develop effective intervention strategies [2].

Thus, the use of SEMs has proven invaluable in advancing road safety research. These models provide a comprehensive framework for understanding the intricate relationships and interdependencies among various factors contributing to road crashes. By elucidating causal mechanisms and mediating/moderating effects, SEMs enable researchers to develop targeted interventions, evaluate policy effectiveness, and ultimately enhance road safety outcomes.

3 Data Description

A naturalistic driving experiment was carried out involving 133 drivers from Belgium, UK and Germany and a large database of 26,908 trips and 500,000 min was created to investigate the most prominent driving behavior indicators, including speeding, headway, duration, distance, and harsh acceleration and harsh brakings. The total number of drivers, trips and minutes is presented in Fig. 2.

Fig. 2. Number of drivers, trips, and minutes per country

Four separate SEM models were estimated in order to explore the relationship between the latent variables of task complexity, coping capacity and risk (expressed as the three stages of the STZ) of speeding and headway (level 1 'normal driving' used as the reference case). The experiment consisted of four phases to assess interventions on driving behavior. Phase 1 involved a 4-week baseline without interventions. In Phase 2, lasting another 4 weeks, real-time warnings via adaptive ADAS were introduced. Phase 3, also 4 weeks, provided feedback through a mobile app. In the final 6-week Phase 4, feedback continued with added gamification. Each phase aimed to observe driving behavior and evaluate the impact of real-time warnings and post-trip interventions like feedback and gamification.

4 Methodology

In order to fulfil the objectives of this study, exploratory analysis, such as Generalized Linear Models (GLMs) were developed, and the most appropriate variables associated to the latent variable "task complexity" and "coping capacity" were estimated from the various indicators. In addition, SEMs were used to explore how the model variables were inter-related, allowing for both direct and indirect relationships to be modelled.

4.1 Generalized Linear Models (GLMs)

In statistics, the GLM is a flexible generalization of ordinary linear regression that allows for response variables that have error distribution models other than a normal distribution. The GLM generalizes linear regression by allowing the linear model to be related to the response variable via a link function and by allowing the magnitude of the variance of each measurement to be a function of its predicted value [3].

In a GLM, each outcome Y of the dependent variables is assumed to be generated from a particular distribution in an exponential family, a large class of probability distributions that includes the normal, binomial, Poisson and gamma distributions, among others. The mean, μ, of the distribution depends on the independent variables, X, through:

$$E(Y|\mathrm{X}) = \mu = g^{-1}(X\beta) \tag{1}$$

where: E(Y|X) is the expected value of Y conditional on X; Xβ is the linear predictor, a linear combination of unknown parameters β; g is the link function.

In this framework, the variance is typically a function, V, of the mean:

$$Var(Y|\mathrm{X}) = V(g^{-1}(X\beta)) \tag{2}$$

It is convenient if V follows from an exponential family of distributions, but it may simply be that the variance is a function of the predicted value.

The unknown parameters, β, are typically estimated with maximum likelihood, maximum quasi-likelihood, or Bayesian techniques.

GLMs were formulated as a way of unifying various other statistical models, including linear regression, logistic regression, and Poisson regression. In particular, Hastie & Tibshirani (1990) [4] proposed an iteratively reweighted least squares method for maximum likelihood estimation of the model parameters. Maximum-likelihood estimation remains popular and is the default method on many statistical computing packages. Other approaches, including Bayesian approaches and least squares fit to variance stabilized responses, have been developed.

A key point in the development of GLM was the generalization of the normal distribution (on which the linear regression model relies) to the exponential family of distributions. This idea was developed by Collins et al. (2001) [5]. Consider a single random variable y whose probability (mass) function (if it is discrete) or probability density function (if it is continuous) depends on a single parameter θ. The distribution belongs to the exponential family if it can be written as follows:

$$f(y;\theta) = s(y)t(\theta)e^{a(y)b(\theta)} \tag{3}$$

where: a, b, s, and t are known functions. The symmetry between y and θ becomes more evident if the equation above is rewritten as follows:

$$f(y;\theta) = \exp[\alpha(y)b(\theta) + c(\theta) + d(y)] \tag{4}$$

where: s(y) = exp[d(y)] and t(θ) = exp[c(θ)]

It should be mentioned that the Variance Inflation Factor (VIF) is a measure of the amount of multicollinearity in regression analysis. Multicollinearity exists when there is a correlation between multiple independent variables in a multiple regression model. The default VIF cut-off value is 5; only variables with a VIF less than 5 will be included in the model (VIF < 5). However, in certain cases, even if VIF is less than 10, then it can be accepted.

4.2 Structural Equation Models (SEM)

Structural Equation Modelling (SEM) or path analysis is a multivariate method used to test hypotheses regarding the influences among interacting observed and unobserved variables [6]. The observed variables are measurable, while unobserved variables are latent constructs.

SEM consist of two components: a measurement model and a structural model. The measurement model is used to assess how well various observable exogenous variables can measure the latent variables, as well as the measurement errors associated with them. The structural model is used to investigate the relationships among the model variables, enabling the modeling of both direct and indirect linkages. In this regard, SEMs distinguish themselves from regular regression techniques by deviating from direct relationships between variables. The general formulation of SEM is as follows [7]:

$$\eta = \beta\eta + \gamma\xi = \varepsilon \tag{5}$$

where: η represents a vector of endogenous variables, ξ represents a vector of exogenous variables, β and γ are vectors of coefficients to be estimated, and ε represents a vector of regression errors.

The measurement models can be described as follows [8]:

$$x = \Lambda x\xi + \delta \text{ for the exogenous variables} \tag{6}$$

$$y = \Lambda y\eta + \zeta \text{ for the endogenous variables} \tag{7}$$

where: x and δ represent vectors associated with the observed exogenous variables and their errors, while y and ζ are vectors represent vectors associated with the observed endogenous variables and their errors. Λx, Λy are structural coefficient matrices that capture the effects of the latent exogenous and endogenous variables on the observed variables.

4.3 Model Goodness-of-Fit Measures

In the context of model selection, model Goodness-of-Fit measures consist of an important part of any statistical model assessment. Several goodness-of-fit metrics are commonly used, including the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), the goodness-of-fit index (GFI), the (standardized) Root Mean Square Error Approximation (RMSEA), the Comparative Fit Index (CFI) and the Tucker-Lewis Index (TLI). Such criteria are based on differences between the observed and modelled variance-covariance matrices. The results of the models were evaluated by satisfying the following statistical tests: p-value < 0.001, CFI > 0.90, TLI > 0.90 and RMSEA < 0.05.

5 Results

5.1 GLM Results

GLMs were employed to investigate the relationship of key performance indicator of speeding for Belgian, UK and German car drivers. The relationship between speeding and risk is widely recognized in the road safety community and as such, speeding is a commonly used dependent variable in transportation human factors research.

The first GLM investigated the relationship between the speeding and several explanatory variables of task complexity and coping capacity (operator state) in Belgium. In particular, the dependent variable of the developed model is the dummy variable "speeding", which is coded with 1 if there is a speeding event and with 0 if not. The model parameter estimates are summarized in Table 1.

Table 1. Parameter estimates and multicollinearity diagnostics of the GLM for Belgium.

Variables	Estimate	Standard Error	z-value	Pr(|z|)	VIF
(Intercept)	3.688	0.043	85.768	<.001	–
Time indicator	0.908	0.078	11.683	<.001	1.882
Weather	0.009	4.217×10^{-4}	20.952	<.001	1.228
High beam - Off	–0.018	7.062×10^{-4}	–25.286	<.001	1.470
Harsh acceleration	2.661	0.181	14.689	<.001	1.013
Distance	-6.128×10^{-4}	7.273×10^{-5}	–8.426	<.001	1.678
Summary statistics					
AIC	17404.428				
BIC	17413.817				
Degrees of freedom	88377				

Based on Table 1, it can be observed that all explanatory variables are statistically significant at a 95% confidence level; there is no issue of multicollinearity as the VIF

values are much lower than 5. With regard to the coefficients, it was revealed that the indicators of task complexity, such as time indicator and wipers were positively correlated with speeding. The former refers to the time of the day (day coded as 1, dusk coded as 2, night coded as 3) which means that higher speeding events occur at night compared to during the day. This may be due to fewer cars on the road, lower visibility, and a false sense of security that comes with driving in the dark. Interestingly, wipers (wipers off coded as 0, wipers on coded as 1) were also found to have a positive correlation with speeding which means that there are more speeding events during adverse (e.g., rainy) weather conditions. This may be due to the fact that wet and slippery roads can make it more difficult to maintain control of the vehicle.

Additionally, rain can reduce visibility and make it harder to see other cars or obstacles on the road. Taking into account the indicator of high beam (indicating lighting conditions; no high beam detected), a negative correlation was identified which means that when high beam was off - and, therefore, it was daytime - there were less speeding events. This finding comes in agreement with the previous argument with the indicator of time of the day that higher speeding events occur at night compared to the day.

Regarding the indicators of coping capacity - operator state, harsh accelerations had a positive relationship with the dependent variable (i.e., speeding), indicating that as the number of harsh accelerations increases, speeding also increases. This is a noteworthy finding of the current research as it confirms that harsh driving behavior events present a statistically significant positive correlation with speeding. Lastly, total distance travelled was negatively correlated with speeding which may be due to the fact that the longer a person drives, the more fatigued they may become, causing them to drive slower and more cautiously.

The second GLM investigated the relationship between the speeding and several explanatory variables of task complexity and coping capacity in UK. The model parameter estimates are summarized in Table 2.

It can be observed that all explanatory variables are statistically significant at a 95% confidence level (VIF is lower than 5). With regard to the coefficients, it was revealed that the indicators of coping capacity are all positively correlated with speeding except for harsh acceleration events that appear to be fewer when speeding occurs. The opposite happens with Forward Collision Warning (FCW) and Lane Departure Warning (LDW) events that appear to be higher in case of speeding. An increase in the trip duration and the distance travelled is associated with an increase in speeding events, as well. The use of wipers though is, as expected, negatively associated with speeding events. Gender was a significant variable in this model showing that male drivers (males coded as 0, females as 1), are possibly prone to speeding while the use of high beams also was connected with higher speeding due to lighter night hours traffic.

The third GLM investigated the relationship between the speeding and several explanatory variables of task complexity and coping capacity (vehicle and operator state) in Germany. The model parameter estimates are summarized in Table 3.

Based on Table 3, it can be observed that all explanatory variables are statistically significant at a 95% confidence level; there is no issue of multicollinearity (VIF is lower than 5). It was revealed that the indicators of task complexity, such as time and high beam (indicating lighting conditions; no high beam detected) were positively correlated with

Table 2. Parameter estimates and multicollinearity diagnostics of the GLM for UK.

Variables	Estimate	Standard Error	z-value	Pr(|z|)	VIF
(Intercept)	–3.824	0.014	–274.620	<.001	–
Duration	4.672×10^{-5}	7.877×10^{-7}	59.317	<.001	1.058
Harsh acceleration	–0.187	0.012	–15.377	<.001	1.014
Weather	–0.273	0.023	–11.713	<.001	1.008
High beam	0.128	0.078	1.635	0.102	1.002
Forward collision warning	10.603	2.479	4.276	<.001	1.001
Right lane departure warning	0.357	0.014	25.348	<.001	1.026
Distance	0.002	1.876×10^{-5}	117.628	<.001	1.072
Gender – Male	0.373	0.012	31.757	<.001	1.056
Summary statistics					
AIC	263599.548				
BIC	263610.743				
Degrees of freedom	537681				

speeding. Regarding the indicators of coping capacity – vehicle state such as fuel type and vehicle age were positively correlated with speeding. Furthermore, it was demonstrated that indicators of coping capacity – operator state, such as harsh accelerations, distance, duration and drowsiness had a positive relationship with the dependent variable (i.e., speeding), indicating that as the values of the aforementioned independent variables increases, speeding also increases.

Taking into consideration socio-demographic characteristics, gender and age were negatively correlated with speeding. Results revealed that the vast majority of male drivers displayed less cautious behavior during their trips and exceeded more often the speed limits than female drivers. It is also remarkable that the negative value of the "Age" coefficient implied that as the value of the variable increased (higher value indicates increased age and, therefore, increased years of participant's experience), the speeding percentage was lower. Young drivers appeared to have a riskier driving behavior than older drivers and were more prone to exceed the speed limits.

5.2 SEM Results

In order to investigate the relationship between the latent variables of task complexity, coping capacity, and risk (represented as the three stages of the STZ), four distinct SEM models were developed.

Table 3. Parameter estimates and multicollinearity diagnostics of the GLM for Germany.

Variables	Estimate	Standard Error	z-value	Pr(|z|)	VIF
(Intercept)	1.105	0.057	19.549	<.001	–
Duration	0.003	3.414×10^{-5}	73.366	<.001	1.262
Distance	5.735×10^{-4}	3.723×10^{-5}	15.404	<.001	1.029
Harsh acceleration	1.282×10^{-4}	1.974×10^{-6}	64.951	<.001	1.222
Fuel type - Petrol	0.219	0.010	21.446	<.001	1.328
Vehicle Age	3.162×10^{-5}	3.340×10^{-6}	9.469	<.001	1.277
Gender – Female	–0.275	0.021	–13.025	<.001	1.256
Age	–0.003	0.001	–2.289	0.022	1.076
Drowsiness	1.009×10^{-5}	2.656×10^{-6}	3.800	<.001	1.113
Time indicator	8.547×10^{-5}	1.925×10^{-6}	44.405	<.001	1.080
High beam - On	0.817	0.059	13.963	<.001	1.073
Summary statistics					
AIC	127971.813				
BIC	127981.881				
Degrees of freedom	174299				

Belgian Cars. The latent variable risk is measured by means of the STZ levels for speeding (level 1 'normal driving' used as the reference case), with positive correlations of risk with the STZ. The structural model between the latent variables shows some interesting findings: first, task complexity and coping capacity are inter-related with a positive correlation – albeit the magnitude of this correlation is very small. This positive correlation indicates that higher task complexity is associated with higher coping capacity implying that drivers' coping capacity increases as the complexity of driving task increases. The more complex the situation becomes as a result of speeding, the better the driver's coping capacity will become, for example because of increased alertness. Figure 3 illustrates the results for each phase.

Coping capacity is associated with higher risk, which is an interesting finding. It could be assumed that higher coping capacity might reduce risk; however, the coping capacity indicators in our sample include static demographic and self-reported behavior indicators and therefore are more representative of driver personality and general driving styles, and less so of the real-time operator state during the experiment. For instance, indicators related to the level of sleepiness, fatigue or distraction were either not available or not significant in this model. Therefore, it can be concluded that younger, more confident and less compliant drivers exhibited lower risk in this experiment, in terms of exceeding the STZ speeding boundaries – a finding which can be attributed to higher alertness and exposure in complex environments, without however taking into account the variations of their state during these trips.

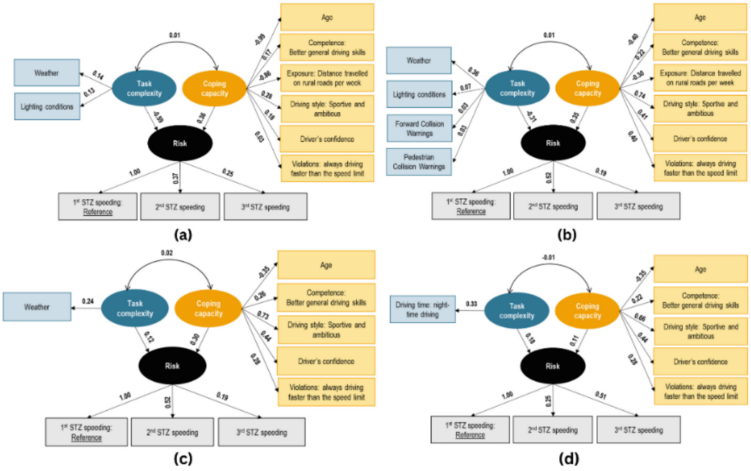

Fig. 3. Results of SEM on risk – Belgian car drivers – experiment phase 1 (a), 2 (b), 3 (c), 4 (d).

The relationships between risk, task complexity, and coping capacity remain consistent across phases, with some noteworthy findings. In phase 2, FCW and PCW indicators load onto task complexity, reflecting real-time events that express demanding and risky situations. However, the overall impact of task complexity on risk only slightly decreases. These events may not be directly linked to exceeding speed limits, which defines risk in this context. Notably, these indicators aren't significant in the 3rd and 4th phases, likely due to lower event occurrences during these phases.

UK Cars. Risk is assessed using STZ levels for headway: level 1 indicates 'normal driving,' level 2 refers to 'dangerous driving,' and level 3 to 'avoidable accident driving.' A negative correlation between risk and STZ indicators was found. Task complexity is measured by the use of high beams and wipers, which reflect visibility and weather conditions, respectively. Both variables have positive loadings on task complexity, showing that as complexity increases, their usage does too. For coping capacity, most indicators, except for general sleeping rate, negatively correlate with risk. Notably, driver style (with the highest estimate), speeding, mobile phone use, and illegal overtaking are critical indicators of coping capacity. Better sleep habits are linked to improved driving capability, while more time spent in the second and third headway levels of STZ is associated with higher risks.

All indicators of task complexity, coping capacity, and risk are statistically significant at the 99.9% confidence level. Task complexity (standardized coefficient = –0.26) and coping capacity (standardized coefficient = –0.19) significantly impact risk. Lower risk relates to more time spent in the first STZ level (i.e., longer headways). In phase 4, task complexity has a greater effect on risk than coping capacity. Interestingly, in this phase, increased driving task difficulty (due to challenging weather or visibility) is associated with lower risk, possibly because drivers become more cautious. Coping capacity follows the same pattern as in other phases, with driver style as the dominant factor, while good sleep habits positively correlate with coping capacity. The results for all phases are shown in Fig. 4.

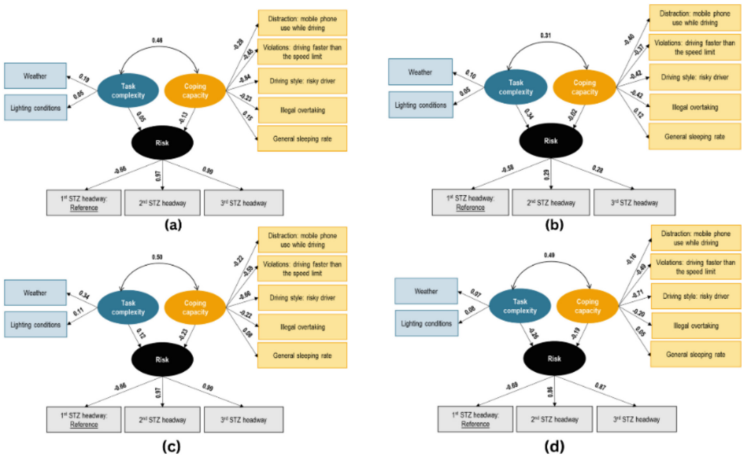

Fig. 4. Results of SEM on risk – UK car drivers – experiment phase 1 (a), 2 (b), 3 (c), 4 (d).

German Cars. The structural model between the latent variables shows some interesting findings: first, task complexity and coping capacity are interrelated with a positive correlation (regression coefficient = 0.003) – which reduces in magnitude as the drivers progress from phases 1 and 2 through phases 3 and 4. This positive correlation indicates that higher task complexity is associated with higher coping capacity implying that drivers' coping capacity increases as the complexity of driving tasks increases. Overall, the structural model between task complexity and risk shows a positive coefficient, which means that increased task complexity relates to increased risk according to the model (regression coefficient = 8.11). On the other hand, the structural model between coping capacity and risk shows a negative coefficient, which means that increased coping capacity relates to decreased risk according to the model (regression coefficient = –0.25).

It is identified that the measurement equations of task complexity and coping capacity are consistent between the different phases. At the same time, the loadings of the observed proportions of the STZ of speeding are consistent between the different phases. The structural model between task complexity and inverse risk (normal driving) are positively correlated among the four phases while coping capacity and risk were found to have a negative relationship in all phases of the experiment.

In Germany, the model for speeding revealed a positive correlation between task complexity and coping capacity, but with the largest correlation in phase 2 of the experiment, where real-time warnings were introduced. At the end of the experiment (phase 4), coping capacity was found to have its largest correlation with risk, while task complexity had its greatest loading during phase 3 of the experiment. The results for all phases are shown in Fig. 5 below.

Table 4 summarizes the model fit of SEM applied for different counties (i.e., Belgium, UK, Germany) and experimental phases.

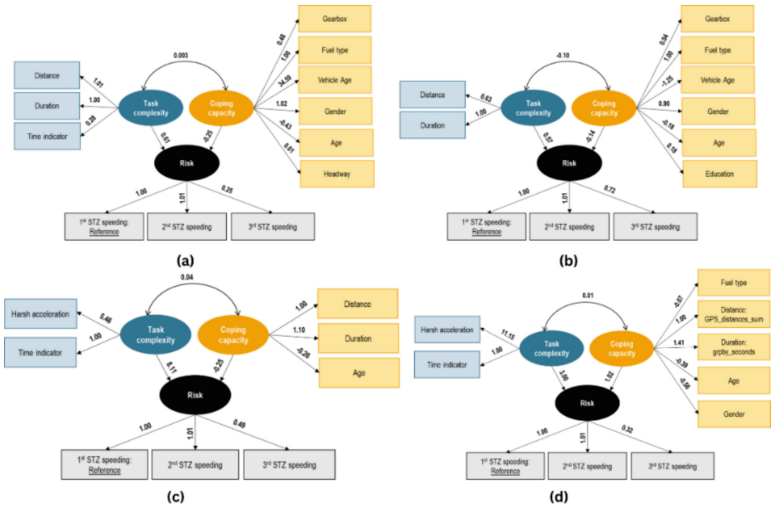

Fig. 5. Results of SEM on risk – German car drivers – experiment phase 1 (a), 2 (b), 3 (c), 4 (d).

6 Discussion

Through the application of SEM models, the analyses revealed that higher task complexity levels lead to higher coping capacity by drivers. Additionally, the effect of task complexity on risk was greater than the impact of coping capacity in Belgium and Germany, while mixed results were observed in the UK. Models fitted on data from different phases of the experiments validated that interventions had a positive influence on risk compensation, increasing drivers' coping capacity and reducing dangerous driving behavior.

As task complexity increases, drivers experience greater cognitive load and divided attention, leading to decreased situational awareness, slower response times, and impaired decision-making, which heightens the risk of errors or collisions. Drivers may become overwhelmed by complex tasks, diverting attention from essential driving activities and delaying responses to critical events. Interactions with in-vehicle technology can further increase cognitive workload and reduce focus on driving.

Drivers with limited coping capacity struggle more with complex tasks, leading to slower reactions, impaired judgment, and a higher risk of crashes. When the demands of driving exceed a driver's coping ability, errors and collisions are more likely. The relationship between task complexity, coping capacity, and risk is context dependent. While higher complexity generally increases crash risk, experience or training can mitigate it. Similarly, coping strategies may help reduce risks but depend on the individual's ability to apply them effectively.

The developed models can be further explored by incorporating additional factors such as road types, personality traits, and driving profiles. Enhancements could include measurements like electrocardiograms, traffic conflicts, and emissions. Future work might also investigate imbalanced learning and unobserved heterogeneity to deepen understanding of the task complexity, coping capacity, and crash risk relationship.

Table 4. Model fit of SEM for different countries

Model Fit measures	Phase 1	Phase 2	Phase 3	Phase 4
Belgian Cars				
AIC	273200.6	57294.26	338636.6	271111.2
BIC	273402.4	57518.77	338808.6	271253.0
CFI	0.661	0.473	0.484	0.817
TLI	0.560	0.335	0.291	0.709
RMSEA	0.121	0.082	0.103	0.037
UK Cars				
AIC	6377.390	4939.518	5266.238	7536.846
BIC	6599.142	5171.580	5489.058	7770.156
CFI	0.984	0.885	0.988	0.989
TLI	0.977	0.834	0.983	0.985
RMSEA	0.042	0.037	0.037	0.035
Germany Cars				
AIC	813827.574	676463.527	282420.347	525983.888
BIC	814118.257	676746.197	282625.175	526243.996
CFI	0.981	0.960	0.996	0.978
TLI	0.974	0.944	0.993	0.966
RMSEA	0.079	0.117	0.059	0.100

7 Conclusions

The objective of this research was to model the relationship between driving task complexity, coping capacity, and crash risk using the i-DREAMS database. Data were collected from 133 drivers in Belgium, Germany, and the UK during a naturalistic driving experiment. Key explanatory variables included time headway, distance traveled, speed, forward collisions, time of day, and weather conditions.

Results indicated that higher task complexity leads to higher coping capacity, as drivers regulate their ability to manage challenges while driving. SEM analysis revealed a positive correlation between task complexity and risk, meaning increased task complexity raised crash risk. Conversely, coping capacity had a negative relationship with risk, showing that increased coping capacity reduced dangerous driving behaviors. Overall, interventions positively influenced drivers by improving coping capacity and lowering crash risk.

The inter-relationship between driving task complexity, coping capacity, and crash risk is multifaceted. Task complexity refers to the cognitive demands of various factors like traffic, road conditions, and distractions. Coping capacity reflects a driver's ability to manage these demands, influenced by experience, skills, and decision-making processes.

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Systematic Analysis of Automation Safety – Combining Different Perspectives by Simulation and Test Bed Evaluation

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Abstract. The overall goal of the presented approach is the identification and reduction of risks introduced by connected, cooperative and automated mobility (CCAM) functions and a process for their evaluation and validation, especially considering critical interactions with other road users. The combination of different tools is emphasized in order to obtain a comprehensive view on the CCAM functionality. Appropriate toolchains for different types of simulations are presented. Furthermore, a real-world test bed is utilized to observe real world behaviour of road users and to evaluate CCAM functions under real conditions. Some results regarding a practical application examples are presented.

Keywords: Automation safety evaluation · human in the loop simulation · model in the loop simulation · real-world test beds

1 Introduction

The technological advances of CCAM systems are improving rapidly and the levels of automation (according to SAE definition [1]) emerging into the market are continuously rising. Level 1 and 2 systems such as adaptive cruise control, stop & go assist, lane keeping and lane change assist, parking assist or traffic jam assist [2] are already broadly available and are continuously gaining market share. Level 3 systems, e.g. traffic jam chauffeur and highway chauffeur, are broadly announced, many prototypes are intensively tested and Mercedes has released a first version of its Drive Pilot [3]. The functionality of Level 4 systems like urban or highway autopilots, are explored in many research projects [4] and first systems are already tested on real roads and prepared for market introduction, e.g. by Cruise [5], AutoX [6] and others. Beside the technical realization, the biggest challenge for systems with Level 3 or higher is to reach a comprehensive assessment, proof of reliability and robustness of the automation under test [7]. Testing on real roads is very expensive and time consuming. With the rising number and complexity of test scenarios, the shift to simulation-based testing and validation of automation function is inevitable [8], where mainly model- (MiL) or software-in-the-loop (SiL) simulations are intended to be used, as they can be parallelized and sometimes

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accelerated. However, there are scenarios which are difficult to set-up both in real world and in MiL/SiL simulation, i.e. including interaction with vulnerable road users (VRUs) [9]. On one hand, real world tests are either to dangerous, ethically not acceptable or hard to achieve. On the other hand, for MiL/SiL simulation VRU behaviour and interaction models have to be used, which, due to the complexity of possible explicit and implicit signals, does not exist yet [9, 10]. Here, human-in-the-loop simulation (HniL), where real people are brought into interaction with automated vehicle systems, can help to solve these challenges. But only the combination of all different test methods is able to provide a comprehensive safety analysis for CCAM functions.

2 Methodology

In order to reach a thorough evaluation of a vehicle automation, HniL simulation, MiL simulation, real-world traffic observation and automation evaluation and validation tests can be combined for a systematic analysis (see Fig. 1).

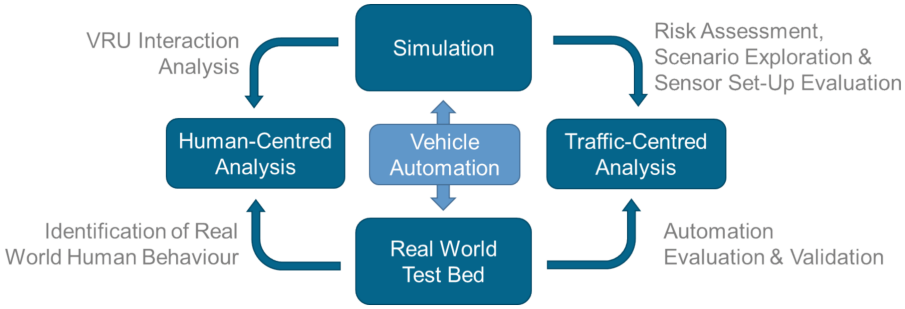

Fig. 1. Schematic of a systematic and comprehensive analysis of an automation system

The basis for the analysis is always the operational design domain (ODD) of the system under test (SuT), the vehicle automation or CCAM function. Starting with the identification of real-world behaviour of road users – both, motorised and non-motorised – which typically interact with the vehicle CCAM function, knowledge about central information about critical behavioural aspects can be obtained. Sensor-based observation serves as a basis for this step of the analysis as well as accident data or similar data basis which allows the extraction of information about certain road users. This knowledge can be used to improve road user models and to obtain parametrised test scenarios for the MiL simulation.

The next step is the identification of critical scenarios with respect to interaction between vulnerable road users (VRU) or other vehicles and the SuT within the current ODD. Especially complex interaction with VRUs has to be evaluated utilizing HniL simulators. However, the more cost- and time-effective analysis can be done with extensive MiL simulations, where criticality metrics in relation to automation safety can be assessed for a broad range of scenarios and parameter variations. Here, the development of appropriate methods for intelligent scenario exploration and a safety argumentation

with guaranteed coverage of scenarios with high criticality is still ongoing [11]. Solving this task will be an important step towards simulation-based safety evaluation which will be able to be accepted by certification institutions.

Finally, real-world test bed evaluations can support the proof of safety of highly automated vehicle systems as a last step in the evaluation and validation process of a new CCAM function. Objective position and velocity data of the CCAM vehicle and the surrounding traffic from drives on the observed test bed roads can provide the necessary information for ODD specific certification. Various tools support the information gathering for the different parts of the comprehend analysis: Different types of simulation frameworks are needed as well as access to a relevant real-world data basis or test beds. In the following, the toolchains operated and used by the DLR Institute of Transportation Systems are presented as appropriate examples for the described task.

2.1 Real-World Test Bed

For the real-world observation, the infrastructure-based detection of the Test Bed Lower Saxony (http://testfeld-nds.de/) will be utilized. Both for collecting data of road users in form of trajectories, i.e. position and velocity information, as well as for the final automation system evaluation. Especially the inner city-ring of Braunschweig (AIM) and a section of the A39 in the east of the city provides infrastructure for camera-based traffic observations. High-precision maps and traffic management service data complement the data collection. ODDs comprehending highway or rural road driving with higher velocities can be evaluated as well as low-speed inner-city ODDs. An example of the usage of the test bed data for the analysis of VRU-vehicle interaction is described by Zhang et.al, utilizing data collected at the research intersection for the evaluation of implicit communication between motorists and cyclists [12].

2.2 Human-Centred Simulation

On the simulation side, HniL interaction exploration studies are conducted in the MoSAIC-VRU-Lab. The laboratory consists of two fixed-base driving simulators, one bicycle simulator and two different pedestrian simulators (Fig. 2), which enable to bring human participants together into a variety of different interaction scenarios [13]. The bicycle and pedestrian simulators are mainly used with VR glasses. The car simulator can either use VR or a monitor set-up as displayed in Fig. 2.

Tracking devices allow for motion capturing, which is necessary for the animation of gestures and body movements in order to enable nonverbal communication between the simulation participants. A first interaction study was performed in 2022, where based on the findings of the real-world analysis of the test bed data [12] a simulator study was conducted, further examining the interaction patterns between motorists and cyclists in a controlled simulation environment [14].

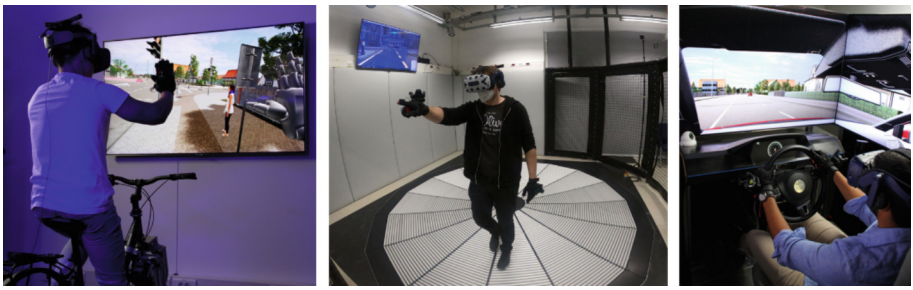

Fig. 2. MoSAIC-VRU-Lab. Bicycle (left), pedestrian (middle) and car simulator (right). Source: DLR

2.3 Traffic-Centred Simulation

As simulation framework for traffic-centred simulation, the open source software "Open Simulation Toolchain for Automotive and Rail Research", short: OSTAR (https://github.com/DLR-TS/OSTAR-Quickstart) is used for massive MiL simulation campaigns [15]. Other open source simulation software like CARLA (https://carla.org/) or openPASS (https://openpass.eclipse.org/) is incorporated as core simulation because many central simulation functionalities are realised in these tools already. The OSTAR framework provides further interfaces to separate simulation modules like the traffic simulation SUMO (https://eclipse.dev/sumo/). In OSTAR all models, ranging from vehicle dynamics to sensor models as well as the automation function can be integrated on the basis of the FMI (https://fmi-standard.org/) and ASAM OSI standards (https://www.asam.net/standards/), which eases the integration and operation of the models. Furthermore, the basic description of road networks and scenarios are implementing ASAM OpenDRIVE and OpenSCENARIO standards in order to allow for a seamless toolchain and reusable scenario descriptions. OSTAR supports the definition of parameter variations, parallel execution of multiple scenarios, online check of criticality metrics and interfering scenario variation algorithms. The intended OSTAR applications range from risk assessment simulation runs and sensor set-up-configuration evaluation to simulation-based CCAM function evaluation.

3 Results and Conclusion

A practical application example currently used for an initial proof-of-concept study is the simulation-based analysis of a protected intersection (PI) design, which is an infrastructure measure for increasing cyclist safety (Fig. 3).

The effect of the shown PI design on subjective and objective metrics and its effects on automated driving was examined using the presented approach. First but not comprehend results are presented in the following to provide an idea of the possible outcome of the presented methodology. The HmiL-Study revealed that participants felt safer on the PI than on the regular intersection design (RI) but more constricted as well (Fig. 5).

Fig. 3. Tostmannplatz in Braunschweig. Protected intersection design (left), current road layout (middle) and SUMO simulation of the current layout (right). Source: DLR

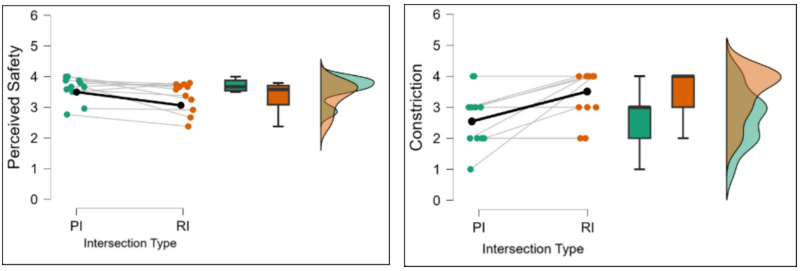

Fig. 4. Bayesian Wilcoxon Signed-Rank Test Results on Perceived Safety (left, $BF_{+0} = 6.236$, $W = 56.0$, $Rhat = 1.007$) and Perceived Constriction (right, $BF\text{-}_0 = 8.181$, $W = 0.0$, $Rhat = 1.002$) from a cyclist perspective.

The traffic-centred analysis on the traffic flow with SUMO revealed some unexpected results: Even though there is no separate lane for right turning vehicles coming from the south-end, the average waiting time on the RI increases with more than 300 vehicles per hour, which does not happen on the PI design (Fig. 5). The analysis shows, that this is caused by vehicles trying to merge from the middle lane to the right turning lane while it is blocked (where the number of right turning vehicles is kept constant to 60 per hour) and hence causing small traffic jams.

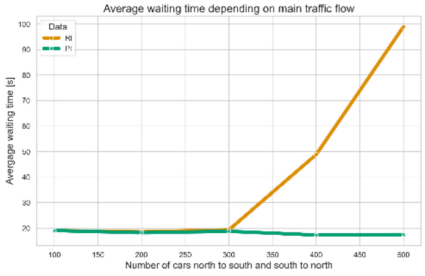

Fig. 5. Traffic flow analysis on average waiting time for the north-south connection.

Additional analysis of the traffic-centred analysis is not finalised yet. But it could already be observed, that the heading angle of an automated vehicle coming from the south and turning right is different for the two intersection designs, which has implications on the time of detection of crossing pedestrians and cyclists by the sensory system of the CCAM function. The obtained insights can serve as an additional measure for the safety level of a certain road infrastructure design.

Subsuming, the presented comprehend methodology helps to get insights from different perspectives on the criticality of a certain infrastructure design, a certain CCAM system set-up or other relevant aspects of automation safety. It is thus emphasised to be considered in future CCAM safety analysis.

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Safety of Low-Speed Automated Driving Systems and Its Implication on Commercial Implementation in the EU

Are Low-Speed Automated Driving Systems Safe Enough for Type Approval?

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Abstract. Urban shuttles in the form of Low-speed Automated Driving (LSAD) systems have been already introduced in many European cities as part of pilot test campaigns. They have undergone several years of development and are reasonable candidates for commercial deployment. Usually, the Operational Design Domain of LSAD vehicles is restricted, eliminating a vast amount of foreseeable critical cases. Nonetheless, the traffic scenarios of the urban environment still expose them to a variety of unsafe situations, where in particular the interaction with Vulnerable Road Users (VRUs) remains a critical aspect. For this reason, the EU Type Approval Regulation for Automated Driving Systems includes specific provisions for these systems to safely interact with VRUs. By means of a dedicated experimental campaign, the present study is assessing the behavior of an LSAD vehicle, using as a reference the provisions of the European Regulation. There was no aim to prove regulatory compliance, but rather to define the safety level of the systems. The results suggest that development is still needed for these types of LSAD vehicles to reach a minimum acceptable level of safety and also provide evidence that the European Regulation is ambitious enough to prevent the deployment of unsafe systems on EU roads.

Keywords: Automated Driving · Policy Support · Testing · Urban Shuttles

1 Introduction

The technological development behind driving automation has recently led Original Equipment Manufacturers (OEMs) to move from experimentations in controlled environments to public road projects [1–3]. Such a transition is a clear signal of the confidence and maturity levels reached by the OEMs in deploying automated vehicles.

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From a regulatory point of view, policymaking bodies did not stand by. Regulations for the type-approval of Automated Driving Systems (ADSs) were adopted, like the (EU) 2022/1426 Regulation on ADS vehicles [4] in 2022. Its appearance was crucial both to enable product deployment and to ensure a sufficient safety level. This act established the regulatory framework for a set of ADS use cases, including fully Automated Vehicles (AVs) in a predefined area, i.e. urban shuttles.

Although up to now there are no automated vehicles approved according to the EU ADS Act requirements [4], there are several large-scale test campaigns and demonstrations which are exposing AVs to the public. This raises some concerns related to the users' perception of ADSs' safety and to the implications of scaling up potentially immature technology that has not undergone yet the type-approval process. At the same time, the requirements and validation methods defined by the type-approval Regulation have not been confirmed in reality due to the lack of commercial products. This may raise concerns among manufacturers and Type-Approval Authorities (TAA) regarding the feasibility of such provisions, and can also raise questions among public authorities about the safety level of the regulatory provisions and their capability to ensure safe deployments.

The present study aims to address these concerns. To fulfill this goal, a test campaign has been performed to assess the safety level of an urban shuttle currently in operation in several cities across Europe vis-à-vis the requirements and test provisions included in [4].

2 Methods

The study is assessing the performance of an LSAD urban shuttle, through an experimental campaign carried out on a proving ground with a series of specifically chosen test scenarios.

EU 2022/1426 [4] contains a general list of functional scenarios suitable for fully automated vehicles. In particular, Annex III, Part 3 of [4], contains a set of 13 main functional scenarios for the safety assessment of the AV. Exact scenarios should be selected according to the actual ODD of the Vehicle Under Test (VUT). These scenarios include general situations like keeping or changing lanes, but also specific scenarios for highways and vehicles with automated parking functionality. Considering the case of LSAD vehicles, several scenarios should be ignored. For instance, lane-changing maneuvers are not needed, since the VUT has a predefined route to follow and is not able to recognize lanes.

3 Case Study and Results

3.1 Vehicle Under Test and Instrumentation

The vehicle used for the test campaign is an LSAD urban shuttle currently operated in a set of European projects. Since it is not a commercial product, the disclosure of the exact vehicle manufacturer and model is not relevant to the objectives of the paper.

Predefined routes with stops for getting on and off the vehicle should be created and the surroundings mapped before starting the automated operation of the vehicle. The output of the mapping process is a high-definition 3D point-cloud of the road and objects along the path of the vehicle. This map also encompasses right-of-way information to allow the shuttle to handle intersections. The maximum operational speed in automated mode was set to 20 km/h for the experiments. The VUT is equipped with five LiDARs that enable 360-degree view around the vehicle. The selection of LiDARs as the only sensor used to achieve automated driving capabilities influenced the design of the testing campaign and the derivation of concrete scenarios as defined below. The VUT did not need additional V2X communication through the testing, cameras were mounted on the vehicle only to support possible remote operation.

The VUT, targets and supporting vehicles were instrumented with a Real-Time Kinematic (RTK)-GNSS unit coupled with an Inertial Measurement Unit (IMU). Three different Vulnerable Road User (VRU) targets were used: an adult pedestrian, a child pedestrian and a cyclist. Additionally, a speed bump was used to test false-positive reactions. The testing campaign lasted two working days and was held at the Smart City module of ZalaZone proving ground in Zalaegerszeg.

3.2 Scenarios, Requirements, Test Provisions and Results

Intersection

Regulation 2022/1426 mandates testing the intersection behavior with and without a leading vehicle and with approaching/passing vehicles from the intersecting lanes. The technical requirements foresee that in case of crossing oncoming traffic or merging with privileged traffic, it must be ensured that the Time To Collision (TTC) is below the dynamical threshold set by [4].

Such a technical requirement was tested at a T-junction, where the VUT was obliged to yield to the crossing traffic in a pre-programmed left-turn intersection.

9 scenarios were recorded at the pre-programmed intersection point in the vehicle map. From these, the authors found 5 scenarios where major non-compliances appeared and the computed TTC was substantially below the dynamical threshold value. According to the observations, the VUT did not yield to the other vehicle and when it came critically close to the VUT, it performed an emergency stop. Several times a lateral maneuver from the other vehicle was needed to maintain safety.

Collision Avoidance

In scenarios with VRU crossings, the reference speed for the pedestrian target is 5 km/h and 15 km/h for the cyclist target in agreement with the EuroNCAP practices. Under these circumstances, the AV should be able to avoid a collision up to 60 km/h in case of no obstruction. Different impact points with the VUT were investigated, namely a near side (25%), center (50%) and far side (75%) assumed point of collision for both types of VRUs.

The VUT managed to stop with smooth braking before a stationary VRU at a distance approximately equal to 4 m in each case. The shuttle is not capable of performing evasive maneuvering which entails leaving the path prescribed in the map. As such, it will remain stuck behind a standing object as long as it stays in its path.

Concerning the scenarios involving pedestrian crossings, the VUT did not prove to fulfill the EU regulation provisions due to three collisions reported out of 12 test runs.

The shuttle managed to avoid a collision with an adult pedestrian in the central (50%) impact point in 6 out of 7 test runs. The 75% impact point cases were all safely handled by the VUT. This does not apply for the near-side impact point test scenarios. In those cases, the VUT has less time to react due to the fact that the pedestrian enters the safety corridor later. This resulted in two collisions out of three test runs. Eventually, it shall be noted that in all the cases the VUT produced an emergency deceleration (-5.0 m/s^2) when the dummy entered the safety corridor, with no detectable sign of anticipated reaction.

The case of the crossing cyclist was only tested with the 50% and 75% impact points. Both scenarios resulted in a collision. In fact, the target was damaged during the 50% case so much, that testing with a cyclist could not be continued. The VUT failed to trigger a timely braking action when the cyclist crossed the road as it was not able to anticipate the appearance of the object.

Avoid emergency Braking Before a Passable Object

The aim of this test scenario is to check whether the ADS produces unnecessary strong braking reactions in the case of a stationary object lying on the road that does not represent a physical impediment. According to the European legislation, the deceleration value should not exceed 5 m/s^2 at any vehicle speed.

The passable object selected for the application was a speed bump module with a nominal height of 8 cm. In a free-flow traffic situation, the VUT had the possibility to recognize the object from far away, providing the occasion to react as it would normally do. In vehicle following scenarios the speed bump was obstructed by the lead vehicle, so reaction time was limited by the following distance. Three repetitions per configuration were executed to detect the consistency of the VUT behavior.

The VUT always stopped before the speed bump when it was following the lead vehicle, using a smooth deceleration. On the contrary, while operating in free-flow, it passed over the speed bump without any deceleration action. This inconsistent behavior was continued throughout the repetitions.

Following a Lead Vehicle

The aim of this scenario is to check whether the ADS is able to maintain and restore a stable motion and the safety distance to a vehicle in front after a perturbation is induced. Moreover, the VUT should be able to avoid a collision with the Lead Vehicle (LV) under any circumstances.

Vehicle following was tested over the full VUT speed range using a real vehicle and a cyclist target as leaders. The VUT resulted to use very large headway distances regardless of the kind of target. The representation of the VUT headway policy in a vehicle following scenario is depicted in Fig. 1. The headway selection implies that the VUT was always able to safely and smoothly stop before the LV even when the target braked with maximum deceleration thus fulfilling the regulatory requirements.

The computed steady state following distance demonstrates an extremely cautious approach by the OEM, corresponding to a 10 s time-gap. This might pose problems in a real-world scenario where other traffic participants may try to cut-in into the large gap

left open by the VUT. Moreover, traffic capacity of the urban road will be substantially deteriorated by the presence of a vehicle with these headway settings.

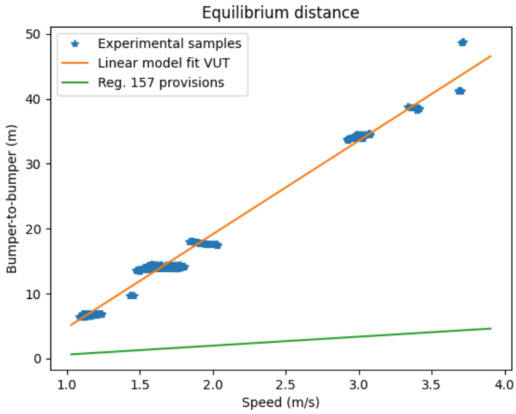

Fig. 1. Car-following equilibrium distance versus speed.

Cut-In Scenarios

Being one of the most safety-relevant traffic scenarios, cut-in was implemented in the test campaign with special attention. Nine cut-in maneuvers were made with a passenger car with different relative speeds and distances. These scenarios included also repetitions of the cut-in vehicle going at a higher speed (30 km/h) than the VUT, in order to investigate its capability to react to different cut-in speeds.

The scenarios were assessed by computing the TTC with respect to the values found [4]. Generally, the VUT managed to fulfill the European legislation requirements. This outcome is not surprising, as the shuttle was clearly tuned to a large following distance with respect to the leader. The authors should additionally note that, in spite of the relatively large TTC, the VUT produced an emergency-stop (e-stop) in 5 out of 10 scenarios analyzed, meaning that it was extremely sensitive to approaching vehicles.

E-stops were consistently activated not just during the cut-in scenarios, but also in any kinds of interactions with other road users close to the VUT. The inspection of the positions in the time instance of e-stop activation revealed, that an e-stop is triggered when an object enters a 2.2 m wide corridor centered in the VUT geometrical center. This area approximately corresponds to a safety area 20 cm larger than the VUT width. The lateral distance of the different road users additionally suggests that no object classification method is used by the VUT with respect to implementing a different braking reaction depending on the target class or lateral velocity of the object.

4 Conclusion

The general behavior assessment carried out suggests that the VUT is using an extremely cautious approach while driving, although this approach is not able to prevent collisions that could have certainly been avoided. Clearly, the long following distances imply

lower deceleration effort in case of an emergency scenario happening in front, which is conservative. Nonetheless, the poor capability to deal with crossing traffic, especially at higher relative speed, seems to suggest that the technology is not ready yet and further refinement is needed to achieve road-worthy performance.

Regarding the testing requirements, it was possible to carry out the test campaign as mandated in the regulation without issues, thanks to the availability of supporting measuring equipment and infrastructure. The paper provides suggestions to set up the testing campaign and derive concrete scenarios based on the ODD and technical specifications for the VUT.

The work has provided methodologies for testing AVs and tools for the assessment of AVs behaviors. The research effort answered the concern raised in several works about missing standards for AVs testing (14) by both researchers and type-approval authorities. The scientific effort demonstrated the feasibility of implementing the requirements listed in EU 2022/1426 regarding the type-approval of L4 vehicles.

Concerning the performance of automated vehicles currently being deployed in Europe, at least those mainly relying on LIDARs for sensing the environment and avoiding obstacles, it seems clear that further development is still needed in order to provide the vehicle with a more natural and road-worthy behavior and to comply with the requirements defined by the European type-approval regulation.

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Hybrid Path Planning Approach for the Autonomous Obstacle Avoidance During Cornering

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Abstract. Autonomous vehicles are a trending research topic which involves a number of different problems. This research work considers the problem of path planning, while taking into account a specific and important traffic scenario – determination of the path in order to perform obstacle avoidance during cornering. In this research work, a novel hybrid path planning approach which consists from two classical planning approaches – the Bezier curves and the Rapidly-exploring random trees, is proposed and experimentally tested. The entire development process of the hybrid path planning approach is described. The experimental testing of the proposed approach was performed while using an actual prototype of the autonomous vehicle. During the experimental testing, different positions of the obstacle, different radius of the corner arc and different angles of the corner arc were considered. Approximately 200 different scenarios were considered and experimentally tested. The results of the experimental testing showed that the general performance of the proposed hybrid path planner is reliable – the planned paths are safe, continuous, and technically feasible.

Keywords: Autonomous Driving · Vehicle · Path Planning · Cornering · Obstacle Avoidance · Bezier curves

1 Introduction

As the interest in the development of autonomous vehicles and their technologies has been constantly growing for a significant amount of time now, autonomous vehicles have already become a long-term trending phenomenon and research topic. The ongoing interest in autonomous vehicles is motivated by the significant amount of possible positive outcomes, which can be achieved through the integration of the autonomous vehicles into the entire traffic system: increased mobility and sustainability; enhanced road safety; new economic opportunities; reduced traffic congestions and emissions, etc. However, significant technological progress is still required before autonomous vehicles will be able to operate reliably in any traffic situations. Further research, development and testing must be done in such fields as sensing and perception; path planning; decision making and control. The problem of path planning plays an essential role while considering safe and efficient autonomous driving in complex traffic situations. Respectively,

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cornering is a crucial manoeuvre, which creates a number of challenges while solving the problem of path planning. Such factors as the geometry of the corner, velocity of the autonomous vehicle or various possible obstacles must be taken into consideration. Due to this reason, the problem of path planning for autonomous cornering is frequently considered in scientific works, such as [1–4]. It can be noted that in most of the scientific works researchers usually try to develop path planning approaches, which would be able to plan an optimal path for moving in corners (turns). However, this research work solves a slightly different research problem of path planning and cornering – planning of the path in order to perform the avoidance of the obstacle, which emerges in the primary path while already cornering (turning). In Sect. 2, the development of the hybrid path planning approach is described. Section 3 describes the experimental tests. Section 4 presents the analysis and discussion part of the work. Final section presents the conclusions of the work.

2 Development of the Hybrid Path Planning Approach

Based on the fundamental characteristics of the Bézier curves and the principles of the Rapidly-exploring random trees, the proposed new application of these methods is defined as follows: path planning for the autonomous obstacle avoidance during cornering is performed by applying the Bézier curves, uncertainties of which are solved by using the Rapidly-exploring random trees. The scheme of the path planning for obstacle avoidance in a constant radius circular arc, while applying the proposed hybrid approach, is provided in Fig. 1. The development of the new hybrid path planning approach was based on these assumptions:

1. The obstacle is in the constant radius circular arc, $r = \text{const.}$ and the velocity of the autonomous vehicle is also constant, $v_{vehicle} = \text{const.}$;
2. The maximum angle of the constant radius circular arc is $\alpha_{max} = 90°$ and the minimum angle of the constant radius circular arc is $\alpha_{min} = 45°$;
3. The environment of the autonomous movement is unstructured. The obstacle can be avoided by the autonomous vehicle while moving by the inner or by the outer side of the circular arc.

Firstly, in order to avoid a collision with the obstacle, a minimal safe longitudinal distance S_{min} at which the obstacle avoidance can begin, must be determined (Fig. 1):

$$S_{min} = r + \left(v_{vehicle} \cdot t_{delay}\right), \tag{1}$$

where t_{delay} is the assumed delay time of the path planning approach performance.

In various research works, such as [5, 6], it is noted that a path, which is being planned while using a high order Bézier curve (fifth or higher order), becomes unstable, i.e., the change of the coordinates of one waypoint has influence on the whole planned path and not on a certain path segment. In this work further a statement is made and substantiated that, after formulating an appropriate dependency between the Bézier curve waypoints, the application of the high order Bézier equations for the planning of paths is reliable and efficient. While seeking to ensure the whole planned path's continuity, technical

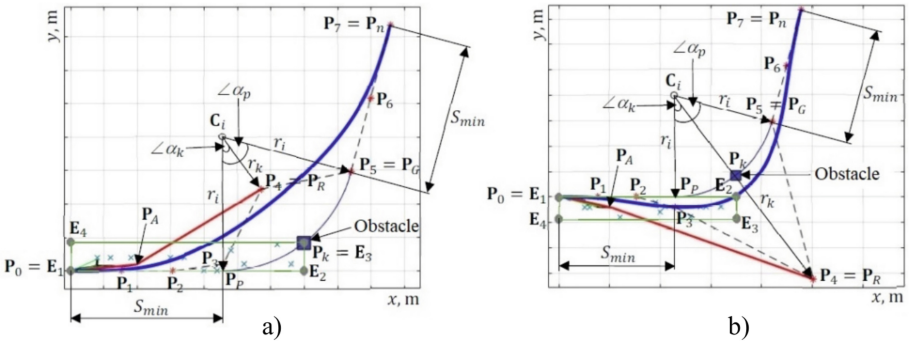

Fig. 1. Scheme of the path planning for obstacle avoidance in a constant radius circular arc, while applying the proposed hybrid approach: a) obstacle avoidance by the inner part of the circular arc; b) obstacle avoidance by the outer part of the circular arc.

feasibility and the least possible demand of the algorithm's computer resources, it was determined that a seventh order Bézier equation should be used:

$$\begin{aligned} P(t_B) = (1-t_B)^7 \cdot \mathbf{P}_0 + 7 \cdot t_B \cdot (1-t_B)^6 \cdot \mathbf{P}_1 + 21 \cdot {t_B}^2 \cdot (1-t_B)^5 \cdot \mathbf{P}_2 + \\ +35 \cdot {t_B}^3 \cdot (1-t_B)^4 \cdot \mathbf{P}_3 + 35 \cdot {t_B}^4 \cdot (1-t_B)^3 \cdot \mathbf{P}_4 + \\ +21 \cdot {t_B}^5 \cdot (1-t_B)^2 \cdot \mathbf{P}_5 + 7 \cdot {t_B}^6 \cdot (1-t_B) \cdot \mathbf{P}_6 + {t_B}^7 \cdot \mathbf{P}_7 \end{aligned}, \quad (2)$$

where t_B is the parameter used to interpolate the Bézier curve, $t_B \in [0,1]$; $\mathbf{P}_i$ is the control points which define the Bézier curve.

While applying the hybrid path planning approach it is assumed that the manoeuvre starts at the waypoint $\mathbf{P}_0$ and that the waypoints $\mathbf{P}_0$, $\mathbf{P}_1$, $\mathbf{P}_2$ are distant from each other by equal lengths, i.e., the waypoint $\mathbf{P}_1$ is the middle point between the waypoints $\mathbf{P}_0$ and $\mathbf{P}_2$. The waypoints $\mathbf{P}_3$ and $\mathbf{P}_4$ for the Bézier curve are going to be selected while using the Rapidly-exploring random trees. Coordinates of the waypoints $\mathbf{P}_5$, $\mathbf{P}_6$, $\mathbf{P}_7$ are going to be selected based on the obstacle position in the constant radius circular arc, radius r of the arc, the angle of the constant radius circular arc and by which side of the constant radius circular arc the obstacle is going to be avoided. The geometrical borders $\mathbf{E}_i$ in which the nodes and random tree branches are going to be generated can be expressed as:

$$\mathbf{E}_i = \begin{cases} \mathbf{E}_1\left(P_{0_x}; P_{0_y}\right) \\ \mathbf{E}_2\left(P_{k_x}; P_{0_y}\right) \\ \mathbf{E}_3\left(P_{k_x}; \pm P_{k_y}\right) \\ \mathbf{E}_4\left(P_{0_x}; \pm P_{k_y}\right) \end{cases}, \quad (3)$$

where P_{0_x} and P_{0_y} are the x and y coordinates of the waypoint $\mathbf{P}_0$; P_{k_x} and P_{k_y} are the x and y coordinates of the waypoint $\mathbf{P}_k$, which defines the position of the obstacle.

The proposed coordinates for all of the waypoints when the obstacle is going to be avoided by the inner side of the circular arc:

$$\mathbf{P}_{inner} = \begin{cases} \mathbf{P}_0(0;0) \\ \mathbf{P}_1\left(\frac{P_{2_x}}{2};0\right) \\ \mathbf{P}_2(S_{min};0) \\ \mathbf{P}_3(S_{min};P_{A_y}) \\ \mathbf{P}_4(P_{R_x};P_{R_y}) \\ \mathbf{P}_5(C_{i_x}+r;P_{4_y}) \\ \mathbf{P}_6\left(P_{5_x};P_{5_y}\pm\frac{S_{min}}{2}\right) \\ \mathbf{P}_7(P_{5_x};P_{5_y}\pm S_{min}) \end{cases}; \mathbf{P}_{outer} = \begin{cases} \mathbf{P}_0(0;0) \\ \mathbf{P}_1\left(\frac{P_{2_x}}{2};0\right) \\ \mathbf{P}_2(S_{min};0) \\ \mathbf{P}_3(S_{min};P_{A_y}) \\ \mathbf{P}_4\left(C_{i_x}+r_k\cdot\cos\left(\frac{3\pi}{2}+\alpha_k\right);C_{i_y}\pm r_k\cdot\sin\left(\frac{3\pi}{2}\pm\alpha_k\right)\right) \\ \mathbf{P}_5\left(C_{i_x}+r;C_{i_y}\pm r_k\cdot\sin\left(\frac{3\pi}{2}\pm\alpha_k\right)\right) \\ \mathbf{P}_6\left(P_{5_x}+\frac{S_{min}}{2}\cdot\cos(\alpha_p);P_{5_y}\pm\frac{S_{min}}{2}\cdot\sin(\alpha_p)\right) \\ \mathbf{P}_7\left(P_{5_x}+S_{min}\cdot\cos(\alpha_p);P_{5_y}\pm S_{min}\cdot\sin(\alpha_p)\right) \end{cases}, \tag{4}$$

where P_{A_y} is the y coordinate of the point $\mathbf{P}_A$, which defines the last tree branch generated by the Rapidly-exploring random trees approach; P_{R_x} and P_{R_y} are the x and y coordinates of the point $\mathbf{P}_R$, which defines the goal point of the Rapidly-exploring random trees approach; C_{i_x} and C_{i_y} are the x and y coordinates of the point $\mathbf{C}_i$, which defines the centre of the constant radius circular arc; r_k is the distance between the points $\mathbf{C}_i$ and $\mathbf{P}_R$; α_k is the angle between the beginning of circular arc and the obstacle $\mathbf{P}_k$; α_p is the angle between the end of circular arc and the obstacle $\mathbf{P}_k$.

In the Eqs. 3 and 4 positive values of the parameters must be used if the turn to the left side is being performed, during the right turn – negative values.

3 Experimental Tests

Experimental path planning and test drives were conducted using an autonomous research vehicle developed at Vilnius Gediminas Technical University. In order to control the movement of the autonomous research vehicle, a modified Stanley controller with an original adaptive tuning function was used. The used autonomous research vehicle is shown in Fig. 2, a more detailed description of the used autonomous research vehicle can be found in [7].

Fig. 2. Autonomous research vehicle which was used during the experimental test drives. (Source: Picture taken by the authors)

During the experimental test drives, these cases were considered and investigated:

1. Different angles of the constant radius circular arc r. These values of the constant radius circular arc r angle were considered: 45^0; 75^0; 90^0;
2. Different values of the circular arc radius r: 12 m; 18 m; 22 m;

3. Different positions of the obstacle in the constant radius circular arc (corner). Obstacle in the: beginning; middle and end of the corner;
4. Path planning and obstacle avoidance was performed by the inner side of the circular arc and by the outer side of the circular arc.

While considering different possible cases during the obstacle avoidance by the inner side of the circular arc, 108 experimental drives were performed and, during the obstacle avoidance by the outer side of the circular arc, 90 experimental drives were performed. During the path planning, the assumed reference velocity of the autonomous vehicle was 3 m/s. However, the actual velocity during the experimental drives was changing between 1.5–4 m/s. All of the experimental drives were done under equal conditions in an enclosed lot on dry asphalt, without vertical slope surface. As the velocity of the autonomous vehicle was relatively low and the vehicle was moving on dry asphalt, active safety systems such as ESC or ABS did not intervene and were not considered during the experimental test drives.

4 Results and Discussion

In Fig. 3, an example of the results of the experimental drives, which were obtained while the autonomous vehicle was performing obstacle avoidance, are presented.

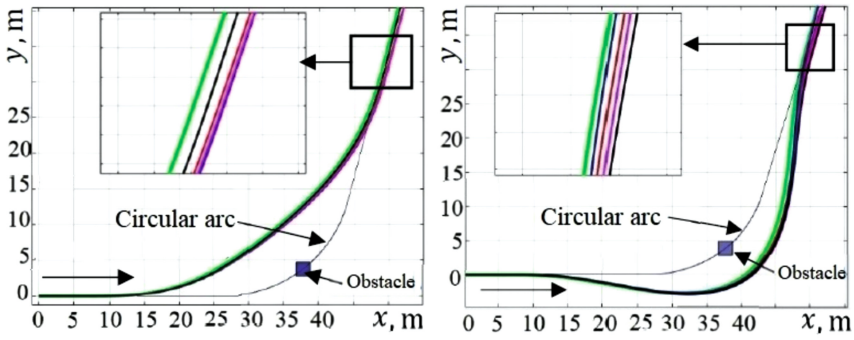

Fig. 3. Examples of the results of the experimental test drives: a) obstacle avoidance by the inner part of the circular arc; b) obstacle avoidance by the outer part of the circular arc.

While considering the results of the almost 200 performed experimental test drives it can be stated that the proposed hybrid path planning approach for the autonomous obstacle avoidance during cornering works properly. All of the planned paths were continuous and technically feasible. Respectively, all of the performed experimental test drives were successful, i.e., in all of the cases the obstacle was avoided. What is more, the performed experimental research shows that the developed combination of the Bézier curve and Rapidly-exploring random trees approaches operates in real-time. The average planning time of the path, intended for avoiding an obstacle in a constant radius

circular arc, was 0.44 s. From the Fig. 3 it can be seen that, during the experimental test drives, there were some autonomous research vehicle movement deviations from the planned paths. The determined average size of the movement deviations in the lateral and longitudinal directions was around 1 m and the average deviation of the yaw angle was around 1^0. However, these deviations can be explained by the relatively inaccurate performance of the controller, which was used in the autonomous research vehicle. Thus, based on the obtained results, an important remark can be made that, after formulating an appropriate dependency between the Bézier curve waypoints, the application of the high order Bézier equations when planning various paths is reliable and the planned path is stable.

5 Conclusions

In this work, a combination of the Bézier curve and Rapidly-exploring random trees approaches was proposed in order to perform path planning and obstacle avoidance during cornering. In the proposed hybrid path planning approach, the Bézier curve was used to plan the curvature of the obstacle avoidance manoeuvre path and the Rapidly-exploring random trees approach was used for the determination of the control points for the Bézier curve. The experimental implementation and analysis revealed that the suggested hybrid path planning approach successfully satisfies the key fundamental requirements of the efficient path planning: the approach is able to perform in real-time (average path planning time – 0.44 s) and the planned path is smooth, safe, continuous and technically feasible. During the performed research, the achieved results allow to state that the proposed hybrid path planning approach is efficient and promising. However, in order to apply the proposed hybrid approach more widely in autonomous vehicles, various improvements and further research are still required.

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Road Safety in Low- and Middle-Income Countries – Analysis and Recommendations

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Abstract. Road accidents continue to be a major cause of death and serious injury for low- and middle-income countries (LMICs). The overall goal of this study is to increase road safety in LMICs by providing them with easier access to knowledge developed by PIARC (World Road Association). The basis of the study was the in-depth analysis of more than 45 PIARC documents with the aim of providing insights to road authorities, operators, planners and other relevant stakeholders into several road safety areas. The PIARC resources were reviewed and analyzed considering eight major road safety areas, based on the Safe System Approach, namely management, data, speed, vulnerable road users, human factors, infrastructure, vehicles and tunnels. This paper summarizes the main challenges identified for each safety area as well as providing a set of recommendations. These findings, while targeted at road transport stakeholders of low- and middle-income countries, can be considered valuable for all countries looking to improve safety on their roads.

Keyword: Road safety · Low- and middle-income countries · Safe System Approach

1 Introduction

Fatalities and serious injuries represent an unacceptable consequence of the road transport system globally. Road accidents continue to be a major cause of death and serious injury for low- and middle-income countries (LMICs). At global level, 90% of road fatalities occur in LMICs, a number – three times higher than in high-income countries [1]. The goal of the PIARC Global Road Safety Knowledge Exchange project is to increase road safety in LMICs by providing road authorities, operators, planners and other relevant stakeholders easier access to a wide depth of knowledge developed by PIARC (World Road Association). The basis of the study was the analysis of more than 45 PIARC technical reports, proceedings of seminars, conferences, case studies, workshops, manuals and webinars. The review considered eight major road safety areas, namely management, data, speed, vulnerable road users (VRUs), human factors, infrastructure, vehicles and tunnels.

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1.1 Safe System Approach

When addressing road safety, the Safe System Approach is one of the most effective methods of addressing fatal and serious accidents on the road network. High-income and low- and middle-income countries alike are encouraged to follow the Safe System Approach in order to achieve both Vizion Zero and global targets of reducing fatalities and serious injuries. The elements of the Safe System Approach are infrastructure, speed management, vehicles and road user behavior [1].

Practitioners from LMICs acknowledge that there is often a lower level of compliance with road rules in most low- and middle-income countries, when compared to HIC. Nevertheless, focusing on improvements in infrastructure and vehicle safety will contribute to providing a forgiving road system for accidents arising from human errors.

2 Methodology

2.1 Low- and Middle-Income Countries

Based on the World Bank classification for countries by income, low- and middle-income countries were defined as low-income countries and lower middle-income countries as shown in Fig. 1.

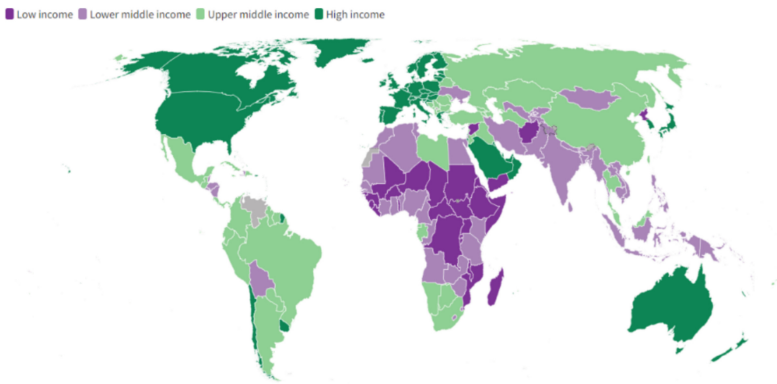

Fig. 1. The world by income 2020. Purple-colored countries designate LMICs considered within this study (Source: [2]) (Color figure online)

2.2 Literature Review Process

To identify and collect the relevant literature, the PIARC knowledge base was reviewed. All the documents are free to access. Reports, case studies, conferences proceedings, seminars, workshops and webinars were considered for the years 2015–2022. Several key words were used to filter the results, including “road safety”, “Safe System approach”, “speed”, “infrastructure”, “vulnerable road users” and others.

The review process consisted of two steps: (i) a brief screening to identify the most relevant documents and (ii) an in-depth review of the filtered documentation.

This resulted in more than 60 online resources consisting of proceedings, reports, webinars, case studies etc. In addition, the online PIARC Road Safety Manual [1] and the PIARC Road Tunnels Manual [3] were reviewed, as they also include valuable information targeted specifically at LMICs. After the first step, 18 documents were considered out of scope, leaving approximately 45 resources for a comprehensive analysis.

3 Results and Discussion

3.1 Management Strategy/Policies

While 87% of LMICs have established a lead agency to guide the national road safety efforts, 37% of low-income and 25% of middle-income countries do not have a national strategy for road safety [1]. In many LMICs, the organizational structure of the management system may suffer from shortcomings, such as lack of leadership, lack of political priority, lack of funding and missing expertise [4, 5].

In order to ensure road safety management and to build road safety expertise, the following actions were identified:

- Develop a strong lead agency, with a set of local guidelines and regulations.
- Develop a robust road safety data system.
- Develop university road safety programs at bachelor and master level.
- Connect to regional road safety observatories and international networks of universities.
- Build centers of road safety excellence to develop road safety management and research capacity at national level.

3.2 Data

Efforts to reduce accidents in low- and middle-income countries are hindered by the lack of accurate crash and fatalities data. A wide range of relevant data types are needed to increase road safety, including road condition and maintenance-related data, traffic data, large scale data on road users' behavior, road safety related data and others. Furthermore, data quality is of high importance, as misleading data can lead to wrong conclusions and ineffective decisions being made [1, 6].

To address these challenges, the following recommendations can be taken:

- Better access to data on the effectiveness and costs associated with specific measures and investments can lead to further improvements and support for a broader implementation of road safety solutions.
- Training of data entry staff and police, improvements in the data collection tools and methods (e.g., crash report documents and devices, sensors) and quality assurance measures can contribute to the enhancement of data quality and reliability.
- Enforcement measures to ensure reporting of accidents, e.g., by making it a legal requirement, should be employed.

3.3 Speed

Speed is considered one of the most important risk factors of road accidents, influenced also by behavior issues such as slow reaction time, fatigue, difficulty in understanding complex traffic situations and "crowd-behavior". An increase of 15% over the mean speed leads to an 88% increase in road accident fatalities [7, 8].

The tackle speed-related challenges, the safety recommendations are:

- Speed limits must be credible, homogenous, consistent, visible and maintained over time to increase driver compliance.
- Speed management requires the planning and designing of appropriate road layouts and networks to ensure safe travel speeds.
- Solutions such as speed bumps, lane narrowings, new pedestrian crossing solutions and chicanes are low-cost essential techniques for LMICs.
- The potential benefits of speed control systems such as Intelligent Speed Assistance (ISA) should be explored for cars, motorcycles and motor-tricycles.

3.4 Vulnerable Road Users

Developing countries have a greater variety of traffic users involving slow-moving and vulnerable non-motorized road users as well as powered two-wheelers with fast-moving motorized vehicles. Moreover, VRU fatalities are higher in LMICs due to lack of resources to maintain safe infrastructure, poor post-crash response and unsafe user behavior due to lack of training and education [4, 5, 9].

The following measures have been identified for increasing VRU safety:

- A paradigm shift from designing roads for cars to focusing on vulnerable road users is needed. Road design should include a self-explaining and failure-forgiving road accounting for the needs for all road users.
- Measures to enhance VRU safety along road sections include wider and paved shoulders, proper crossing facilities, separated footpaths and lanes for cyclists/mopeds and appropriate road lane widths.
- To ensure compliance, a combination of communication and education campaigns and enforcement measures should be employed.

3.5 Human Factors/Behavior

Despite progress in improving legislation across key human behavior risk factors – speeding, drink-driving, helmet use, seatbelt use and driver distraction – enforcement remains a major challenge in most countries, particularly LMICs [1, 4, 10].

To tackle the human behavior related challenges, several recommendations can be provided:

- The road transport system needs to anticipate and accommodate for human errors and prevent fatalities and serious injuries. This includes road infrastructure that facilitates safe behavior such as clear road signage, traffic calming designs and physical separation of road users.
- Road safety evaluations and inspections should be made by an interdisciplinary team including human factors and behavior experts.

- Developing countries should consider strategies that haven been successfully implemented in other countries. This might include the adoption of technologies such as alcohol interlocks and seat-belt warning systems.
- Legislative measures such as setting speed limits, establishing blood alcohol limits and mandating the use of protective equipment should be enacted and enforced.

3.6 Infrastructure

Road infrastructure often represents the most significant factor contributing to the severity outcome of an accident. Challenges related to the successful implementation of infrastructure measures include cost, design issues, maintenance and acceptance/compliance issues [1, 4, 5, 7, 11].

The ensuing road infrastructure recommendations can be pinpointed:

- Clear and well-defined policies related to the implementation of Safe System infrastructure are needed to drive road safety improvements.
- Risk assessments should be performed systematically by road authorities for the whole network when possible, as well as at known high-accident locations.
- Developing countries should prepare for automation by implementing road infrastructure improvements related to pavements, lane markings and visibility of traffic signs, leading to safer roads for vehicles at all levels of automation.

3.7 Vehicles

In many LMICs, vehicle safety is not sufficiently regulated through design standards or maintained through mandatory vehicle inspection schemes. A particular challenge is related to overweight vehicles, where overloading for cost savings and lack of enforcement leads to increased safety risks [1, 12, 13].

Vehicle safety can be improved through the following measures:

- The adoption of high-quality harmonized safety standards is necessary, through mandatory certification and registration systems for new and used vehicles, based on safety requirements and combined with routine inspections.
- A combination of passive safety measures and systems such as electronic stability control could provide a strong improvement in vehicle safety.
- With regards to automation, LMICs should focus on deployment of the most mature safety-related services and starting with small pilots.

3.8 Tunnels

The consequences of a serious accident in a tunnel environment are potentially more severe than on the open road. Tunnels require specific approaches to identify and evaluate the need for improvements [3].

The recommendations for improving road safety in tunnels are:

- The design of road tunnels and their operation should consider human factors; the measures implemented for safety should be easily understood and adopted by the users.

- Specific and appropriate training is necessary, as well as establishing optimum protocols and post-crash intervention sequences.
- Risk assessment can be used to address and evaluate the safety features of a tunnel system.

4 Outlook

The road transport system needs to anticipate and accommodate for human errors. Building awareness of the Safe System Approach's application is a crucial step for low- and middle-income countries. While this study was undertaken for improving road safety in LMICs, the recommendations and observations identified can be considered relevant and valuable for all countries aiming to improve safety on their roads.

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Empirical Analysis of Risk Factors Associated with Two-Lane Rural Road Crashes Under Mixed Traffic Conditions

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Abstract. Road safety continues to be a major concern in low-middle-income countries (LMICs). In India, approximately 37% of road crash fatalities occur on rural two-lane roads. Segmenting the roadways into sections with an appropriate segment length is the initial and crucial step in statistical crash analysis. The existing segmentation methods depend on individual experience and engineering judgment. This investigation aims to identify critical crash contributing factors affecting fatal crash occurrence on rural two-lane roads, which have been discretized into segments of an appropriate length using power spectral analysis. The study methodology is based on power spectral analysis of crashes in a one-dimensional Spatial Frequency Domain. Based on this finding, the power spectral density and power spectral percentage are calculated in order to determine the power spectral segment length, also termed Optimal Segment Length (OSL). This study utilized three years (2017–2019) of fatal crash incidents and several Negative Binomial (NB) model extensions with OSL to assess the impact of roadside infrastructure on fatal crash occurrence on two rural two-lane National Highways (NH) in Haryana, India. The crash analysis incorporated explanatory variables such as roadway geometric features, traffic characteristics, roadside Points of Interest and population. The model results showed that the Random Parameter Negative Binomial (RPNB) model and the Correlated Random Parameter Negative Binomial (CRPNB) model performed better than the standard NB model. The model findings indicated that variables such as the presence of fuel stations, eateries, culverts, and minor access points along highways were identified as significant risk factors for fatal crashes.

Keywords: Exploratory Analysis · Road Safety · Optimal Segmentation

1 Introduction

Every day, Road Crashes (RCs) result in more than 3700 fatalities, ranking them as the eighth leading cause of mortality globally [1]. Moreover, the mortality rate associated with RCs is three times greater in LMICs compared to high-income countries. Being

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LMIC, India is no exception, where RCs account for approximately 40% of fatalities, and RC-related injuries are the second leading cause of death among young (30–34 years) people. The Indian Road network is the world's second-largest network, spanning a distance of 4.26 lakh kilometres. Two-lane rural roads account for approximately 48% of the total road network [2]. The safety performance evaluation of two-lane roads in the country holds great significance due to relatively substandard road design geometrics and inseparable as well as heterogeneous traffic from two opposing directions. These roads have a share of 37% of total road crash fatalities [3].

Segment-oriented road safety analyses are mainly based on widely accepted assumptions that road crashes are not completely randomly distributed; rather, these are significantly influenced by traffic characteristics, roadside infrastructure and geometric design attributes. In road safety literature, researchers have used fixed-length, homogenous-length and dynamic-length approaches depending upon the research objectives, nature of available data, and analyst's preference [4]. Each approach has its advantages and disadvantages. Despite this fact, the researchers decide the segment length based on engineering judgment, their expertise, and their suitability to research objectives. Essentially, determining an appropriate minimum and maximum possible segment length is not immediately obvious and lacks a consensus among road safety experts. Hence, researchers have had a long-standing concern over the selection of an appropriate segmentation approach and optimal segment length for conducting crash analysis.

Therefore, this study aims to identify critical crash risk factors influencing fatal crash occurrence on that road, which has been discretized into segments of an optimal length using power spectral analysis. This study has utilized the NB count data model and its extensions, such as RPNB and CRPNB models, to account for both structured and unstructured heterogeneities in the dataset.

2 Study Area, Data Collection and Methodology

The study investigated fatal crash occurrences on two rural two-lane NHs, i.e., NH 334B and NH 709, in the state of Haryana. The data related to fatal crashes was obtained from the Haryana Vision Zero (HVZ) database, a flagship road safety program launched by the Transport Department of the Government of Haryana. The traffic volume data was compiled using a functional mobility plan prepared by the National Capital Region Planning Board (NCRPB), as well as through field surveys. The operating speeds of vehicles were collected utilizing a portable LASER technology-based speed and ranging device during field surveys. The roadside population data was retrieved from the Meta platform managed by the Center for International Earth Science Information Network (CIESIN), Columbia University. The data regarding Point of Interest (PoI), including the number of fuel stations and eateries, as well as culverts and the number of minor access points, is collected through field surveys and using Google Earth.

2.1 Optimal Segment Length Determination

The study methodology relies on the spectrum analysis of crash density within the Spatial Frequency Domain (SFD) framework since it can differentiate between probabilistic

factors (i.e., weather conditions, road user behaviour) and deterministic (i.e., road design characteristics) by examining the frequency components in the spatial data.

Crashes primarily occur in three-dimensional systems. However, projecting crash data into one-dimensional space provides an easy, viable, and practical method for aggregating crash data on continuous linear features of concerned highways. The output from quantification of crash data, which is projected into 1-D space, is known as Crash Density Sequence (CDS). The CDS illustrates how the crash density changes over the distance along a linear feature. This study utilizes the Kernel Density Estimation (KDE) approach to quantify crash data due to its better flexibility and robustness in estimating crash density. The SFD representation of the CDS shows how the crashes are distributed across each spatial frequency band for a specific range of frequencies. The Discrete Fourier Transformation (DFT) technique converts CDSs from a spatial domain to the SFD.

Furthermore, this study utilizes the periodogram, a non-parametric approach for estimating the Power Spectral Density (PSD) and examines the distribution of energy across various spatial frequencies in a CDS. A CDS comprises both systematic and random components. The systematic components are rationally related to low-frequency SFD components and specific spatial locations, while random components correlate with high-frequency components and are spatially independent. Therefore, it is hypothesized that a corridor's CDS has significant power in low-frequency bands. The PSD plots, as shown in Fig. 1, validate the hypothesis that the CDS of a corridor has a major Power Spectral Percentage (PSP) concentrated in these bands [5].

The prevalence of power spectral concentration in low-frequency bands suggests that Power Spectral Segment Length (PSSL), also termed OSL, is an appropriate length that can effectively capture the primary components in low-frequency bands to meet the requirements of safety analysis assignments. Mathematically, it can be represented as

$$L = \frac{1}{2f} \tag{1}$$

where L is the effective maximum segment length, and f is the upper limit of the frequency band. The methodology is explained using data from the NH 334B highway. Considering 100 m and 250 m segments as a baseline, PSP was estimated for the upper-frequency band where the signal dies, and accordingly, PSSL was obtained for 250 m and 500 m using Eq. (1), respectively. From Fig. 1. and Table 1, the analysis revealed that approximately 185 m and 230 m segment lengths were the OSL corresponding to the NH 334B and NH 709, respectively. These optimal segment lengths were further used to develop statistical models and identify the critical crash risk factors associated with rural highways.

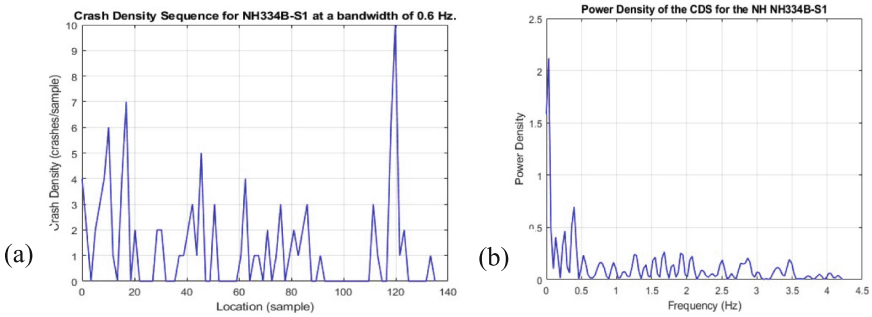

Fig. 1. (a) The CDS and the corresponding, (b) PSD for the NH 334B at 0.6S-Hz.

Table 1. PSSL for selected highway sections

HW	L	CC	PSP(%) (0–2.2 S-Hz/0–2.14 S-Hz) (500 m/250 m)	PSSL (m) (500m/250m)	PSP(%) (0–2.2 S-Hz/0–2.14 S-Hz) (250 m/100 m)	PSSL(m) (250 m/100 m)
NH 334B	53	115	97.01	185.40	93.0	187.60
NH 709	33	102	96.30	227.63	99.7	233.39

Note: HW – Highway, L-Length (km), CC-Crash Count

2.2 Crash Data Analysis

The present research has attempted to investigate the impact of traffic, roadway geometric design, and roadside PoI features on fatal crashes occurring on two distinct two-lane NHs, i.e., NH709 and NH 334B, in Haryana, India. Considering the OSL corresponding to each NH, crash frequency models were developed to investigate the factors contributing to crashes. Two different modelling approaches, namely RPNB and CRPNB models, were developed to address unobserved heterogeneity in the crash data. The two models were compared with the standard NB model. Tables 2 and 3 show the statistics of all three models developed in the study.

Considering the sign convention of the coefficients, the statistical significance of the variables, AIC, and Chi-square values, the CRPNB model performs best in explaining the crash data. However, the variables describing the crash data were found to be different for the two highways. For NH 334B, the presence of fuel stations (P_F), number of access points (M_A), presence of eateries (P_E), culverts (P_C), log of two-wheelers' (2-W) and bus speed were positively associated with the crash data and are statistically significant. Whereas in the case of NH 709, pavement width (P_W), M_A, and log of population were positively associated and statistically significant in explaining the crash data.

Table 2. Model estimation results for fatal crashes on NH 334B

Variables	NB	RPNB	CRPNB
	Coeff	Coeff.(Std. Dev)	Coeff. (Std. Dev.)
	Fixed Parameters		
P_W	−3.32	−3.79	−2.35
P_F	3.09	1.44***	1.47***
P_E	0.38***	0.93***	0.75***
P_C	0.94***	1.01***	1.14***
M_A	0.47***	0.61***	0.58***
Log of AADT	−6.95	−1.06	−2.02
	Random Parameters		
Log of Population		0.05** (0.601)***	0.17** (0.109)***
Log of 2-W Speed		7.81* (0.006)***	8.75** (0.013)***
Log of Car Speed		−2.21*** (0.094)***	−1.53*** (0.390)***
Log of Bus Speed		2.19 (0.174)***	4.09 (0.024)***
AIC	508.74	460.30	451.94
No. of Parameters	6	14	17
CRPNB vs NB model		***CRPNB vs RPNB model***	
Degree of Freedom	8	3	
Chi-square	24.79	18.62	
Critical Chi-square	15.507	7.815	

Table 3. Model estimation results for fatal crashes on NH 709

Variables	NB	RPNB	CRPNB
	Coeff	Coeff.(Std. Dev)	Coeff. (Std. Dev.)
	Fixed Parameters		
P_W	2.95***	2.67***	2.53***
P_F	2.54	0.37	0.16
P_E	0.26***	0.26**	0.25*
P_C	0.23	0.19	0.25
M_A	0.22***	0.21***	0.21***
Log of AADT	−2.43	−2.44*	−2.45*

(*continued*)

Table 3. (*continued*)

Variables	NB	RPNB	CRPNB
	Random Parameters		
Log of Population		0.33*** (0.005)***	0.36*** (0.024)***
Log of 2-W Speed		−1.65*** (0.851)**	−0.30** (0.056)**
Log of Car Speed		1.86*** (0.576)*	0.55*** (0.390)***
Log of Bus Speed		0.72*** (0.174)*	0.95*** (0.024)*
AIC	386.64	380.12	378.32
No. of Parameters	6	14	17
CRPNB vs NB model		***CRPNB vs RPNB model***	
Degree of Freedom	8	3	
Chi-square	32.48	26.62	
Critical Chi-square	15.507	7.815	

Note: P_W = Pavement width; P_F = Presence of Fuel Station; P_E = Presence of Eateries; P_C = Presence of culverts; M_A = Minor access locations. "***", "**", and "*" indicate that means and standard deviations (Std. Dev.) are significant at 1%, 5% and 10% levels, respectively

3 Conclusions

This study has investigated the impact of traffic, roadway geometric design, and roadside PoI features on crashes occurring on two distinct two-lane national highways (NH 709 and NH 334B) in Haryana, India. Power spectrum analysis of crash density within the SFD framework was used to identify the PSSL or OSL. The PSSL analysis found 185m and 230m segment lengths as the optimal segment lengths corresponding to NH 334B and NH 709, respectively. Considering the optimal segment length, crash frequency models were developed, and it was found that CRPNB performed better than the standard NB and RPNB models. The first interesting aspect of this study is that the segment lengths were different for both highways. Second, the variables explaining the crash data were different for the two highways. In future, researchers may consider crashes other than fatal in the analysis. Future studies can include a comprehensive evaluation of the predictive capabilities of random-parameter count models in contrast to different methodologies, such as deep learning methods.

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Road Deaths in French Overseas Territories

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Abstract. In France, road accidents in overseas territories have been little studied. Relevant data for Overseas France are collected late and very partially. Although overseas territories account for only 3% to 4% of road traffic injuries for the whole of France, their specific features deserve highlighting. While mobility, and therefore exposure to road risk, is lower in Overseas France, road risk is just as high, and in some areas significantly higher than in Metropolitan France.

Disparities among the overseas territories deserve as much attention as those observed between Metropolitan and Overseas France.

The differences in density of these territories do not explain everything. Each territory has its own specificities, including in relation to vulnerable populations and issues in terms of road safety. Thus, if vulnerable road users remain a major issue in these territories, the motorization of the population and the ageing of the population reveal new road safety issues. Further sociological and epidemiological studies should be carried out to explain these differences. However, the hypothesis of a benefit of a better social cohesion on these territories may be studied. If this hypothesis were to be corroborated by further analysis, it could also serve to highlight the differences in the level of road safety between peri-urban areas in France.

Keywords: Road Traffic Accident · Disparities · Overseas Territories

1 Introduction

Generally, the effects of social inequalities on road risk are studied using two approaches: via studies on socioeconomic status (SES) of populations of road users or according to the socio-economic characteristics of the territories. In this study, we choose the territorial perspective due to lack of data on the SES of the populations.

In metropolitan France, territorial disparities in road risk were studied in terms of fatality rates. However, no study has addressed the specific case of the Overseas Territories where the quality of the data is less good (Aptel et al. 1999). In this paper, we will study the differences in road mortality between metropolitan France, Corsica and the overseas departments and regions (Guadeloupe, Martinique, Guyana, Reunion).

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2 Materials and Methodology

2.1 Presentation of France, Its Overseas Departments and Regions

The national statistical institute provide a variety of information about the study regions, including their social, economic and demographic characteristics. There are other notable differences between the Overseas Departments & Regions (Guadeloupe, Martinique, French Guiana, Réunion) and mainland France. The unemployment rate is about 8% in Metropolitan France, while it is nearly twice as high in the Overseas Departments & Regions (15% in Martinique, 21% in Réunion). The median household disposable incomed income in mainland France is €1,750 versus €1,360 in Martinique, dropping to €920 in French Guiana. The household motorization rate in mainland France is 81%, compared to 73%, 72%, 70%, and 58% in Martinique, Réunion, Guadeloupe, and French Guiana, respectively.

In order to study the road accident risk factors, we used the French database of road traffic injuries of the National Road Safety Observatory (ONISR 2019). This data is collected every year in France from reports filed by police when they are called to the scene of an accident. While not exhaustive, these police files nevertheless provide a good overview of road accidents in France.

In Fig. 1, we show a map of fatality rates in both Metropolitan France and the overseas departments & regions (Guadeloupe, Martinique, French Guiana, Réunion, and Mayotte), as well as two Overseas Communities (French Polynesia and New Caledonia). We used the free QGIS software to create this map based on INSEE data.

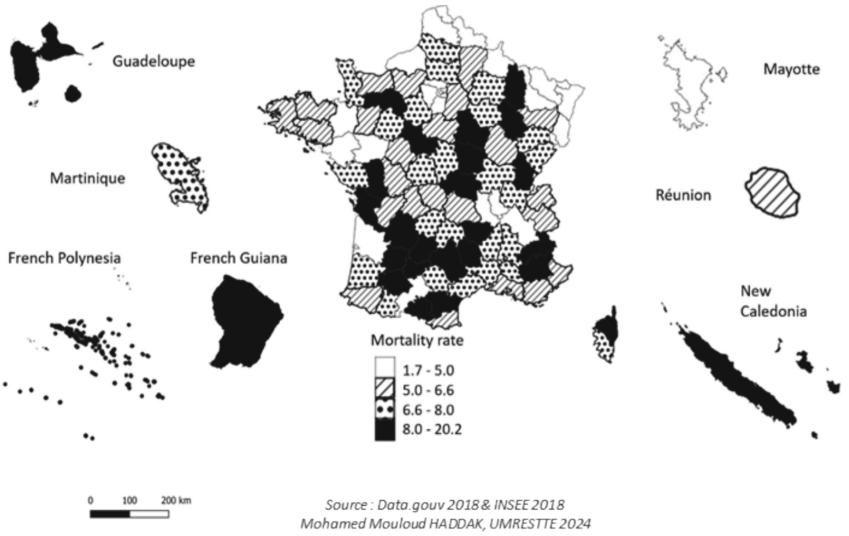

Fig. 1. Map of average mortality rates (number of road accident deaths per 100,000 inhabitants) recorded between 2014 and 2018 (interquartile ranges)

We define 'mainland France' as the European part of France that excludes the Mediterranean French island of Corsica. In summary, the differences in the level of

road safety are as high between the regions of mainland France as between the overseas territories (see Fig. 1).

2.2 Statistical Analysis

Table 1. Odds-ratios of individual risk factors of killed versus injured by study region between 2014 and 2018.

Individual risk factors		Mailand Fr OR [IC 95%]	Corsica OR [IC 95%]	Guadeloupe OR [IC 95%]	Fr Guiana OR [IC 95%]	Martinique OR [IC 95%]	Reunion OR [IC 95%]
Gender	Female	0.59 [0.58–0.60]	0.56 [0.44–0.71]	0.50 [0.41–0.63]	0.56 [0.43–0.73]	0.48 [0.36–0.64]	0.48 [0.38–0.61]
	Male	1	1	1	1	1	1
Age	0–13 y.o	0.49 [0.46–0.52]	0.47 [0.21–1.04]	0.35 [0.22–0.56]	0.74 [0.47–1.15]	0.25 [0.11–0.59]	0.19 [0.11–0.33]
	14–17 y.o	0.56 [0.53–0.59]	0.62 [0.36–1.05]	0.44 [0.29–0.66]	0.66 [0.41–1.08]	0.79 [0.48–1.31]	0.48 [0.32–0.72]
	18–24 y.o	0.77 [0.75–0.79]	0.89 [0.66–1.21]	0.53 [0.41–0.67]	0.93 [0.68–1.28]	0.79 [0.58–1.06]	0.61 [0.48–0.79]
	25–34 y.o	0.78 [0.76–0.80]	0.94 [0.70–1.27]	0.65 [0.51–0.82]	0.82 [0.60–1.12]	0.74 [0.54–1.00]	0.72 [0.56–0.92]
	35–44 y.o	0.82 [0.79–0.84]	0.96 [0.70–1.32]	0.57 [0.43–0.74]	0.82 [0.58–1.16]	0.64 [0.45–0.91]	0.85 [0.65–1.11]
	65–74 y.o	1.69 [1.63–1.76]	1.61 [1.07–2.43]	1.45 [1.02–2.05]	1.98 [1.16–3.37]	1.20 [0.73–1.97]	1.71 [1.17–2.51]
	>74 y.o	3.33 [3.22–3.45]	2.76 [1.83–4.14]	2.61 [1.79–3.79]	0.94 [0.32–2.75]	3.23 [2.01–5.17]	1.77 [1.09–2.89]
	45–64 y.o	1	1	1	1	1	1
Road users	M2W >50 cm^3	1.79 [1.74–1.84]	2.62 [1.99–3.45]	2.77 [2.15–3.55]	2.17 [1.44–3.27]	2.68 [2.03–3.56]	2.96 [2.23–3.93]
	Moped < 50 cm^3	1.32 [1.27–1.37]	1.69 [1.08–2.63]	2.44 [1.87–3.18]	1.51 [1.08–2.12]	1.64 [1.16–2.33]	2.19 [1.64–2.93]
	H.G.V	1.30 [1.22–1.40]	1.86 [0.96–3.62]	0.50 [0.15–1.66]	0.28 [0.10–0.81]	0.54 [0.13–2.27]	0.75 [0.17–3.24]
	Pedestrians	3.26 [3.04–3.50]	6.65 [2.98–4.86]	3.18 [1.95–5.20]	5.72 [3.18–0.29]	1.78 [1.00–3.17]	9.92 [5.95–16.54]
	Car passenger	0.87 [0.84–0.90]	1.42 [1.03–1.94]	1.05 [0.79–1.39]	0.93 [0.64–1.36]	1.24 [0.87–1.76]	1.38 [1.00–1.91]
	L.G.V	0.94 [0.89–0.99]	1.03 [0.60–1.75]	0.94 [0.56–1.57]	0.89 [0.51–1.55]	0.90 [0.41–1.99]	1.13 [0.62–2.05]
	Cyclist	1.74 [1.65–1.82]	3.80 [2.04–7.10]	2.78 [1.88–4.12]	2.03 [1.30–3.19]	1.89 [1.02–3.49]	3.14 [2.09–4.71]
	Car driver	1	1	1	1	1	1

(*continued*)

Table 1. (*continued*)

Individual risk factors		Mailand Fr OR [IC 95%]	Corsica OR [IC 95%]	Guadeloupe OR [IC 95%]	Fr Guiana OR [IC 95%]	Martinique OR [IC 95%]	Reunion OR [IC 95%]
Journey	Work	0.80 [0.78–0.82]	0.99 [0.73–1.33]		0.89 [0.63–1.26]	0.67 [0.46–0.97]	0.79 [0.58–1.06]
	Free time	1	1		1	1	1

Individual risk factors (see Table 1): Few gender and age differences in fatality risk were observed between regions. An age gradient for fatality risk is observed in mainland France, Guadeloupe, and Réunion. However, there are regional differences in the risk for types of users: the largest differences are observed for heavy goods vehicles, which have a higher risk in mainland France (OR: 1.30 [1.22–1.40]), while heavy goods vehicle users have a lower risk in French Guiana (OR: 0.28 [0.10–0.81]). A similar phenomenon was observed among light vehicle passengers, with an increased risk in Corsica (OR: 1.42 [1.03–1.94]) and Réunion (OR: 1.38 [1.00–1.91]), and a lower risk in mainland France (OR: 0.87 [0.84–0.90]). Other, more subtle differences were also observed. Users of two-wheeled motorized vehicles (engine capacity $> 50\ cm^3$) have a lower risk in mainland France than in other regions. For mopeds (engine size $< 5\ 0cm^3$), the risk of death is slightly higher in Guadeloupe and Réunion. For cyclists, the risk is higher in Corsica, Guadeloupe and Réunion. Finally, for pedestrians, the odds ratios are very high, especially in Réunion (OR: 9.92 [5.95–16.54]). There was no great difference between regions for the "reason for journey" variable.

Table 2. Odds-ratios of some contextual risk factors of killed versus injured by study region between 2014 and 2018.

Contextual Risk Factors		Mainland Fr OR [IC 95%]	Corsica OR [IC 95%]	Guadeloupe OR [IC 95%]	Fr Guiana OR [IC 95%]	Martinique OR [IC 95%]	Réunion OR [IC 95%]
Road	Main	1.86	4.11	1.69	3.59	2.90	2.75
Type	Roads	1.79–1.93	2.80–6.02	1.34–2.13	2.62–4.92	1.99–4.20	2.20–3.44
	Regional	2.18	2.43	1.21	2.06	2.14	1.75
	Roads	2.12–2.24	1.63–3.60	0.95–1.54	1.52–2.81	1.48–3.11	1.37–2.25
	Communal road	1	1	1	1	1	1
Luminosity	Night	1.64 1.60–1.67	2.07 1.66–2.58	1.50 1.28–1.76	1.52 1.23–1.89	1.66 1.36–2.03	2.32 1.95–2.75
	Day	1	1	1	1	1	1
Area	Rural	3.20 3.12–3.28	2.52 1.97–3.24	2.10 1.75–2.51	2.88 2.22–3.73	1.55 1.25–1.91	1.77 1.47–2.13
	Urban	1	1	1	1	1	1

Contextual risk factors (see Table 2): For the environmental variables, it can be seen that night-time accidents are more fatal than daytime accidents, especially in Corsica and Reunion. As some territories do not have motorways, we have grouped in a same road category, main roads, the motorways and the national roads. This is why the risk is higher than usual on motorways, like in French Guiana (OR: 3.59 [2.62–4.92]). Regarding location, accidents occurring in rural areas were more fatal in mainland France than in the other regions (OR: 3.20 [3.12–3.28]).

3 Discussion

Mainland/Metropolitan France: We have seen that the individuals most at risk of dying or being seriously injured in a road accident in mainland France are the elderly (over 65 years old). Indeed, the proportion of elderly people is higher mainland than in overseas. However, young people aged 18–34 years accounted for 31.2% of road deaths in France in 2018 (ONISR 2019), and road accidents represent the leading cause of death in this age group. Regarding users at risk, we noted that users of heavy trucks, motorized two-wheelers, as well as cyclists and pedestrians are at greater risk of death. These results are consistent with the fact that pedestrians, cyclists and motorcyclists are the least protected road users in accidents, and therefore the most vulnerable. For heavy goods vehicle users, the severity of accidents could be explained by the working conditions of heavy goods vehicle drivers which lead to reduced alertness (drowsiness and fatigue).

Regarding environmental conditions, we found a higher casualty risk for accidents occurring at night and in rural areas. This confirms the results of a study of motor vehicles and motorcycles in Taiwan (Li et al. 2009), where accidents occurring at night or at dusk/dawn are more likely to result in fatalities than accidents occurring during the day. Another study of cyclists showed that nighttime crashes were more severe, as were crashes in rural areas with higher speed limits (Boufous et al. 2012).

Réunion: In the study of risk factors for road accidents, we found that Réunion is the overseas territory with the most similarities to Metropolitan France. However, the socio-economic characteristics of Réunion are very different, with a median disposable household income that is lower than in Metropolitan France and an unemployment rate that is twice as high. A study carried out in the Cook Islands revealed social and cultural differences that could explain the higher rate of road accidents (Denny et al. 2016). Indeed, 10% of the teenagers interviewed stated that they had already had a road accident, which the authors explained by the fact that they did not wear seat belts, as well as by a lack of restrictions on children or on use of mobile phones while driving.

French Antilles (French West Indies): Guadeloupe and Martinique, sometimes referred to as the French Antilles or French West Indies, have a different profile from Réunion and Metropolitan France. Studies have shown that tourism has an impact on road accidents on islands in general (Petridou et al. 1997; Rosselló and Saenz-de-Miera 2011). Some tourists drive on a different side of the road in their country of origin than that of their tourist destination, and this can result in error and accident. It could be interesting to take into account the number of tourists, as well as the exposition to road risk, in future studies.

French Guiana: French Guiana is the overseas department with the most different profile from Metropolitan France, in terms of both road accidents and socio-economic factors (the median disposable household income in French Guiana is among the lowest of the overseas territories studied here). Unlike other overseas departments, French Guiana is not an island. This large territory is on the northeast coast of South America. Social and cultural differences could explain the differences observed with Metropolitan France and the other overseas departments. However, studies of these territories are rare. Taking such characteristics into account in future analyses could provide a better understanding of their road risks.

4 Conclusion

Accident data for Overseas France are partial, brief and sometimes unavailable (e.g., New Caledonia). They do not allow a comparative analysis with Metropolitan France for all risk factors, in particular those relating to the casualties: their socio-professional category, their reasons for traveling and their risk behaviors. There are justifiable doubts about the quality and completeness of data collected. Similarly, data relating to mobility practices are very summary and cannot be used here. It is nonetheless noteworthy that despite much lower mobility, the overseas territories have a higher risk of serious accidents than Metropolitan France (Bouaoun et al. 2015). Overall, road safety is worse in the overseas territories than in Metropolitan France, in terms of road deaths. There are also significant disparities in road safety between these overseas territories. At particular risk are the pedestrians and the motorized two-wheelers. This accident profile of the overseas territories seems to lie between those of middle-income countries and those of low-income countries. Efforts must be made to collect the same information on accidents in Overseas France as in Metropolitan France, and within the same time frame. This would allow more comprehensive analyses.

More extensive comparative epidemiological studies would make it possible to better highlight the risk factors specific to each context. It would improve our understanding of differences between Réunion and other territories and verify whether they can be explained by a higher standard of living or by a better social mix. Sociological and psychosocial studies would make it possible to understand the behavior and attitudes of road users (Haddak et al. 2016) and their perception of road risk. Results of these studies could shed light on the situation in working-class suburbs and add to our understanding of their accident rates. It is difficult to assess the impact of new modes of travel, such as individual electric scooters, on the level of road safety, given the lack of precise data. Similarly, it is difficult to assess the impact of socio-economic conditions and new forms of employment (self-employed, gig economy, etc.) on road risk since the socio-occupational categories of victims are not provided.

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Future Crash Configurations: Analysis of the Impact of Future Vehicles in Mixed Traffic

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Abstract. Within the EU-funded SALIENT project (https://www.salient-project.eu), an analysis of crash configurations of new and future vehicle fleets (including heavier SUV-type vehicles and autonomous vehicles) has been developed. The future crash scenarios identified will be translated into relevant scenarios for further simulations and crash tests. The work laid out in this paper contains the results of a detailed literature and state-of-the-art review and a data analysis of relevant international datasets, to then propose considerations for future crash configurations and scenarios. These considerations explore in detail real-world data of crashes involving CCAM and automated vehicles. The results of this research aim to serve as a basis for a safe transition from today's user-driven vehicles to SAVs (semi-autonomous vehicles) and AVs (autonomous vehicles) in mixed traffic, to maximise compatibility between vehicles.

1 Introduction

The characteristics of privately owned cars are changing rapidly: not only are new models larger [1], but also heavier and with time [2], they are also equipped more frequently with higher levels of Advanced Driving Assistance Systems (ADAS) [3], which automate and connect the vehicles. This change needs to be reflected in the considerations of safety research for private vehicles, especially the considerations for collision constellations and crash scenarios in an updated vehicle traffic mix. This paper aims at introducing different factors, which may influence future crash scenarios and gives recommendations for safety designs of vehicles for car manufacturers, Original Equipment Manufacturers (OEMs), crash test houses and governments.

This piece of research is part of the SALIENT project [4], which seeks in designing and validating a new design for the Front-End Structures (FES) of cars to future-proof them by creating an alternative which is safer, lightweight, circular, smart and can predict and counter-act on crashes before they happen.

2 Methods

In order to ensure a detailed analysis of the state of the art and future projection of vehicle fleets, a plethora of sources were consulted and analysed. The following approach was applied to abstract the most common crash scenarios between Autonomous Vehicles

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(AV, with advanced ADAS systems) and Sport Activity Vehicles (SAV, representing the trend towards larger and heavier cars). The following methodology has been followed to gather insight and data on both vehicle types in sufficient number and detail:

1. Review of pre-existing and on-going research & development projects (namely OSCCAR [5] and SAFE-UP [6]);
2. Review of existing and open databases of mixed traffic accidents (namely the California Department of Motor Vehicles (DMV) collision reports, USA [7], STATS19, UK [8], RAIDS, UK [9], iGLAD, SE [10], GIDAS, GER [11], VOIESUR, FR [12]);
3. Filtering, cleaning, sorting and exploitation of data in terms for passenger safety of AVs;
4. Study of influence of environmental impacts (namely vehicle weight, electrification of fleets).

3 OSCCAR and SAFE-UP Projects

This paper builds on two pre-existing EU-funded projects. Before presenting the most important findings of these projects on the current paper, it is important to also highlight their limitations, which was complimented by the further analysis. Both projects used data stemming from both real-world datasets and simulations, which is based on the assumption of linear impact velocities. Only a limited number of datasets are openly available, and the data is complex and difficult to interpret, larger datasets over longer periods will be required. Sophisticated filters were needed to create simulations which include abstracted data such as crash angles or overlaps. The datasets varied considerably between countries, which led to differences of up to 26% in the accuracy of results, demonstrating a high heterogeneity of data.

OSCCAR identified gaps of the existing accident scenario catalogue, with a focus on the gradual introduction of ADAS and AV into the average vehicle fleet mix on motorways, urban and rural roads. A market penetration of SAVs was estimated at 3% by 2025 and 66% by 2050, which is one of the baselines applied to our analysis. The project demonstrated that the number of crashes can be reduced, although the frequency of crashes at intersections (which ADAS systems are particularly unfit for) increased from 42% to 57%.

SAFE-UP analysed real-world data of car-to-car, car-to-Heavy Goods Vehicle (HGV) and car-to-Vulnerable Road User (VRU) encounters. HGV with a total weight $\geq$ 3.5 tons are disproportionally often involved in heads-on crashes in urban settings. Several different configurations can be adopted from the project findings, especially those involving a mix of light and heavy vehicle cases.

4 Databases and Data Analysis

National databases were also consulted, although many of them were excluded due to a lack of accuracy in the data collected, a statistically insignificant number of data entries or lack of documentation of the parameters per crash. The most accurate and therefore valuable to the data analyses is the openly available data of the DMV in California, US and the National Highway Traffic Safety Administration (NHTSA). This data has been

extrapolated from the rest of the available data to create artificial samples applied to other datasets. In particular, two European databases: one of the City of Madrid, Spain [13] and one provided by the French Road Safety Observatory (OINSR) and extracted from the BAAC (French Government) [14].

US American databases are more comprehensive in the detail of accident characteristics and environmental conditions. A low level of stringency in selection criteria is applied due to the lack of uniformity in the different databases. Accidents with two vehicles and autonomous functionalities are be considered, whether these features are in operation when the accident occurs. In addition, a study of accidents with contextual data is conducted. In previous studies, the data considered was referenced to the relative velocity, which is related to the severity of the accident. This could be useful if relevant data, such as yaw angle, were available, but it must be analysed correctly since the collision point is not enough to obtain the necessary data for the correct simulation of the accidents. Collisions with two moving vehicles require both angles from the different vehicles as different reference systems, which cannot be obtained in all the datasets.

4.1 Front-End AV Collisions

In the first analysis of the collisions shows the areas affected by impacts in relation to the frequency in the filtered DMV dataset. AVs have a higher impact rate on the right-hand side than other vehicles when in motion. However, in stationary state, the front of the car shows a more even distribution of damage. This incompatibility between the vehicles could be the source of human error.

Table 1. Statistical weights for front-end involved impacts in AVs in mixed traffic, DNV database.

Crash with	AV in movement ($n = 339$)		Opponent in movement ($n = 302$)		General	
	$\frac{x}{n}$	x	$\frac{x}{n}$	x	$\frac{x}{n}$	x
AV stopped	–	–	0.00728	22	0.9145	310
Opponent stopped	0.05	17	–	–	0.8377	253
General	0.0855	29	0.1623	49	–	–

Further analysis into the behaviour of front-end damage in specific cases where vehicles collided with stationary vehicles was conducted. It is remarkable that there is a difference in the damage to the front-end of the various vehicles. The relative weights for frontal collisions in the DMV Database are shown in Table 1. The data shows a tendency for AVs to receive more collisions while stationary in traffic (91.45%) than in the case of a non-AVs (83.77%). AVs in motion account for 5% of the collisions with stationary vehicles, with AVs being hit by other moving vehicles 7.28% of the time for head-on collisions in this selection of cases. Most of the damage is concentrated around the front passenger and the right side of the car. This shows that they may also be caused by human error and poor adaptation of humans to driving dynamics of AVs. The distribution of

Table 2. Selected crash scenarios in mixed traffic settings.

Impact area	Impact reason	Research focus
Rear	Unexpected breaking of AV, causing a rear collision into the AV on motorways, inner-city and intersection settings	1) AIS1-2 injuries of AV occupants/passengers 2) Criticality for occupant/passengers of AV
Side	Collision at turning point of intersection	Criticality for occupant/passenger safety on-board of both vehicles
Front	1) Failed detection of object in front of AV 2) Human error of vehicle in on-coming traffic (e.g., wrong way drivers)	Criticality for occupant/passenger safety on-board of AV

available data for each set also shows the comparison between datasets. The data handled by the different databases are of mixed traffic, but not all of them contain information about the level of autonomy of the AVs.

5 Results and Discussion

The safety benefits of a new FES are clear; however, despite the availability of international standards and consumer tests, the current fleet of vehicles often fails to meet real-life accident issues. By establishing legal requirements, governments can ensure that no matter what the manufacturer's design goals are, a minimum level of safety is always provided. Safety conditions considering a new and lighter FES with respect to existing production cars, involves the considerations of car manufacturers, current legislations, tested for existing FES, consumer testing and specific needs of current vehicles. Therefore, a coherent plan for the future of vehicle safety will be needed that combines consumer testing, appropriate regulation, and new technology developments.

The crash scenarios considered in this paper are mainly rear impact, side impact, and frontal impact. Within the rear impact category, the motorway rear end and inner-city rear end will be studied further within the SALIENT project. For frontal impact, the analysis will cover both frontal crashes and head-on collisions in terms of energy absorption, deformation control, and intrusion protection. The results of the simulations will be used to develop new FES designs that can meet the safety performance requirements for the different crash scenarios, identify potential areas of improvement, and develop new designs that can meet the safety performance requirements for the different crash scenarios. The following scenarios are of great importance when it comes to the validation of FES systems:

- Legal ECE-R94-43, R-100 (offset, 40% overlap deformable barrier at a speed of 56 km/h);
- Legal UN R137 (full frontal rigid barrier, 50 km/h);
- EuroNCAP (consumer testing scenarios);

- Additional scenarios that test improved compatibility (e.g., different weight, different height of bumper);
- MPDB with increased weight (IIHS side impact or equivalent) and height;

According to literature, the prospective studies performed in OSCCAR and SAFE-UP should be considered. The following scenarios appear as relevant - all three of them should be explored during all of the following technical SALIENT WPs, from design conceptualisation, simulation design and crash test evaluation (Table 2):

In addition to the crash scenarios mentioned in the previous sections, SALIENT will also consider the following crash scenarios:

- Rigid barrier with full overlap at a speed of 56 km/h;
- Offset, 40% overlap deformable barrier at a speed of 56 km/h;
- Mobile Progressive Deformable Barrier (MPDB), increased weight and height;
- Mobile Progressive Deformable Barrier (MPDB) at different angles (~ 0–30°), impact points 0–60% overlap;
- Stationary barriers and adjusted speeds (reduced relative velocities compared to ECE and current Euro NCAP test protocols);
- Combination of compatibility testing and crash angle/ velocity;
- Crash avoidance scenarios (e.g., swerving to avoid a pedestrian, cyclist, vehicle.

6 Conclusions

This research draws key conclusions from consulting all available sources regarding collisions in mixed traffic from 2000–2017. This analysis provides a basis for the further development of a safety solutions for the current context and adapted to mixed traffic scenarios while meeting the requirements of circular economy, eco-design, and environmental friendliness. The results obtained through the analysis of different databases show that rear-end collisions are more frequent depending on weight and angle, which demonstrates the need to consider the different weights of light and heavy vehicles to increase crash compatibility. It can be observed that simulations map the ability of standardised active safety systems to mitigate crashes by 26–27% [11]. However, when the same approach was used by the SAFE-UP project on the same database, different results for rear-end collisions between heavy goods vehicles and light passenger cars emerged, suggesting additional countermeasures for light-weight vehicles.

The research feeds the understanding of the context of mixed traffic which are relevant in the evaluation of safety solutions, in the design of restraint systems, in the study of the dynamic behaviour of autonomous and electric vehicles in collisions and as a basis for a better understanding of the effects of their uptake in the context of mixed traffic. Moreover, this research lays the foundations for the SALIENT project to design a FES that considers all aspects and taking into account contextual data. The results serve as a basis for a transition from user-driven vehicles to SAVs and AVs in mixed traffic, to maximise compatibility between vehicles to minimise human injuries in accidents.

7 Declarations

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Use of Accident Prediction Models in Road Safety Management – An Irish Case Study

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Abstract. Evaluation of road safety measures can be a challenging element of road safety management systems in Europe. To deliver Vision Zero and implement the Road Infrastructure Safety Management Directive, national road authorities need reliable estimation tools for road safety countermeasures. Accident Prediction Models (APMs) provide an objective and cost-effective way to analyse potential safety improvements and estimate the potential impact in terms of collision reduction. However, most National Road Administrations (NRAs) do not develop or use APMs. The objective of this paper is to present research undertaken for Ireland's first APM including the modelling technique used and the data challenges faced. The primary aim of the APM development is to provide local (Irish) estimates for Crash Modification Factors (CMFs) to feed into a tool for use by Road Safety Engineers when estimating the potential collision savings of various interventions.

Keywords: Accident Prediction Models · Crash Modification Factors · road safety · safe systems · collision data

1 Introduction

The aim of this work was to develop Ireland's first Accident Prediction Model (APM) to provide Irish Crash Modification Factors (CMFs) for the benefit of Transport Infrastructure Ireland (TII), local authorities and road safety practitioners who wish to identify cost effective road safety interventions and measures to reduce road traffic collisions.

The project investigated:

- The extent to which APMs can feasibly be developed from Irish data using established methodologies (identified through a literature review).
- How the output from the APMs and existing CMFs from other sources can be used to develop a tool for practitioners to improve road safety.

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2 Feasibility of Model Development

2.1 Literature Review

A review of international literature was carried out to identify applicable modelling approaches in the European context. The literature review also informed the expected factors contributing to collisions.

More than 25 published papers and reports were reviewed to understand the practical aspects of APM development (e.g., the datasets, variables, and methods for assigning these to the network) and the statistical approaches used to develop the models.

Considerations for APM Development. The key conclusions from the review were:

- Most papers reviewed used five or six years of collision data and modelled all injury collisions as this offered a good balance between obtaining sufficient collisions per road segment for the modelling and reducing the chance of there being major differences in the road factors present over time.
- Traffic flow is always the most significant factor that explains collision occurrence in APMs.
- The approach applied to divide the roads into segments is very important. The aim is to define segments with relatively few zero collision counts whilst capturing enough variability in the other explanatory parameters. A recommended approach is to divide the network into segments with the same flows and/or other specific features, mainly curvature.
- Commonly occurring variables that were significant in developed APMs were identified and assessed within the Irish data (see Sect. 2.2).
- Main road types (motorway, dual carriageway and undivided roads) will have differing characteristics. For this reason, models should be developed for specific road types.

Statistical Approaches for Model Development. Themost common statistical approach for the development of APMs was Generalised Linear Modelling (GLMs); both Poisson and Negative Binomial GLMs were used in the literature. Where significant numbers of segments have no (zero) collisions, zero-inflated models were considered.

2.2 Road Data Identification and Assessment

Pre-existing data sources for a range of road features and traffic characteristics on the road network from TII asset databases were assessed for use in the modelling. Throughout this process several challenges with using pre-existing data were identified and resolved. A few challenges remain which could form the basis for future work.

Collision records have co-ordinates which permit linking to road segments. Including damage only collisions in addition to injury incidents increases the total number of collisions for modelling, reducing the number of segments on which there are zero collisions (necessary for the modelling). In Ireland, collisions cannot be accurately linked to carriageways so both directions were combined for the modelling.

Based on the data assessment and exploratory analysis, decisions were made on how to divide the road into the short sections ('segments') that will be modelled. Segments were created for each of the road types according to variation in radius (curvature), traffic flow (AADT) and number of lanes. Sufficiently large changes in these parameters mark the boundary points between segments. To reduce the frequency of segments with a zero-collision count, a minimum segment length (200 m) was imposed. A maximum segment length (5km) was also used.

Roundabouts, link roads and ramps have been excluded from the modelling as these combined accounted for less than 5% of the network length and 10% of collisions. The number of a major and minor junctions on each mainline was identified for each segment but, due to data availability, it has not been possible to model the risk at junctions separately from the mainline. More detailed information on junction types, including whether the junction is signalised or not, the number of turning movements, the number of arms and the flows on each of these would enable separate junction models to be developed.

Four models, one for each of the road types (motorways, dual carriageways, single carriageway and legacy roads) which make up the TII network, were deemed feasible to develop based on the data available and methodologies identified in the literature. Aggregation of the potential explanatory variables on the segments was carried out. The following variables were tested for inclusion in the models:

- Traffic information (AADT, %HGVs)
- Road characteristics (gradient, crossfall, radius, friction coefficient, hard shoulder & median widths, verge & median barrier presence)
- Junction/access information (minor & major junction density, business, commercial & residential access density)
- Road classification (urban/rural, flag for segments on the M50 as this was considered a high-risk road, flag for 1+1 and 2+1 lane segments)

No suitable dataset for vehicle speeds was identified during the assessment and as a result, this was excluded from the list above. It is recommended that TII consider how suitable speed data might be collected in the future; as a minimum this should include mean and 85th percentile speeds to enable the range of operating speeds to be understood.

For some variables, additional data collection was needed in the form of a visual inspection using Google Earth imagery. As a result, these variables (hard shoulder and median widths, verge barriers) were only used some of the models as the scale of data collection needed for the whole network was outside of the scope of this project. TII are investing in more reliable data collection methods which could be used for future modelling activities.

3 Model Results

3.1 Modelling Process

Negative Binomial zero-inflated models were determined to be the best fit for the data. Zero inflated models involve two different model processes:

1. A binomial logit model to model whether the observation is zero or not. This model represents the "structural/excessive zeros" – these are observations which are always zero.
2. A Negative Binomial model to model the non-zero count data. Within this model, "sampling zeros" are modelled for those segments which are exposed to the risk but do not report the outcome (collisions) during the data.

For the first part of the modelling (the logit model), AADT was the only predictor included. Whilst this variable was not significant in all of the road type models, it makes logical sense that as the AADT increases, the probability of no collisions on a segment decreases – this is supported by the direction of the sign (negative) for the coefficient in each of the four models.

For each road type, a base negative binomial model was developed using AADT and segment length which are known from the literature to be the key variables affecting collision risk. For the other variables a stepwise variable selection process, according to how significant variables were (using their p-values) and the change in Akaike's Information Criterion (AIC) was used for variable selection.

For each of the final models selected, various goodness of fit measures were used to compare the base model to the final model. Predictive performance of the model was assessed using K-fold cross-validation.

3.2 Model Results

Table 1 shows the results from the negative binomial part of the zero-inflated model for the motorway network. Models for the other three road types were also created.

Table 1. Variables included in the Negative Binomial motorway model

Variable	Coefficient	p-value
Intercept	−9.192	$p < 0.001$
Log(segment length)	0.765	$p < 0.001$
Log(AADT)	1.157	$p < 0.001$
Gradient	0.176	$p < 0.001$
HGV %	1.804	$p < 0.001$
Radius	−0.187	0.004

The direction of the coefficients (positive or negative) is as expected:

- As the segment length or AADT increase, the positive coefficients indicate that collision risk increases:
  - The segment length coefficient is less than 1 which indicates that as you double segment length, you don't quite double collision risk.

  - The AADT coefficient is slightly greater than 1, suggesting that as the flow increases, the collision risk increases.

- Increases in gradient and increases in the percentage of vehicles which are HGVs, both increase collision risk, possibly due to increased speed differentials between vehicle types.
- As the radius increases (i.e., the road becomes less bendy), the collision risk decreases.

Figure 1 shows the model predictions compared with the actual collisions on each segment; the predictions are relatively close to y = x the line.

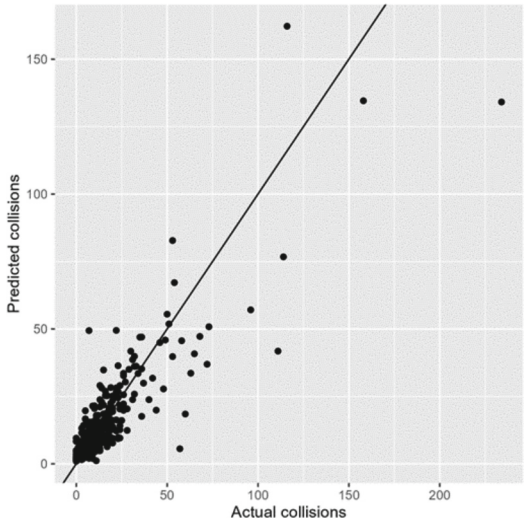

Fig. 1. Model predictions compared to actual collisions by segment for the motorway model

The results from all four negative binomial models indicate that collisions decrease as the road environmental conditions improved. For example, reducing the number of accesses or junctions, improved pavement condition, and increasing the proportion of dual carriageway with a median barrier, all decreased collision risk. These results agree with findings in other jurisdictions and demonstrate that these models can be useful for the evaluation of safety countermeasures at the local level, supporting Ireland's Vision Zero aims.

4 Tool Development

Using the output of the models, and published Crash Modification Factors (CMFs) from other sources [1], TRL has built a tool for TII which can be used for estimating the impact of different packages of countermeasures on collisions on the Irish national road network. The tool allows Road Safety Engineers to select multiple countermeasures and assess their impact on collisions by road type and severity. The resulting first year rate of return (FYRR) is also calculated to enable an economic appraisal of the interventions.

The tool can be obtained on the TII Publications website [2].

5 Conclusions

Ireland is a relatively small country with small road collision numbers relative to other countries. This can present methodological challenges when using GLMs to develop APMs. This research demonstrates that APMs can be developed under these circumstances, using a zero-inflated modelling approach, to provide empirical evidence-based information for road safety programmes.

APMs have been found to be a more cost-efficient way to carry out evaluation of safety interventions compared to studies of individual features or sites. This research highlighted limitations associated with using existing datasets collected for other purposes. While asset data is routinely collected by national road authorities, these data may not be easily transferred to other purposes; authorities should consider data analytics and digitisation for all data collection as part of a Safe Systems approach to road safety.

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Exploitation of Naturalistic Driving Data to Estimate Crash Risk Through Machine Learning Techniques

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Abstract. Despite continuous investment in road and vehicle safety, as well as improvements in technology standards, the total amount of road crashes has been increasing over the last decades. The aim of the current study was to identify the most critical precursors of risk from both the task complexity and the coping capacity side. To that end, data collected from 30 drivers who participated in a naturalistic driving experiment for four months in UK were collected and analyzed. Several Structural Equation Models (SEMs) were applied in order to explore the effect between the latent variables of task complexity, coping capacity and risk. Results indicated that demographic characteristics, such as gender and age had a negative correlation with coping capacity indicating that male drivers and especially elderly people had a lower level of coping capacity, Moreover, better general driving skills were associated with higher coping capacity. It was also revealed that vehicle strain (increased vehicle age) along with type of fuel and trip difficulty were associated with higher task complexity levels. Overall, it is important to consider the specific factors and context involved when assessing the relationship between task complexity, coping capacity and risk.

Keywords: Task Complexity · Coping Capacity · Naturalistic Driving Experiment · Structural Equation Models · Road Safety

1 Introduction

In modern society and reality, road transport is an integral part of people's daily lives, as they use it for all their activities during the course of a day. With the global increase in road transport, road crashes are also increasing, bringing to the surface the critical issue of road safety. According to the World Health Organization, annual road traffic fatalities amount to 1.35 million and are the leading cause of death in people aged 5–29 years, with 1 in 2 victims being pedestrians, motorcyclists or cyclists (WHO 2018).

The aim of the current study was to identify the most critical precursors of risk from both the task complexity and the coping capacity side. To that end, data collected from 30 drivers who participated in a naturalistic driving experiment for four months in UK were collected and analyzed.

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The paper is set up as follows. The project and its overarching goal are thoroughly described at the outset. After that, a thorough background on the statistical methods used to analyze driving behavior is offered. The research methodology is then explained, along with the models' theoretical underpinnings. Finally, the results are discussed, followed by important conclusions about how crucial elements like task complexity and coping capacity affect risk.

2 Background

To begin with, task complexity relates to the current status of the real world context in which a vehicle is being operated. In particular, task complexity context is monitored via registration of road layout (i.e. highway, rural, urban), time and location, traffic volumes (i.e. high, medium, low) and weather. On the other hand, coping capacity is dependent upon two underlying factors and it consists of several aspects of both vehicle and operator state. More specifically, the latent variables associated to "vehicle state" are estimated on the basis of various metrics, such as technical specifications, actuators & admitted actions and current vehicle status. Additionally, the latent variables associated to "operator state" are estimated on the basis of several aspects, such as mental state, driving behavior, competencies, personality, sociodemographic profile and health status. Figure 1 illustrates the conceptual framework for the prediction of risk in function of coping capacity and task complexity.

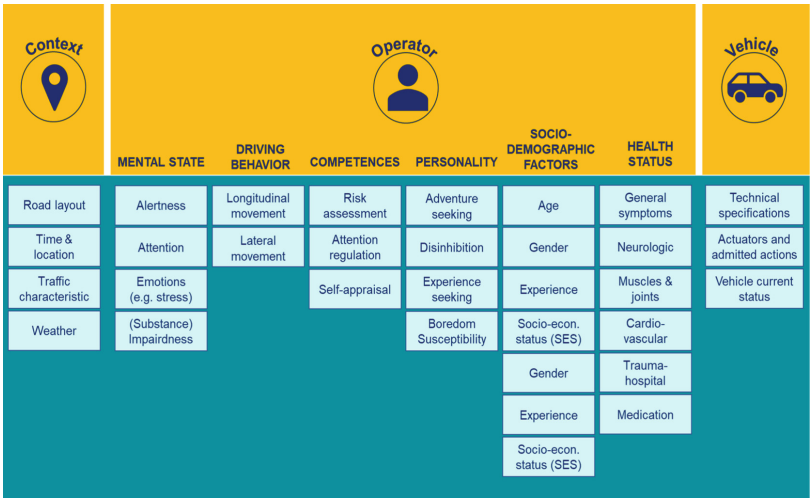

Fig. 1. Prediction of risk in function of coping capacity and task complexity

The research by Ofori et al. (2023) examined the safety procedures and performance of Ghana's crucial oil, gas, and related energy sector. The aim of the work was to present an integrated approach for examining new antecedent metrics for improving the safety performance using partial least squares structural equation modelling (PLS-SEM). The

outcomes showed that efficient safety training is another safety management technique that can aid in creating a successful safety policy. Nevertheless, neither safety training nor safety compliance had any discernible impact on safety performance.

The study by Useche et al. (2021), examined the risky behaviour of pedestrians on a road network by separating them into males and females using Structural Equation Models (SEM). This study investigated the influence of gender, both on violations of the Road Traffic Code, and on dangerous behaviors committed unintentionally, by applying SEM. According to the researchers, in male pedestrians, latent risk perception and educational level played a significant role in committing violations.

3 Methodology

3.1 Structural Equation Models (SEMs)

SEM is frequently used to describe intricate and multi-layered relationships between variables that are observed and those that are not, like "task complexity," etc. Unobserved variables are latent constructs, which are comparable to the components in a factor/principal component analysis, whereas observed variables are quantifiable.

A measurement model and a structural model make up structural equation models. The measurement model is used to calculate the associated measurement errors as well as how well different observable exogenous variables can measure (i.e. stress on) the latent variables. The SEM is used to investigate the relationships among the model variables, enabling the modeling of both direct and indirect linkages. SEMs are distinct from ordinary regression approaches where relationships among variables are direct.

The general formulation of SEM is as follows (Washington et al. 2020):

$$\eta = \beta\eta + \gamma\xi = \varepsilon \tag{1}$$

where η is a vector of endogenous variables, ξ is a vector of exogenous variables, β and γ are vectors of coefficients to be estimated, and ε is a vector of regression errors. The measurement models are then as follows (Chen 2007):

$$x = \Lambda x\xi + \delta \text{ for the exogenous variables} \tag{2}$$

$$y = \Lambda y\eta + \zeta \text{ for the endogenous variables} \tag{3}$$

where x and δ are vectors which denote the observed exogenous variables and their errors, y and ζ are vectors which denote the observed endogenous variables and their errors, and Λx, Λy are structural coefficient matrices for the effects of the latent exogenous and endogenous variables on the observed variables. A path analysis, which illustrates how a group of 'explanatory' variables might have an impact on a 'dependent' variable, is frequently used to portray the structural model.

In the context of model selection, model Goodness-of-Fit measures consist an important part of any statistical model assessment. Several metrics are commonly used for the model evaluation. More specifically, the aforementioned metrics are the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), the Goodness-of-Fit

Index (GFI), the (standardized) Root Mean Square Error Approximation (RMSEA), the Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI) and the Hoelter index.

The latent variables and their constructs, used in this paper are the product of the authors own work and have been selected after continuous testing based on the optimum efficiency. A critical step in the operation of SEM models is the clustering of variables, in order to provide useful information and conclusions about latent variables. Following the principles of sequencing and hermeneutics, the clustering of variables was carried out. In particular, four latent variables were formed: i.e. task complexity, coping capacity-operator state, coping capacity-vehicle state and synthesis of risk factors.

The latent variables represent unobserved variables. A regression is then performed between the unobserved and observed independent variables, which are finally correlated with several dependent variables. Through tests carried out, the dependent variables for which the most significant results were obtained were speeding and harsh braking. The results of the models were evaluated by satisfying the following statistical tests: p-value < 0.001, CFI > 0.90, TLI > 0.90, SRMR < 0.05 and RMSEA < 0.05.

4 Results

4.1 Speeding

Risk is measured by means of the STZ (Safety Tolerance Zone) levels for speeding (level 1 refers to 'normal driving' used as the reference case, level 2 refers to 'dangerous driving' while level 3 refers to 'avoidable accident driving'), with positive correlations of Risk with the STZ indicators. Figure 2 summarizes the model fit of SEM applied for speeding. The numbers on the arrows indicate the correlation between the variables.

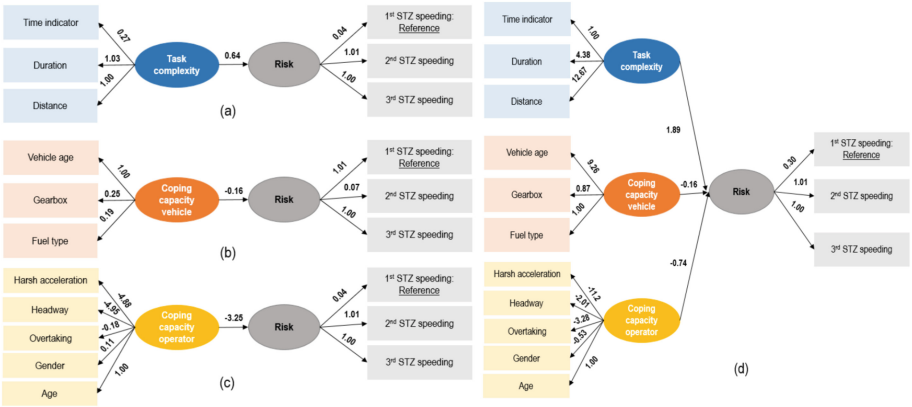

Fig. 2. Results of SEM for speeding; experiment phase 1 (a), 2 (b), 3 (c), 4 (d)

The latent variable task complexity is measured by means of the environmental indicators "Time indicator". The exposure indicator of trip duration was also included in the task complexity analysis. The most important finding is the positive correlation between

the complexity of the driving task and risk, meaning that increased task complexity relates to increased risk according to the model (regression coefficient = 0.64).

The latent coping capacity is measured by means of operator state indicators, such as harsh acceleration, headway, illegal overtaking, age and gender. At the same time, the indicators of coping capacity - vehicle state, such as vehicle age, gearbox or fuel type are included in the SEM applied. It is noted that the structural model between coping capacity and risk shows a negative coefficient, which means that increased coping capacity relates to decreased risk according to the model (regression coefficient = −0.16 (vehicle state)/−3.25 (operator state).

Overall, the structural model between task complexity and risk shows a positive coefficient, which means that increased task complexity relates to increased risk according to the model (regression coefficient = 1.89). On the other hand, the structural model between coping capacity and risk shows a negative coefficient, which means that increased coping capacity relates to decreased risk according to the model; regression coefficient = −0.16 (vehicle state)/−0.74 (operator state).

4.2 Harsh Braking

Risk was measured through the types of harsh events and the level of severity at which they occur. For harsh braking, there are high severity events (1st STZ level), moderate severity events (2nd STZ level) and low severity events (3rd STZ level). Figure 3 illustrates the SEM results for harsh braking per each phase.

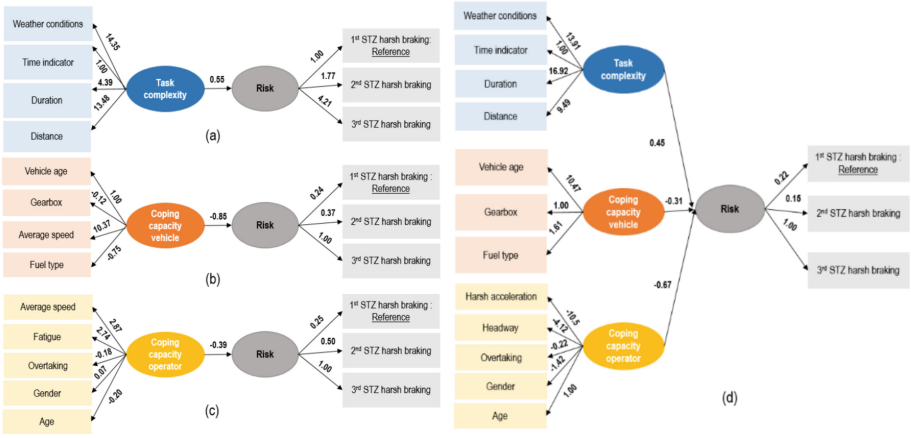

Fig. 3. Results of SEM for harsh braking; experiment phase 1 (a), 2 (b), 3 (c), 4 (d)

As shown in Table 1, p-values < 0.001 across all metrics revealed strong evidence of model fit for both speeding and harsh braking. For speeding, all metrics demonstrated high levels of fit, with CFI values ranging from 0.997 to 0.981, TLI values ranging from 0.994 to 0.969, SRMR values between 0.032 and 0.066, and RMSEA values between 0.052 and 0.101. Similarly, for harsh braking, significant p-values alongside CFI values

Table 1. Model Fit Summary for speeding and harsh braking

Model fit metrics	Task complexity	Coping capacity operator state	Coping capacity vehicle state	Synthesis	Task complexity	Coping capacity operator state	Coping capacity vehicle state	Synthesis
Speeding					***Harsh braking***			
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CFI	0.997	0.992	0.730	0.952	0.981	0.707	0.897	0.832
TLI	0.994	0.987	0.601	0.936	0.969	0.613	0.848	0.845
SRMR	0.048	0.045	0.153	0.074	0.032	0.090	0.066	0.064
RMSEA	0.062	0.080	0.440	0.100	0.052	0.148	0.101	0.085

ranging from 0.992 to 0.707, TLI values between 0.987 and 0.613, SRMR values from 0.045 to 0.090, and RMSEA values spanning 0.080 to 0.148 affirm the robustness of the model fit across various dimensions, highlighting its reliability in capturing the complexities associated with both driving behaviors. The effect of the weather conditions was only considered in the "harsh braking" model and not the "speeding" model after continuous testing of multiple variables based on the optimum efficiency.

The task complexity latent variable takes into account all the variables and indicators obtained in the excessive speed category above, as well as the indicator of weather, which indicates the weather conditions prevailing on the route in question. It is noted that there is a positive correlation between trip complexity and risk (regression coefficient = 0.55). The structural model between coping capacity and risk shows a negative coefficient, which means that increased coping capacity relates to decreased risk according to the model (regression coefficient = −0.85 (vehicle state)/ −0.39 (operator state). Overall, there is a positive correlation between task complexity and risk (regression coefficient = 0.45), while there is a negative correlation between vehicle and operator state and risk. On the other hand, SEM between coping capacity and risk shows a negative coefficient, which means that increased coping capacity relates to decreased risk (coefficient = − 0.31 (vehicle state)/ −0.67 (operator state)).

5 Conclusions

The ultimate goal of the analyses in this work was to identify the impact that the balance between task complexity and coping capacity has on the risk of a crash. To that end, 30 drivers participated in a naturalistic driving experiment carried out in UK and a large dataset of thousand of trips was analyzed. Explanatory variables of risk and the most reliable indicators, such as time headway, distance traveled, speed, time of the day (lighting indicators), or weather conditions were assessed.

To fulfill the aforementioned objective, SEMs were used to explore how the model variables were interrelated, allowing for both direct and in-direct relationships. Results demonstrated that coping capacity and risk displayed a negative relationship across all phases, indicating that higher coping capacity was associated with reduced risk.

The relationship among task complexity, coping capacity and risk, may depend on the specific context and the type of task or activity involved. In general, higher task complexity may increase the potential for errors or crashes, as it can lead to greater cognitive or physical demands on the individual performing the task. Similarly, a higher coping capacity may help to reduce the risk of crashes or errors, as it can provide individuals with the resources or strategies needed to effectively manage challenging or stressful situations. It is important to consider the specific factors and context involved when assessing the relationship among task complexity, coping capacity, and risk.

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SAFER TO SCHOOL – The Slovenian Approach

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Abstract. Considering the EU Road Safety Policy Framework 2021–2030 - Next steps towards "Vision Zero", Slovenian Infrastructure Agency has adopted systematic approach to improve children safety around the schools and on the way to/from school.

To improve the traffic safety of children, the Agency has prepared "SAFER TO SCHOOL guidelines for installing urban equipment and architectural design of traffic areas to improve road safety for school children" in which it suggests how to systematically re-design roads, to be more self-explaining, and to intuitively warn road users of the proximity of the school or school path.

The system was designed considering Human Factors (traffic psychology) in road design, and was previously verified by several monitoring's. By the approach synergies between safety and sustainability measures are established, so children can walk and cycle in safer road environment.

The concept is also a very good contra measure combatting existing issues of inadequate spatial planning, providing safer roads, speeds and road users.

Keywords: Traffic Safety · Human Factors · Safer to School

1 Facing Challenges

An outdated concept of road planning (land use, spatial planning (urbanism), road access, linear settlements etc.), lead to the issue of inadequate roads functions (functionally and design), and with that poor self-explanatory road design, so drivers tend to subconsciously violate road traffic rules.

Due to above mentioned issues, roads often do not provide proper (intuitive) information, about specific traffic conditions, like presence of schoolchildren on the road, and speed limits. In addition, the dangers indicated by traffic signs are not logical, predictable, understandable and therefore, acceptable by the drivers (Fig. 1).

1.1 Challenge and Opportunity

Slovenian Infrastructure Agency has faced the challenge, and took it as an opportunity to start with the pilot projects and their evaluation and developed systematical approach, a concept based on Human Factors knowledge in road design, to tackle challenges of

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Fig. 1. Non self-explanatory road design with different speed limits inside a town (the pictures of Slovenian roads with different speed limits).

Fig. 2. Slovenian approach "Safer and Healthier to School" [1].

improper speeds and driving behavior around Schools, by developing guidelines "Safer to School" [7] (Fig. 2).

Ministry for Infrastructure recognized the benefits of pilot projects and concept "Safer to School" and approached to the amendment of the Roads Act. By adding urban equipment and architectural design of traffic areas in the article of traffic calming devices and measures, it has enable Slovenian Infrastructure Agency to move from pilot projects to systematic approach.

The Agency created an Investment Project Identification Document to ensure for stabile and long term investments for improving School areas in enhancing children safety.

Ministry also supported the Agency with implementation of the concept, starting with ten School areas across Slovenia in ten different Municipalities, where state roads pass by Schools.

Collaboration with the Municipalities. To gain wider support and understanding from local community and road users, the Agency collaborated with the Municipalities from the beginning. It was crucial to get firsthand information of the challenges people, especially schoolchildren, are facing in those areas, so that solutions could be adapted to the respective needs.

After making of project designs, the implementations followed and the project "Safer to School" gain its momentum. User responses were positive and Municipalities saw an opportunity to start with the concept also on municipality roads.

2 Safer to School Implementation

Thankfully, selected locations were very different regarding road geometry and its elements, traffic volume, traffic safety challenges children are facing etc., and with that, we came to many diverse solutions; upon we could learn and gain needed experience.

We also managed to include some designs in project and implementations in progress (Figs. 3 and 5). Other ten interventions were orientated more towards prompt low cost measures, so that implementation could be finish during summer break and before beginning of a new school year.

In pictures below are just some implemented solutions to give general overview of the concept (Figs. 4 and 6).

Fig. 3. School area with speed limit 50 km/h added in construction phase (the picture of implemented solutions on Slovenian roads).

One of the challenges was also how to mark locations, where only School buses stop, for picking up and dropping off children on the way to/from School. Those locations are not for public transport and can change when children stop going to School or move away, which is why locations are not equipped according to design standard for bus stops. School buses (properly marked for School transport) can stop beside the road using all four flashing lights according to the Road Traffic Rules Act.

Fig. 4. School area with speed limit 50 km/h - road without middle lane due to its width (the pictures of implemented solutions on Slovenian roads).

Fig. 5. School area with with additional visual road narrowing, added in design scheme (the picture of implemented solutions on Slovenian roads).

That is why system BUSko [3] was developed and verified on several location as appropriate low cost solution. With this approach, we assure waiting area for schoolchildren, so they do not have to stand on the road while waiting for school bus, and with especially designed "school bus stop" sign, driver give proper information of possible presence of children alongside the road (Fig. 7).

With implemented designs, we managed to slow down drivers and raise their attention. What was previously also proven with pilot projects [1–4]. In one case we even managed to slow down traffic in such a way that local community waived from the request to implement physical traffic calming device – speed bump. Since the implementation, there were no further complaints or requests for additional measures to reduce traffic speeds or influence driving behavior.

Of course, winter and regular maintenance must not be forgotten, especially when dealing with children safety and promotion of walking to School (Fig. 8).

Fig. 6. School area with speed limit 30 km/h (the pictures of implemented solutions on Slovenian roads).

Fig. 7. School bus stop (BUSko), before and after the implementation (the pictures of implemented solutions on Slovenian roads).

2.1 Lessons Learned

We learned that is at most importance to make designs at designing stage as detailed as possible. In complicated situations, even simulation (from drivers' point of view) is

Fig. 8. Proper winter maintenance of School path (the pictures of implemented solutions on Slovenian roads).

necessary, to provide a true representation of what the final solution should look like in reality and if coincides with the imagined solution. Design solutions should not be designed just in the office. Designer (traffic engineer) must carefully inspect the terrain and use Human Factor knowledge/understanding, before going to the drawing board. Designer must also put together detailed requirements of material and equipment, so that there are no doubts in the tender and construction phase.

Construction supervision must be well acquainted with all the solutions, details and requirements and if needed work together with the designer and/or road operator. In case of suspicion about the installed material and equipment, the external control must also be engaged.

During construction, basic demands must be meet, in order not to reduce traffic safety in any case (Fig. 9).

Fig. 9. Case in which traffic bollards obstruct the view from the side road (the pictures of implemented solutions on Slovenian roads).

In some cases, we even came to a challenge how to implement road markings due to bad condition of upper layer of the surface, especially for long lasting marking materials with high skid resistance. Sometimes there was also a challenge where to put urban equipment, due to land ownership or specifics in the urban and road environment. Such matters must be foreseen before, at design stage.

Municipalities are becoming increasingly involved in "Safe to School" concept, what is very encouraging. The challenge is, that due to lack of their own cadre of employees, they leave decisions completely up to designers, who are not all properly trained and do not have enough specific professional knowledge. Copy paste solutions are definitely not acceptable, as each location has its own specifics. In addition, decisions are made on

local political level to make proposed designs cheaper (less colorful design or equipment and cheaper materials), so solutions they propose are sometimes very unacceptable.

There is still room for improvement, to share experience and knowledge, to communicate, and educate.

Things To Do. We are still facing challenges for improving access and walkability from disperse settlements towards bus stops, Schools etc., where side walk is not economically feasible, at least not for a long time, due to many needs. One of the solutions that is currently in design stage are typical schemes (depending of road width, traffic etc.), to establish uniform solutions across the country.

With this approach, we are aiming to move children walking directly on the edge of the road, away towards the stabilized hard shoulder or embankment (Fig. 10).

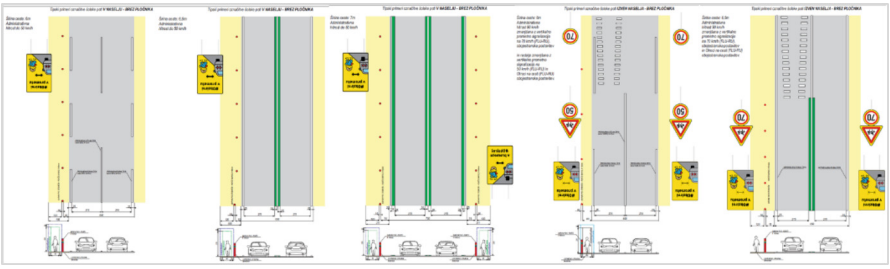

Fig. 10. Principles of a design concept solutions for traffic calming alongside School routes.

With the concept, we are trying to harmonize the solutions involving children on their way to School and around School areas. We believe that with self-explaining road design, we will be able to intuitively provide safer driving (lover speeds and more attentive drivers), and with that increase road safety. Of course, we have still a lot of work to do, and we are well aware that those solutions are not always the solution, and sometimes bigger construction interventions are needed.

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3rd Generation Safety Indicator for Traffic Lights: A Data Driven Risk Approach Based on Existing Data

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Abstract. Cities in Europe mainly rely on accident databases to estimate the level of safety at traffic light controlled intersections. Cities have already contributed significantly to improve road safety over the past years. But what if we could predict if intersections are unsafe or if realized measures have the predicted effect, based on actual data of the traffic light? The data driven risk approach was implemented in a 3rd generation safety indicator. This generation aims at combining infrastructure and behavior information.

With uniformed real time logging from the traffic light controller like state of signal head and occupation of loop detectors several questions are addressed in an algorithm, like:

1. Has there been a red light violation by a vehicle?
2. Were there conflicting vehicles (conflicting traffic) on other lanes that could have been impacted?
3. If so, what would the severity be?

By combining "likelihood" (question 1 & 2) and "severity" (3) it is possible to assess the risk road users are exposed to and so it is easy to compare the effects on safety for any changes brought. Additional research was conducted to see if changes like extension of green light could have a positive effect on safety. For one examined intersection the improvements brought led to a decrease of the risk of 15% and had no significant impact on traffic flow. These first positive tests could be further developed and upscaled through additional collaboration between experts of road safety and traffic management to improve road safety.

Keywords: Road Safety · Traffic Lights · Data

1 Road Safety and Traffic Lights in the Netherlands

1.1 A Brief History on Road Safety

Road authorities in the Netherlands are investing heavily in road safety since the 1970's. During that period the amount of casualties decreased from over 3,000 to about 600 [1]. Still over 20,000 people get wounded every year in traffic and over 430,000 are involved in an accident [2]. The total annual costs for the community of unsafety are estimated between 17 and 27 billion euros [3].

Over 10% of all the casualties happen at an intersection controlled by traffic lights [4]. For accidents with only wounded people figures are not available.

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1.2 Data Driven Risk Approach

Road authorities always reacted, when a situation was assessed as unsafe (because of the number of accidents), and measures were taken. In 2018 the national government introduced the "Strategical Plan Road Safety" with new zero casualties as a goal for 2030 [5]. In this plan the data driven risk approach was introduced. If possible we want to predict whether a situation is unsafe or which measures are more effective than others for a specific situation.

Data driven risk approach uses safety performance indicators (SPI). They can be categorized in generations:

- 1st generation: only looks at behavior or infrastructure. For instance, driver usage of alcohol, speeding or road design;
- 2nd generation: a model where accident locations are compared with 1st generation SPI's. For instance: speeding and accidents.

With those SPI's it is still difficult to address the cause of road unsafety or the combination of behaviour and infrastructure. The 3rd generation SPI should do just that.

1.3 Traffic Lights

In the Netherlands there are roughly 6,000 intersections controlled by traffic lights [6]. This may be small compared to cities and other countries, but most of them are state of the art. Almost all of them are equipped with a uniformed logging protocol (V-LOG) and the availability of camera's or loop detectors to sense traffic is generous. Whenever a detector is occupied, the timestamp is logged and also for the signal heads.

From the traffic management perspective red light violation is used as a KPI for determination of road safety at traffic lights. Mostly when more than 2% of all the vehicles neglects the red light it is marked as unsafe. Of course, red light violation is never acceptable, but unsafety only emerges when there is conflicting traffic. And that was not yet taken into account.

2 Safety Indicator for Traffic Lights

2.1 Genesis

Quite a lot of experts are active in the field of road safety and traffic management, all with their own knowledge. But speaking the same "language" and understanding each other is not self-evident. And what improves road safety can have a negative impact on traffic flow or vice versa. Comparing the predicted results of measures is difficult as well, because impact on road safety can only be measured afterwards and takes up quite a while before there is enough reliable data.

Experts from road safety and traffic management addressed the lack of a joint language at the end of 2019. Their main conclusion was that we should not look at red light violation, but at the impact of a possible collision caused by red light violation. And not only by judging the design of an intersection, but based on actual V-LOG data of the traffic light and take the actual risk into account.

This creates one of the first of its kind 3rd generation safety indicators by combining behaviour (red light violation) and infrastructure (lay-out of the intersection). The estimation was that within weeks you have enough samples of data to assess the performances on road safety and traffic flow. Such a short period of time fits perfectly in the data driven risk approach that was introduced by the national government.

2.2 Algorithm

In the algorithm of the safety indicator are three steps to assess the risk of a possible collision:

1. Has there been a red light violation by a vehicle at the intersection?
2. Were there vehicles (conflicting traffic) on other lanes that could have been impacted?
3. If so, what would be the severity of the impact?

In step 1 the V-LOG data is used and a configuration file of the intersection. This configuration file is similar to the MAP an intelligent traffic light controller provides to vehicles and contains the road lay-out, location of stop lines, detection loops and maximum speeds. An algorithm determines if there was a red light violation, at what time and on which lane.

Another algorithm in step 2 calculates a trajectory for every vehicle that neglected the red light. This trajectory is matched with the calculated trajectories of vehicles that pass through green or amber on conflicting lanes. If the locations and timestamps of two trajectories match it is assumable that this could lead to a collision. However, the trajectory after the stop line is an estimation and the speed of the vehicle could change. Therefore, a probability is used, if the location and timestamp match almost perfectly the risk of collision is 100%. When the difference in time increases, the probability decreases. The correlation between difference and probability for now is based on expert judgement because research is hardly ever done on this topic. The outcome of step 2 is also known as the "chance" of an accident.

In step 3 is determined how severe a collision would be. This severity consists of three elements:

- The speed of the vehicles;
- How the two trajectories interfere with each other;
- What were the vehicle types.

The higher the speed of the vehicle, the higher the severity probably would be because of the kinetic energy involved. The speed was already calculated in step 2.

The way two trajectories interfere with each other is determined by comparing them based on the MAP-file. The result of a right-angled collision is more severe than two colliding vehicles under an angle.

The third element is the vehicle type. A collision with a truck and a pedestrian is often more severe than two passenger cars. The presence of a truck is estimated based on the occupation loops.

With these three elements combined it is possible to determine the severity of a possible collision. The outcome of step 3 is also known as "consequence".

By multiplying the chance and consequence the risk is being calculated. And by adding up all the red light crossers it is possible to give a value for a period for an intersection.

3 Safety Indicator in Practice

3.1 Trial North-Brabant

The province of North-Brabant has more fatal accidents than other provinces and became a front-runner in improving road safety to make a change. Together with the 5 biggest municipalities (Eindhoven, Tilburg, Breda, 's-Hertogenbosch and Helmond) they started a 6-month pilot with the safety indicator for almost 60 intersections. A wide variety of intersections was chosen with different lay-outs, speed regimes and traffic intensities. In the working group experts from traffic management and road safety were evenly present. The Safety Indicator pilot and project management were hosted by the developers and founders "Vialis" and "Walraad Verkeersadvisering".

During the 6-month pilot different activities were performed by expert groups and developers:

- Setting up an initial severity matrix for all the conflicts and vehicle types;
- Improving of algorithms for cyclists and pedestrians;
- Adding risks of possible head-to-tail accidents when a traffic light is turning to amber;
- Improving algorithms for multiple signal heads on one lane (dedicated public transport and car for instance);
- Improving estimations when opposite signal heads are simultaneously green (partial conflicts);
- Improvements on the quality of MAP-files and occupation loops, quite a lot of errors were caused by minor flaws;
- Regular meetings were progress, experiences and lessons learned were discussed.

In the end it did not prove possible to reliably assess every of the 60 intersections due to inaccuracy of some occupation loops.

3.2 Influence Traffic Lights on Road Safety

In the working group the assumption grew that if we could lower the predicted risk of an intersection by changing the traffic light control program. Changes of intergreen or amber times were not allowed, as well as infrastructural changes. Only adjusting green times and or the order in which the signal heads receive green were permitted. These parameters are quite often also assessed in yearly maintenance programs.

One intersection near 's-Hertogenbosch was chosen as a "guinea pig" and was subjected to research in what caused the risk. One of the first conclusions was that the maximum speed was higher than the actual speed because of turning left or right at the traffic light. The gap times on occupation loops were too short for approaching traffic to extend the green time and this led to red light violation. Small alterations were also made to some parameters involved in calculating the maximum green times.

At the beginning of December 2020 the changes were implemented and led to a decrease of the risk of almost 15% while traffic intensities were only 1.5% lower. Further investigation showed that the amount of red light violation stayed roughly stable, but that the red light violators could run into less vehicles. Traffic flow was hardly impacted by the changes [7].

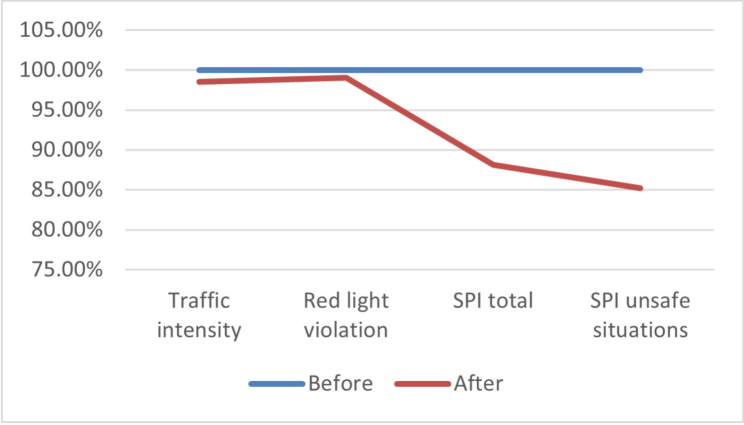

Fig. 1. Comparison of before and after situation on one intersection near 's-Hertogenbosch that show that traffic safety can be influenced

The claim that road safety can be influenced by traffic lights seems credible. However, confirmation of this claim needs extra research. But at least it gave experts of road safety and traffic management a common language that can be used to assess a situation and see if changes have an effect. And if so, the cost of these changes is extremely low and have an immediate impact, especially compared to infrastructural measures or behavioral campaigns (Fig. 1).

3.3 Future?

After the pilot the founders used the lessons learned to update the safety indicator and make it available in an online platform. Usage by road authorities is still in a premature phase. Main reasons are:

- Data quality of MAP-files and occupation loops needs to be of a high standard and sometimes it is difficult to find the faults;
- There is hardly any knowledge on data driven risk approaches, let alone for traffic lights. What does a certain value mean? And how can we compare intersections? Just now the data driven risk approach appears in new road safety plans and policy documents, but we all lack experience working with it. We need to get familiar with the new opportunities that arise.

Developments are projected on improving the algorithms, also with the increase of available Floating Car Data. That creates chances for other countries as well to set steps in a data driven risk approach that joins forces for traffic management and road safety with an end goal of zero fatalities.

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Choosing Computer Vision Based Technologies for Traffic Safety Assessment at Intersections

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Abstract. The integration of artificial intelligence and machine learning through computer vision (CV) technologies has gained widespread acceptance for the evaluation of traffic safety. While these technologies offer substantial advantages, they are accompanied by constraints and cost implications. This paper introduces a pragmatic framework for selecting a cost-efficient CV system for assessing traffic safety at intersections. The approach is designed based on Weighting Rating and Calculating (WRC) model and involves evaluating the tasks across all stages of the projects encompassing video collection, pre-processing, video analytics, and traffic safety analysis to aid in informed technology selection. The framework was applied to real-world projects, with resultant observations and outcomes discussed. The projects aimed to accurately identify conflict zones within intersections, where complex interactions and behaviours occur among categorized vehicles and vulnerable road users. Future enhancements to the framework and the software are also proposed. This paper intends to offer transport authorities and consultancy firms a structured methodology for choosing cost-effective technologies that align with their intersection safety assessment needs.

Keywords: traffic safety · junction assessment · video analytics · digital mobility

1 Introduction

Traffic safety assessment at road intersections is highly important due to their association with a significant proportion of accidents [1, 2], the complexity of interactions among various road users, the potential for severe injuries, and the need to accommodate diverse modes of transportation. Therefore, understanding the traffic behaviour and reducing the number of accidents at intersections is crucial. Traffic safety assessment at intersections comprises two primary tasks: the recognition of vehicle trajectories and conducting safety analysis through the application of safety measurements. The trajectories are composed of a series of spatial points and timestamps that together describe the movement of a vehicle. Analysing vehicle trajectories allows transportation engineers and planners to understand how vehicles interact and move within an intersection, which is crucial for assessing safety.

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In the past, the acquisition of vehicle trajectories mainly relied on manual observations, a method fraught with major issues and challenges such as human inability, labour-intensity, errors, and inconsistency. With the rapid advancements in computing power computer vision-based technologies fuelled by AI algorithms have transformed traffic safety assessment at intersections. These technologies leverage the capabilities of a variety of sensors and AI algorithms to collect data, automatically generate trajectories, and analyse various aspects of traffic behaviour. They offer significant advantages and benefits. CV-based safety assessment generally consists of four distinct stages as shown in Fig. 1.

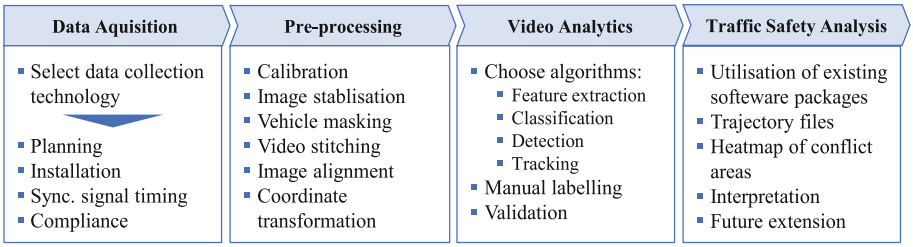

Fig. 1. Four stages of computer vision-based traffic assessment

Researchers have studied a diverse range of technologies and algorithms and detailed the advantages of individual techniques. For example, higher trajectory detection accuracy has been achieved through advanced algorithms and CCTV data [3], LiDAR sensors for connected vehicles [4], and data collected by Radar-cameras [5] and LiDAR-cameras [6]. However, no study has yet presented a framework for selecting a set of techniques that collectively optimizes overall cost-effectiveness throughout the project stages. Therefore, this paper attempts to address this gap by providing a structured approach based on to systematically select a collection of techniques that achieve cost-efficiency across the four stages. The approach is developed based on the Weighting Rating and Calculating (WRC) method which is widely used for decision making within the civil engineering industry. The paper also demonstrates a software system that was developed based on the approach proposed. Finally, prospects for enhancing the approach and software are also explored in the context of future work.

2 Related Work

While the research efforts commenced several years ago, the widespread adoption of computer vision-based technologies has primarily transpired in recent times, coinciding with a significant surge in computing power. Consequently, the literature review concentrated on research conducted during these recent years. Extensive research for analysis of traffic safety based on the data collected by LiDAR [4, 7], CCTV [3], drones, or the combination of these methods [5, 6]. Every technology possesses its own set of strengths and limitations. For instance, a meta-analysis encompassing findings from 39 studies concluded that LiDAR proved to be a viable choice for examining the interaction

between pedestrians and vehicles [8]. Nevertheless, one significant drawback of LiDAR is its difficulty in accurately classifying vehicles, while accurate vehicle classification is important for junction safety assessment. Hence, it becomes essential to make trade-offs in order to reach a holistic and optimal solution as a whole.

A recent study presented an extensive review of computer vision techniques and their applications in the context of Surrogate Safety Measures-based modelling [9]. Aiming to provide transport professionals with a guidance on choosing suitable computer vision techniques for trajectory-based safety assessment the paper summarised the algorithms developed for vehicle detection and tracking and discussed the practical challenges related to their implementation. This paper by far is the most extensive review on the subject. Yet, the research focused on assessing and contrasting techniques in isolation, rather than treating them as integral components of a complete solution encompassing all four stages depicted in Fig. 1. Notably, the aspect of overall cost, a major factor in real projects, was under-emphasized in the review. To achieve an overall cost-effective solution is still a challenging task to transport professionals.

3 Proposed Approach

The framework is designed based on the WRC model. WRC is a value-based method and has been widely applied in the civil engineering industry for informed decision making [10]. The application of the model is illustrated in Fig. 2, depicting its integration within the context of a computer vision-based solution for assessing traffic safety at intersections.

Factors	**Data Acquisition**							**Pre-processing**							**Video Analytics**							**Safety Analysis**						
Stage Weight	20							20							23							22						
Factors and critera	Technology maturity	Availability	Setup / installation	Synchronize signal timing	Planning	Regulation and restrictions	**Data acquisition weighted total**	Calibration	Image stabilisation	Data privacy handling	Video stiching	Image alignment	Coordinate transformation	**Pre-processing weighted total**	Object detection	Object feature extraction	Object classification	Object tracking	Labelling	Model validation	**Video analytics weithed total**	Use of existing software	Trajectory output	Conflict area generation	Results interpretation	System integration	**Safety analysis weighted total**	**Total Weighted Scores**
Factor weight (1 - 5)	*4*	*3*	*1*	*3*	*5*	*4*		*4*	*4*	*3*	*3*	*2*	*4*		*5*	*5*	*5*	*5*	*2*	*1*		*4*	*5*	*4*	*5*	*4*		
LiDAR (1 - 10)	5	6	6	7	5	8	122	5	4	9	5	4	8	118	9	5	3	5	4	6	124	4	8	3	5	5	113	477
CCTV (1 - 10)	8	8	8	7	8	8	157	6	8	5	5	6	8	130	8	7	8	8	6	8	175	5	8	8	9	8	169	631
Drone (1 - 10)	9	9	8	7	6	6	174	8	7	9	5	5	6	136	8	8	8	9	7	8	187	4	8	8	9	8	165	662

Fig. 2. The proposed framework with example factor weights and score values

The methods employed for video collection exert a substantial influence on the performance of subsequent tasks and their associated efforts [11]. First, the alternative technologies utilized for computer vision-based data collection are listed in the table. In this case they are LiDAR, CCTV, and Drone. The factor weights were subsequently determined by referencing the tasks delineated within each stage as depicted in Fig. 1. The weights are defined by considering inherent factors within the organisation that influence choice of CV-based technologies, such as availability of expertise across the

disciplines involved in video analytics and traffic safety modelling, training costs, and project management. These factor weights generally remain consistent across different technological options. The weights are between 1 to 5, where 5 represents the highest cost-efficient or highest availability. As an illustration, the weight value of 1 is designated for the installation or setup aspect within the data acquisition stage, considering the work will have to be outsourced. The tasks of labelling and validation demand a higher level of expertise from skilled human resources, hence low weights are assigned.

While factor weights are derived from an understanding of the organization's internal factors, score values are established through a comprehensive analysis of existing literature, consultation with domain experts, and the utilization of insights garnered from previous project experiences. The score value assigned to each technology option against each factor is influenced by specific technology being evaluated. To allow for a more nuanced and tailored assessment considering the unique characteristics of each technology the scores fall within the range of 1 to 10, where 10 represents the highest performance or cost-efficient, which offers a finer level of distinction. The values reflect the specific technology's performance, such as accuracy and performance against the criteria. The Weighted Total is the sum of the products of the Factor Weight and the corresponding Score across the tasks of that stage. Finally, the Total Weighted Score the sum of Weighted Totals across the stages. These final scores are used for making choice among options. In Table 1, Drones is chosen as it has the highest score.

4 Applications

The proposed framework was applied to assess and choose the optimal data collection method for several real projects. These projects leveraged deep neural networks to extract the positions, velocities, and classification of road users from the video. The surrogate safety measures used for the analysis were Post-Encroachment Time (PET) and Time-to-Collision (TTC), which have been adopted by 65% of the researchers stemming from their simplicity and interpretability [14]. The factor weights and score values were assigned by domain experts across video collection, video analytics, and safety analysis. Conflict areas identified are demonstrated with interactive heatmaps (as shown in Fig. 3).

These heatmaps provide a comprehensive visualisation that highlight the severity, distribution, and density of traffic conflicts within a given road intersection (as shown in Fig. 2).

When it comes to gathering video footage for various projects, the decision often revolves around selecting between stationary or temporarily installed CCTV cameras, utilising drones, or using panoramic cameras. In nearly all situations, the algorithms that were trained exhibited reliable performance in fulfilling the project's requirements. Some projects required detailed safety analysis focusing on pedestrians and vehicles. If the choice is made to use a drone, videos captured from an angled perspective typically yield higher accuracy compared to top-down views, as the angled perspective enhances the recognition of pedestrians. This highlighted the need for a more detailed examination of the available video collection alternatives.

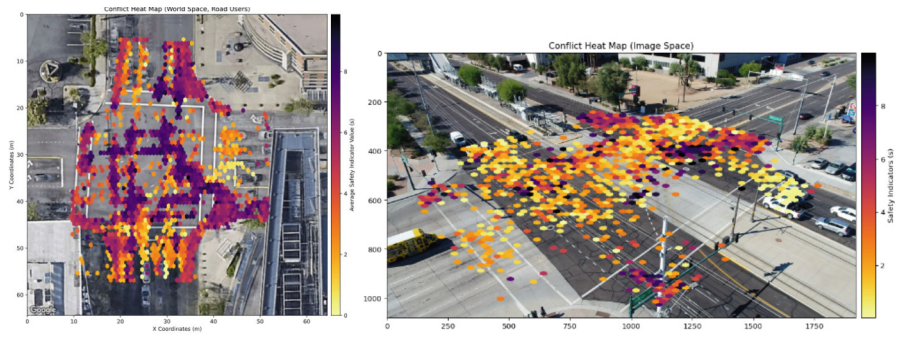

Fig. 3. Conflict areas from analysis of video collected by drones (top view and angle view) (Images courtesy: Transoft Solutions Inc. Results generated by TrafxSAFE.)

5 Discussion and Future Work

The applications of the framework showed that LiDAR based technologies typically involved greater efforts on planning, feature extraction, vehicle classification, tracking, and labelling, and its relatively high technology costs. Therefore, the score values assigned to these tasks are comparatively low. By contrast, the latest algorithms for video processing generally exhibit strong performance in both accuracy and efficiency. Once these models have been trained, they can be readily applied to other similar projects. Therefore, in the framework it is reasonable to assign relatively high score values to related tasks such as object detection and tracking. Using this framework for comparison, the usual decisions revolve around choosing between CCTV and drone-based options. Also, the score values vary significantly from project to project depending on factors like the availability of existing infrastructure. Generally, when high masts are accessible, the CCTV option frequently garners the highest scores, indicating its superior suitability compared to other available options.

The suggested framework offers an evidence-driven approach for choosing computer vision systems for assessing traffic safety at intersections. However, being a high-level approach, it has several limitations. First, all the factor weights and score values are based on empirical and subjective assessments, which potentially introducing bias in favour of specific technologies. The Choosing By Advantages (CBA) model can be utilized to make the process more objective, given its advantages when compared to the WRC model [12]. Secondly, there are more data collection technologies available such as data from connected vehicles which could significantly improve the accuracy of the analysis and prediction [13] and will become cheaper in the future. Thirdly, the selection process can be enhanced through a more detailed breakdown of tasks, such as dissecting video analytics tasks into algorithmic components. Finally, the proposed framework represents an ongoing learning journey, and the selection outcomes align more closely with real-world conditions as time progresses and the number of projects grows.

6 Conclusions

In this paper, a framework is introduced for the systematic selection of CV technologies for analysing traffic safety at intersections. It encompasses all stages of the project and captures and integrates inherent factors that are applicable across different technologies with those that are technology specific. The aim is to facilitate an optimal decision-making process that balances cost considerations and performance outcomes. It allows for creating transparency, building consensus, and continuous learning and innovation among project participants and stakeholders. While initially designed for projects focused on traffic safety analysis at intersections, this framework can be readily adapted and employed for other projects that require the selection of computer vision technologies. The framework is developed based on the adaptation of WRC model, a widely adopted tool by civil engineers. This allows transportation engineers to seamlessly incorporate it into their practices. Simultaneously, transportation authorities can harness its capabilities to extract valuable insights regarding technology selection procedures employed by service providers and their specialized proficiencies, potentially embedding such insights into their tender evaluation criteria.

In conclusion, the presented framework primarily functions as a high-level tool for technology selection and is not designed for conducting price comparisons among various service providers. Enhancements to its subjective selection approach can be achieved by incorporating quantitative models and providing a more comprehensive breakdown of project stage tasks.

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Characterisation of Road Friction Based on Vehicle Telematics Data

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Abstract. Road friction is a critical factor for road users' safety. Although various methods exist to measure road friction, these do not enable road managers to assess how continuously evolving environmental and traffic conditions affect road surface properties and the ability of drivers to stop their vehicle safely. In order to overcome the limitations of standard methods, NIRA Dynamics has developed algorithms to estimate friction based on vehicle telematics data, which is put to trial. By replicating a number of common driving and emergency braking situations at a local test track, data were collected using a station wagon type of car. A combination of hypothesis testing, clustering analysis and feature importance algorithms has enabled the use of NIRA's data to differentiate between pavement materials and conditions, as characterised by different friction properties. Results show great potential for vehicle telematics technology to revolutionise the world of road condition monitoring, to better understand tyre-pavement interaction and levels of road friction required to keep drivers of modern vehicles safe. This will help road managers optimise their asset management and maintenance strategies, to keep their networks safe and reliable all year round, based on near real-time information.

Keywords: Road Friction · Road Surface Characteristics · Road Condition Monitoring · Real-Time Monitoring · Vehicle Telematics

1 Introduction

Loss of control due to skidding can be a significant factor of accidents, especially in wet conditions [1,2]. As a result, ensuring that an adequate level of skidding resistance (road friction) is provided to vehicles, in all conditions, is crucial for road users' safety. Tyre-road interaction and the resulting level of friction between tyre tread and the road surface can be influenced by several factors, including vehicle speed, weather conditions and road surface characteristics. From a pavement engineering and road asset management perspectives,

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low friction levels can be a significant factor in driving design, operational, maintenance and rehabilitation decisions and strategies.

In the United Kingdom (UK), the friction properties of wetted pavement surfaces are monitored annually, using either the Sideway-Force Coefficient Routine Investigation Machine (SCRIM) or GripTester [3]. This has allowed UK road authorities to manage the condition on their networks consistently, enabling them to reduce the effects of skidding as a contributory factor in road accidents at a national scale [4]. However, these standard methods can fail to detect the temporal variations of road friction and may not reflect the level of friction generated by the latest vehicle/tyre technology and pavement surfaces.

Recently, a few studies have focused their attention on using vehicle telematics data for road performance investigation [5–8]. For example, NIRA Dynamics, part of the Volkswagen group, have developed algorithms to use this information to estimate friction. Although NIRA's technology has demonstrated invaluable to solve some of the most pressing severe weather related challenges, including to identify the presence of large amounts of water or ice-formation on the road surface, it is currently unclear whether the technology can be used to characterise the friction properties of road pavements, distinguish between materials and deterioration levels, as SCRIM and GripTester do.

This study investigates the current level of preparedness of the NIRA Dynamics' product to distinguish between pavement materials, conditions, and explores opportunities for vehicle telematics technology to support decision-making in the areas of pavement engineering and road asset management.

2 Methodology

The methodology developed and applied in the study consists of two phases, 1) the technology trial set up (data collection), and 2) the data analysis. Details about both phases are elucidated in the following sections.

2.1 Technology Trial Set up

The testing was performed at three circuits of the HORIBA Mira proving ground, in Nuneaton (UK):

- Data from the Straight Line Wet Grip were captured from three lanes (2, 3 and 4). Lanes are 100 m each, and are surfaced with Basalt tiles, ISO Braking Asphalt, and a share of Bridport Pebble and ISO Asphalt respectively. Sprinklers allows to wet the road surface uniformly on the circuit.
- The materials tested on the Handling and Cornering are the same as on the Straight Line Wet Grip. Also this facility has sprinklers. Performing similar tests on the two circuits allows to consider more unfavourable circumstances.
- Data from the Twin Straights facility were captured from three sections of the circuit: 1) 150 m of some newly laid Stone Mastic Asphalt (SMA), 2) 150 m of some newly laid Hot Rolled Asphalt (HRA), and 3) about 100 m of some

old HRA. The facility does not have sprinklers and so a water bowser was used to wet the road surface ahead of vehicle use. This may have not enabled to recreate a fully uniform layer of water on the pavement.

The vehicle used for the testing was an Audi A6. The data is collected by NIRA telematically, using a proprietary algorithm which allows to communicate with the vehicle electronic control unit (ECU) and retreive standard CAN-bus data such as GPS location, individual wheel speed, etc. The data is then processed to estimate friction i.e. tyre grip point upper and lower bounds. In addition, the travelled distance in metres, elapsed time from previous data point in seconds, instantaneous speed, instantaneous acceleration, and type of manoeuvre were calculated. As the data can be sensitive, the information retrieved is never stored by NIRA, which releases the information straight away.

Four sets of tyres were used during the testing. This is to better understand the effect of using different tyres on the tyre-road interaction and resulting friction levels. Figure 1 shows the tyre treads that were tested. The tread patterns of the four tyres are different as they are designed for use during different seasons.

Fig. 1. Pictures of the tyres used (Source: Produced by the authors).

Tests were repeated by NIRA both in acceleration and deceleration (more details provided in previous publications [9]).

2.2 Data Analysis

A total of 88,654 data points were collected, with about 20,000 data points collected with each set of tyres. In order to analyse the data, two methods were adopted in the study:

a. The first method is tailored to situations where the position of the materials on each circuit is known (i.e. Straight Line and Handling and Cornering) and statistical tests can be used to make comparisons. For this purpose:
   1) first, data distributions are plotted and compared for different routes.

2) then, the Kolmogorov-Smirnov [10] and Levene's tests [11] are used to test the normality and equality of variance of the data. p-value < 0.05 enables to reject the hypotheses of normality and equal variances.
3) as the data reveal to be non-normally distributed and with unequal variance, the Kruskal-Wallis non-parametric test [12] is then used to compare the data for different tyres and materials. Here a p-value < 0.05 allows to reject the hypothesis that samples come from the same data distribution, confirming how the data can differentiate between materials.

b. The second is tailored to real-world scenarios where the position of different materials or conditions are not known a priori (i.e. Twin Straights):
1) the k-means clustering algorithm [13] is applied, with different numbers of clusters (from 2 to 5) experimented, to uncover different patterns.
2) as the k-means clustering algorithm does not appear enough to differentiate between materials, the Random Forest feature importance algorithm [14] is then adopted to uncover the relationships between NIRA's estimates of road friction, pavement materials, tyre type and driving manoeuvre. The grid (exhaustive) search optimisation approach [15] and cross validation [16] are adopted to identify the best hyperparameters.
3) finally, data is plotted colour-coded on a map to define the position of the different materials tested on site.

Table 1 summarise average and standard deviation of the data collected. All data analysis steps and algorithms were implemented in Python.

Table 1. Statistical summary of road friction per tyre and circuit.

		Tyres			
Circuit	Route	Summer 1	All Season	Summer 2	Winter
Straight Line Wet Grip	Lane 2	0.14 ± 0.09	0.15 ± 0.06	0.14 ± 0.06	0.16 ± 0.04
	Lane 3	0.55 ± 0.10	0.55 ± 0.11	0.71 ± 0.08	0.58 ± 0.08
	Lane 4 Lower	0.36 ± 0.09	0.29 ± 0.07	0.34 ± 0.08	0.31 ± 0.07
	Lane 4 Upper	0.63 ± 0.09	0.56 ± 0.09	0.69 ± 0.07	0.53 ± 0.07
Handling and Cornering	Inner	0.09 ± 0.08	0.08 ± 0.07	0.08 ± 0.08	N/A
	Middle	0.16 ± 0.08	0.13 ± 0.06	0.20 ± 0.06	0.25 ± 0.06
	Outer	0.68 ± 0.05	0.56 ± 0.11	0.71 ± 0.05	0.58 ± 0.05
Twin Straights		0.76 ± 0.07	0.73 ± 0.06	0.81 ± 0.07	0.66 ± 0.06

3 Results and Discussion

Results of the Kruskal-Wallis tests applied to data from the Straight Line wet Grip and Handling and Cornering facilities show p-values < 0.05 representing

significant differences between the data collected from the vehicle equipped with different tyres, highlighting the importance of tyre type on friction levels.

Testing differences in friction for the data collected along different lanes (different pavement materials) using different tyres, the calculated p-values show significant differences ($p < 0.05$) in friction levels between materials, except for Lane 3 and part of Lane 4 which share similar materials ($p = 0.478$).

These results provide indications that NIRA's technology can differentiate between pavement materials and tyre types on the Straight Line Wet Grip and Handling and Cornering circuits, as characterised by different friction properties.

Looking at the data from the Twin Straights, no clear clusters were obtained from the k-means algorithm. This could be due to the uneven distribution of water across the circuit produced by the bowser.

Application of the Random Forest feature importance ranking algorithm highlights how vehicle speed and tyre type are the most influential parameters considered in the study, followed by acceleration and GPS location.

Filtering the data based on speed and tyre type, two clear clusters of lower and higher friction levels representing the locations of the new HRA and SMA were identified (Fig. 2). This constitutes additional evidence that NIRA's technology can distinguish between materials and their condition, with confidence.

Fig. 2. Friction clusters uncovered (Source: Produced by the authors in Python).

4 Conclusions

Scope of this study was to analyse the output from NIRA's algorithms and evaluate their ability to characterise pavement friction, based on vehicle telematics. Data were collected using an Audi A6 driven along different circuits, performing different types of manoeuvres. Statistical methods and semi-supervised learning techniques were used to highlight differences between materials.

Results from the statistical analysis and k-means semi-supervised learning algorithm show that the information provided by NIRA Dynamics' can be used to characterise the friction properties of road pavements and conditions based on vehicle telematics data, even without knowing their initial location.

Results also indicate the significant effect of tyre type and manoeuvre on friction, with the measurements that present large variance, as expected. This also reminds of the many limitations that standard measurements present, which impede road authorities to consider the temporal variations of friction that yearly measurements cannot evidence.

Going forward it is recommended that vehicle telematics technology is trialled in an operational environment. This will provide critical information to better understand current limitations of the technology, and guide future research for application of this data in the areas of road safety and asset management.

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High Density Observation Network for Near Real Time Detection of Hail Events

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Abstract. This paper outlines the problems associated with sudden onset hail events on the Transport Infrastructure Ireland road network which have led to a number of road traffic accidents in recent years. In an attempt to minimise these accidents a dense network of weather observing sensors is defined and explained which enable rapid identification of events as they happen in order to warn drivers approaching the event area. The paper sets out the problem in detail and also identifies the sensors to be used in the deployed network. This incudes the novel use of IoT based sensors as supplementary to a grid of reference grade present weather detectors. The methodology for the network design is explained and the primary network is shown with reference to the need to detect hail events that can be of relatively small footprint area, hence explaining the need for a dense observing network to detect these events in real time.

1 Background

Over the last few years there has been growing concern regarding the number of accidents occurring on the road network of Ireland that are attributed to hailstorm events. This may in part be due to gradual changes in Irelands climate, but also to the fact that many roads have been built or upgraded that are now able to offer faster maximum speeds to road users.

Vehicles, when approaching a localised hail event are, in effect, encountering conditions normally found in winter, potentially moving from perfect driving conditions to a sheet of ice within just a few metres. This then leads to loss of control and accidents due to the sudden increase in stopping distance as shown in Fig. 1 below.

All accidents that have mentioned hail have been recorded and collated to form a heatmap as shown in Fig. 2.

What is immediately apparent is that there appears to be an area of highest incidence in the West of the country surrounding Galway then south to around Limerick and then eastwards along the motorway network.

The accidents have been serious with fatalities and multiple vehicles being involved in single incidents. Apart from the obvious and saddening human cost of those that lost their lives or had life-changing injuries, there is a clear economic cost to these accidents. One set of incidents in the Birdhill area in January 2018 involving 2 fatalities, and a 13 car incident between Moneygall and Roscrea junctions with one seriously injured, is

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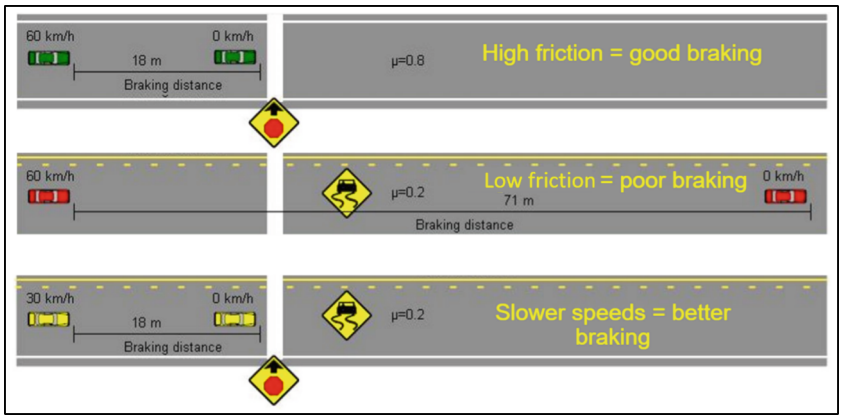

Fig. 1. Demonstration of braking distances under different conditions. Braking distance for a vehicle travelling at 60 km/h increases from 18m when friction is very good ($\mu = 0.8$ where μ is the friction coefficient) to 71m when friction is very poor as in intense hail deposition on the road surface ($\mu = 0.2$). However, by reducing the speed to 30km/h the original 18m stopping distance can be maintained.

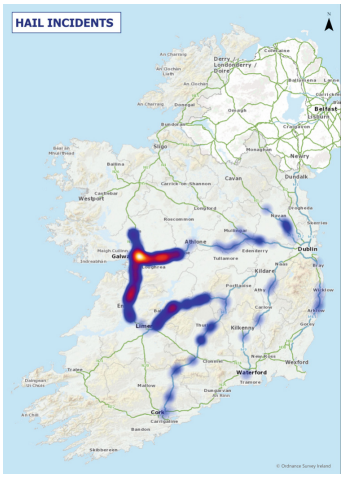

Fig. 2. Heatmap of recorded accidents attributed to hail events [1].

estimated to have an economic cost of close to €6m. In addition to this are the costs of the delays to traffic travelling those days on the M7.

2 Hail from a Meteorological Perspective

Hail comes from convective clouds that have grown up through the first layer of the atmosphere and have rapid and strong circulations of air within. What should be noted however, is that even though the cloud is large, the area of precipitation that contains

the hail can be relatively small. A hail event was captured by an existing weather station located on the M7 at Birdhill on May 3rd 2021. Figure 3 shows the radar image for the event at the time of the road becoming covered in hail. As can be seen the footprint of the hail event is very small in comparison to the cloud size.

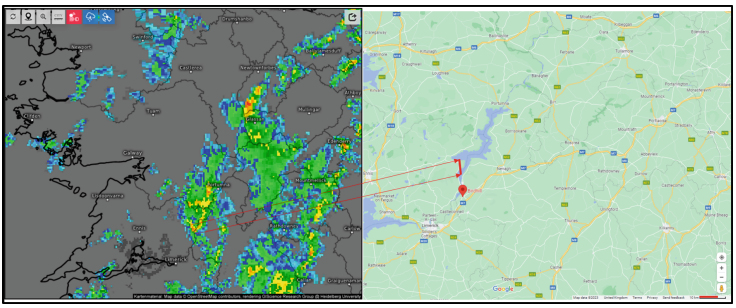

Fig. 3. Weather radar image of a hail event affecting the Vaisala Road Weather Station on the M7 near Birdhill on May 3rd 2021

3 High Density Observation Network for the Near Real Time Detection of Hail Events

The ideal scenario during a hail event is to be able to slow vehicles in such a way that they are travelling at safe speeds when they enter the hail zone. To achieve this any system will need to be able to identify hail quickly and ascertain the footprint of the event so that messages can be sent to the driver ahead of them crossing the boundary between relatively good conditions and those found inside the hailstorm.

Given that the footprint is potentially small (between 5 and 10km) any observation network should be at a high enough density to capture the event rather than let it slip through the gaps unobserved.

For observations, the Vaisala Forward Scatter Sensor FD70 [2] is reference level, and best in class at detecting the several types of precipitation that can fall (See Fig. 4). FD70 is a high-precision optical instrument with proven operational performance in all weather conditions. It can be set to identify precipitation particle by particle and report present weather, precipitation type, intensity, accumulation, droplet size distribution, radar reflectivity, droplet fall speed distribution and kinetic energy.

However, volume deployment may be cost prohibitive. As a result, there may be a need to fill the gaps between the FD70 deployments in such a way that relevant, proxy information can be captured to allow a high enough observation grid resolution. The achieve this the chosen option is to install Vaisala TempCast [3] sensors to measure rapid falls in road surface temperature. During the aforementioned Birdhill hail event significant changes in road surface temperature were recorded as shown (see Fig. 5).

The TempCast sensor measures ambient temperature, humidity and road surface temperature (See Fig. 6). It is a compact, battery-powered, IoT-based device (NB-IoT) that is easy to install especially on existing roadside furniture within sight of the road.

Fig. 4. Vaisala Forward Scatter Sensor FD70

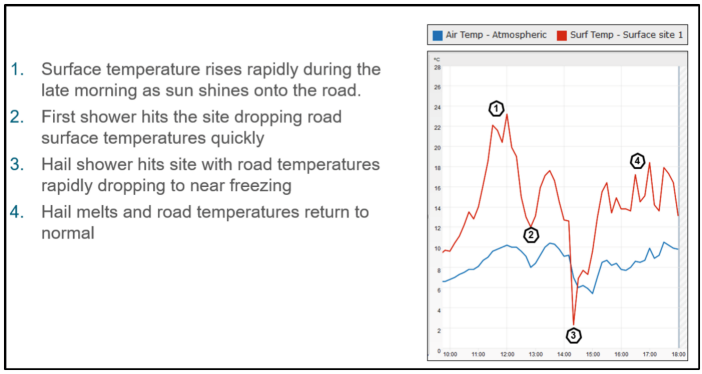

Fig. 5. Variations in Road Surface Temperature for the day of the hail event at M7 Birdhill on May 3rd 2021. Point 3 demonstrates the rapid loss of temperature as hail strikes the area dropping from around 12C to just 2C.

Fig. 6. TempCast IoT sensor measuring Ambient air temperature, humidity and road surface temperature

Although the readings taken from the TempCast sensor are not direct measurements of hail, the temperature drop displayed during a hail event are relatively exclusive to

frozen precipitation. Hence, in combination with data provided from the FD70 the project will investigate whether these 'proxy' readings can be utilised to identify the boundaries of any event, whilst allowing the FD70 to confirm the absolute presence of hail.

4 Network Specifics

The primary goal of the observation network is to identify the presence of hail as fast as possible thereby allowing communication to drivers approaching the area in a timely enough fashion for them to take the necessary action, which is envisaged primarily as speed reduction.

By way of example Fig. 7 demonstrates the projects configuration for a Proof-of-Concept Hail Observation Network.

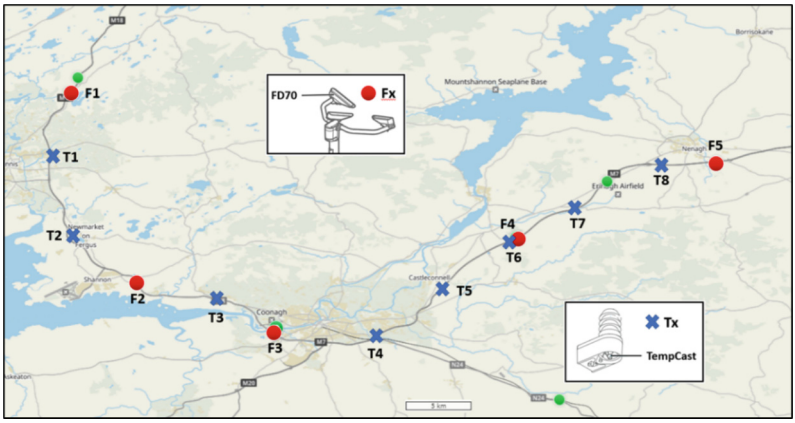

Fig. 7. Possible network layout for proof of concept with FD70 present weather detector co-located with existing weather stations, with infill observations provided by TempCast road surface temperature readings.

The network proposed co-locates FD70 Present Weather Detectors with existing Road Weather stations whilst the TempCast sensors will be interspersed at intervals of between 5 and 8 km along the same road network as site availability and communications dictate. One site at Birdhill will have all sensors co-located as a control site to monitor interoperability. The network is primarily a detection network to ascertain whether it is indeed possible to detect hail events in real-time. If its effectiveness is established, then communications methods such as Variable Message Signs or Connected vehicle alerts will be considered.

5 Conclusion

The critical need to address is the high number of hail related accidents happening on the Irish road network. This paper outlines the conditions that lead to these accidents and explores how a dense observation network may help in detecting a hail event in

very near real time. This will then allow transport authorities to activate strategies that address the need for vehicle speeds to be reduced before entering the hailstorm event. This speed reduction and forewarning of the driver is to ensure that control is not lost when entering a zone where road surfaces are covered in hail and thereby reduce the risk of accident substantially.

The network will become operational during the winter of 2023–24 and as such we hope to present case studies at the upcoming TRA 2024 conference in addition to the background presented here.

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Naturalistic Spatial Road Safety Analysis: The SmartMaps Project

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Abstract. This paper aims to leverage large-scale spatio-temporal data from smartphone sensors and geometric design characteristics for spatial analysis of telematics-based surrogate safety measures across various road environments. Two distinct statistical models have been developed: a non-spatial log-linear model and a spatial error model. The dependent variable in both models is the logarithm of the number of harsh braking events observed in each considered segment. The study area is located within the Western Greece Region and encompasses 9,355 road segments. The findings reveal a positive correlation between harsh braking events and the length of road segments as well as the number of recorded trips per segment. Furthermore, variables associated with speeding, mobile phone usage, and road segment linearity exhibit positive correlations with the number of harsh braking events in the examined segments. Moreover, harsh braking events on motorways are found to be lower when compared to other road types. In conclusion, the results of this study indicate that the spatial error model outperforms the non-spatial model in terms of data fit and yields more reliable outcomes.

Keywords: Spatial Analysis · Surrogate Safety Measures · Harsh Braking

1 Introduction

In recent years, there has been growing research focus on Surrogate Safety Measures (SSMs). Several factors have contributed to this research direction, primarily driven by technological advancements that have made data acquisition and analysis significantly more feasible and cost-effective (Nikolaou et al., 2023). SSMs offer several comparative advantages over crash data. They serve as proactive road safety indicators, enabling the analysis of road safety conditions before crashes occur, or even when events do not necessarily lead to crashes. Moreover, the crash data collection processes remain non-automated and may carry inherent limitations and biases, such as unavailable or inaccurate data (Imprialou and Quddus 2019), or variations in under-reporting rates

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among countries (Yannis et al. 2014). These are issues that can be mitigated by leveraging automatically collected SSMs. (Tarko 2018) emphasized that SSMs assist in identifying excessive crash risks on the road, enhancing the understanding of crash conditions, and providing a more robust evaluation of the effectiveness of experimental and existing countermeasures.

In a study of 668 road sections of the Olympia Odos motorway in Greece, a Negative Binomial regression model was developed with the number of road crashes (property damage and injury) as the dependent variable and two telematics-based SSMs (harsh accelerations and harsh brakings), the Annual Average Daily Traffic (AADT) and the segment length as independent variables (Nikolaou et al., 2023). The results of the study indicated a statistically significant and positive correlation between the two harsh driving behaviour metrics and road crash frequency. However, as a follow-up to this research, it was found that harsh brakings contribute significantly to predicting the crash risk level of the road segments under consideration, which is not the case for harsh accelerations (Nikolaou et al., 2023). It is therefore concluded that harsh brakings are a plausible SSM that can be used in various proactive road safety analyses.

Another notable study is that of (Stipancic et al. 2018). The authors modelled road crash frequencies using a Full Bayes model with SSMs as independent variables. The study used large-scale GPS data from smartphones and obtained several SSMs such as harsh braking and traffic flow parameters. The authors used a Latent Gaussian spatial model to model crash frequencies and reported that incorporating spatial correlations provided the greatest improvement in model fit.

Based on the aforementioned, the objective of this research is to use large-scale spatio-temporal data from smartphone sensors and geometric design characteristics for spatial analysis of telematics-based surrogate safety measures across different road environments in the Region of Western Greece.

2 Methodology

2.1 Data Collection

In the framework of the SmartMaps research project, data collection from various sources has been carried out to develop maps of driver behaviour with online information on safety conditions and eco-driving. The ultimate goal is to create a complete and comprehensive tool to promote driving behaviour in order to make it safe and environmentally friendly, while making the overall traffic more efficient and manageable, with application in Greece and around the world.

The dataset examined for the region of Western Greece comprises 9,355 road sections, with an average length of 223 m. In terms of road types, the distribution is as follows: residential roads (74%), tertiary roads (7%), primary roads (6%), secondary roads (5%), motorways (4%), and the remaining 4% comprises other road types. These data were derived by utilizing OpenStreetMap data, which were processed using appropriate packages in the R programming language (Padgham et al. 2017).

With regard to the naturalistic driving data, this study utilizes data obtained from an existing smartphone application developed by OSeven Telematics (www.oseven.io). A total of 14,161 trips in the study area within the year 2021 were examined, and a spatial matching of the naturalistic driving data and the road segments examined was performed. Table 1 demonstrates some key descriptive statistics of the collected data by road segment.

Table 1. Key descriptive statistics of geometry and driving behaviour data per road segment.

Variable	Min	Mean	Max
trip [count]	0.0	61.3	1,293.0
length [m]	1.3	222.7	18,029.1
linearity index [0–1]	0.03	0.95	1.00
harsh braking [count]	0.0	1.3	221.0
speeding [sec]	0.0	30.5	27,279.0
mobile phone usage [sec]	0.0	35.2	8,561.0

2.2 Statistical Analysis

The data presented in Sect. 2.1. Including road geometric features and naturalistic driving behaviour data via smart phone sensors were analysed by applying two distinct statistical models: a non-spatial log-linear model and a spatial error model. Log-linear regression is a widely known and simple technique and as such the mathematics behind it are omitted. The spatial error model handles the spatial autocorrelation in the residuals. The idea is that residuals from regression are autocorrelated in that the error from one spatial feature can be modeled as a weighted average of the errors of its neighbors. This model can be expressed as:

$$y = X\beta + u,\ u = \lambda_{Err} Wu + \varepsilon \tag{1}$$

where y is a (N × 1) vector of observations on a dependent variable taken at each of N locations, X is a (N × k) matrix of covariates, β is a (k × 1) vector of parameters, u is a (N × 1) spatially autocorrelated disturbance vector, ε is a (N × 1) vector of independent and identically distributed disturbances and λ_{Err} is a scalar spatial parameter.

The non-spatial log-linear regression model and the spatial error model can be compared using the Akaike Information Criterion (AIC), where lower values of this criterion indicate better statistical model quality (Akaike 1970).

3 Results and Discussion

As mentioned in the Introduction, harsh brakings are SSMs that can be used in analyses before road crashes occur. To this end, harsh brakings were used as a dependent variable in both the non-spatial log-linear model and the spatial error model of this study. The results of the two developed statistical models are presented in Table 2.

Table 2. Non-spatial log-linear regression and Spatial Error Model results.

Dependent variable: log (harsh brakings + 1)				
Parameters	Log-linear Model		Spatial Error Model	
	Estimate	p-value	Estimate	p-value
(Intercept)	−0.756	<0.001	−0.756	<0.001
trip count	0.003	<0.001	0.003	<0.001
log(1 + length)	0.099	<0.001	0.099	<0.001
log(1 + speeding)	0.115	<0.001	0.115	<0.001
log(1 + linearity index)	0.468	<0.001	0.467	<0.001
Mob. Phone use/trips	0.012	<0.001	0.012	<0.001
Motorway	−0.169	<0.001	−0.167	<0.001
Lamda	–	–	0.016	0.041
R-squared	0.556	–	–	–
AIC	11,826	–	11,824	–

Based on Table 2 results, the values and the signs of the independent variables' coefficients remain consistent between the two developed models. Specifically, both the length of the road segment under consideration and the number of trips per road segment can be considered as indicators of risk exposure and, as expected, are positively correlated with the number of harsh brakings. In addition, the positive sign of the independent variable of the road segment linearity index suggests that road segments with fewer curves have a higher number of harsh braking events. Moreover, the variables related to speeding and mobile phone use are positively correlated with the number of harsh brakings on the road segments considered. Lastly, harsh braking events on motorways are found to be lower when compared to other types of roads.

Regarding the spatial error model, the Lambda value of 0.016 is statistically significant, indicating that the error term is spatially autoregressive. Moreover, based on AIC values, it can also be observed that the spatial error model outperforms the non-spatial log-linear model. The spatial error model's predictions for harsh braking events in the Western Greece Region's road network are illustrated in Fig. 1. Figure 2 offers a close-up look at the predictions specifically for the city of Patras, Greece.

Fig. 1. Spatial error model results for the examined road network of Western Greece.

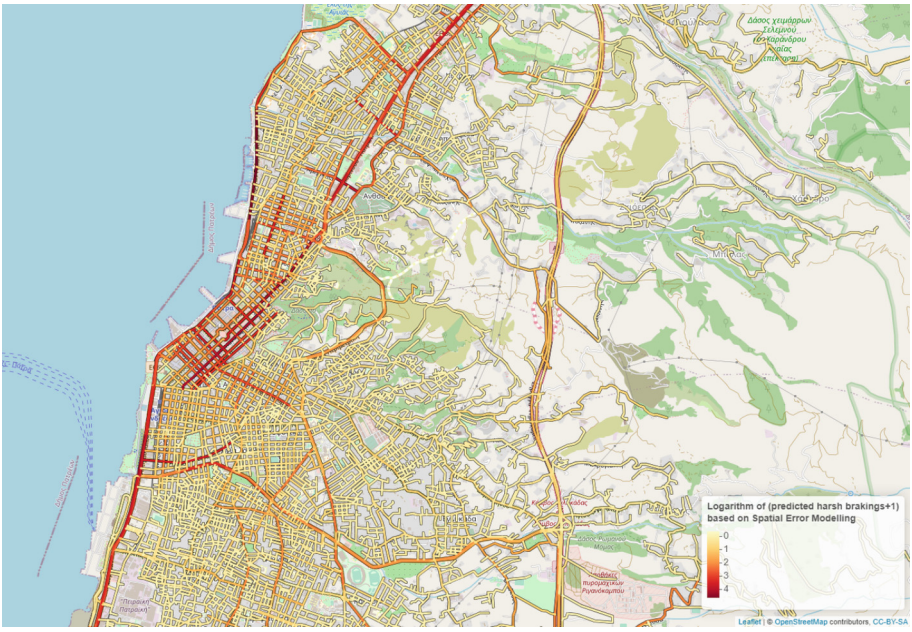

Fig. 2. Spatial error model results for the center of Patras, Greece.

4 Conclusions

This research aims to utilize spatiotemporal data from smartphone sensors on driving behaviour and geometric road features for spatial analysis of SSMs in various road environments in the Western Greece region. Specifically, two different types of statistical models were developed: a non-spatial log-linear model and a spatial error model. The dependent variable in the developed models was the logarithm of the number of harsh

braking events per examined segment, as it constitutes a SSM that can be used in road safety analyses either in cases where the exact location of road crashes is not available or as a proactive indicator before road crashes occur.

The results indicated that the number of harsh brakings in the examined road segments is positively correlated with the length and the number of recorded trips per segment. This finding can be considered expected since these variables are risk exposure indicators, and an increase in them leads to more harsh braking events. Furthermore, variables related to speeding and mobile phone use were positively associated with the number of harsh brakings in the examined road segments. Moreover, the results of this research revealed that the spatial error model demonstrates better fit to the data and lead to more reliable results than the non-spatial model.

Finally, it is worth noting that the ultimate goal and the intention of the research team is to create a comprehensive mapping tool covering all regions of Greece, promoting safe and environmentally friendly driving behaviour.

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• OptiMo, been financed by the Basic Research Financing (Horizontal support for all Sciences), National Recovery and Resilience Plan (Greece 2.0) (project number: 15629)

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Holistic Approach to the Transport Safety Assessment: A Case of Multimodal Transport Ecosystem

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Abstract. This paper explores methodologies, criteria, and frameworks utilized in safety evaluation within multimodal transportations. However, existing approaches to safety assessment have drawbacks when applied to complex systems, such as multimodal transportation. This includes issues, such as achieving local optimum, managing safety without direct infrastructure ownership, and unifying safety estimates across multiple modes of transport. The safety of these systems relies on both objective conditions and subjective factors aimed at preserving integrity and functionality. Therefore, there's a need for modeling safety assessments specifically tailored to multimodal freight transportation. This research utilizes mathematical modeling methods to develop an approach for assessing safety, addressing shortcomings of previous studies. The proposed method was applied to an existing multimodal transportation system, demonstrating its potential in evaluating safety levels and optimizing transportation routes.

Keywords: Transport Safety · Multimodal Transportation · Risk · Reliability · Holistic Mathematical Model

1 Introduction

The concept of "transport safety of multimodal transportation" comprises various aspects of safety, i.e. aviation safety, road safety, rail safety, sea safety and pipeline safety.

An analysis of transportation safety assessment approaches reveals two main perspectives: evaluating safety positively, focusing on reliability and sustainability [1–3], and assessing safety negatively, considering concepts of vulnerability, risk, danger, or threat [4–8]. While risk theory predominates modern safety assessments, some methods incorporate the human factor concept, requiring informal approaches due to complexity [9]. An analysis of scientific papers reveals several issues in this area: local modeling challenge (safety assessments are often specific to individual infrastructure objects or modes of transport, making comparisons difficult due to differing characteristic); one-sided safety assessment (most methods focus solely on assessing the safety of a transport hub or evaluating the probability of emergencies on transportation routes); safety

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management complexity (many methods are only suitable for transport companies that directly control transport infrastructure).

This paper aims to investigate methodological aspects of emergency risk assessment in multimodal transportation and provide a mechanism for selecting the optimal multimodal route during its design stage. It contributes to the literature by offering a new holistic mathematical model for assessing transport safety in multimodal transportation scenarios.

2 Method

The proposed method for transport safety assessment in case of multimodal transportation consists of two stages: evaluation of transport hub safety and assessment of critical failures on transportation routes.

The initial step involves estimating the reliability of transport hubs along a multimodal route. Security system in transport hubs can be considered as a non-redundant recoverable system. The stationary indicators can be expressed in terms of the average time between failures (T), the average recovery time of system elements (T_r), the readiness coefficient (K_r), the system failure rate (λ_s) and the recovery rate (μ_s) [10]:

$$T = \frac{1}{\lambda_s} = \frac{1}{\sum_{i=1}^{n} \lambda_i}; T_r = \frac{1}{\lambda_s} \cdot \sum_{i=1}^{n} \frac{\lambda_i}{\mu_i}; K_r = \frac{T}{T + T_r} = \frac{1}{1 + \sum_{i=1}^{n} \frac{\lambda_i}{\mu_i}} \quad (1)$$

$$K_r(t) = \frac{\mu_s}{\lambda_s + \mu_s} + \frac{\lambda_s}{\lambda_s + \mu_s} exp(-(\lambda_s + \mu_s) \cdot t) \quad (2)$$

The readiness coefficient (K_r) and the readiness function ($K_r(t)$) therefore can be considered as certain assessments of transport safety.

Following the evaluation of transport hub reliability, the next step in the proposed methodology involves conducting a risk assessment for critical failures on transportation routes. The calculation of apriori probabilities of emergency situations (ES) based on the ratio of the number of vehicles caught in an emergency (N_a) to the total number of vehicles passing through a route (N_l) is a straightforward approach to estimate the probability of an emergency occurring on a specific route.

$$P_j^s = \frac{\sum_l N_a}{\sum_l N_l}; \delta^2 = \frac{\left(P_j^s - P_j^e\right)^2}{2}; P_j = \frac{P_j^s + 4P_j^m + P_j^e}{\delta} \quad (3)$$

where P_j is the weighted average probability of occurrence of events j; P_j^s – apriori statistical probability of events j occurrence; P_j^m – the most probable value of events j; P_j^e – apriori (expert) value of the probability of events j occurrence; δ – dispersion coefficient.

Calculating the intensity of critical failures (i) for a specific time period (T) using statistics for each section of the route (l) involves assessing the rate at which critical failures occur within that time frame:

$$\gamma_{ij} = \frac{\sum_l N_i}{T \cdot \sum_l N_l} \quad (4)$$

The probability of failure (P_{ij}) and probability of critical failures (R_{ij}) can be expressed in the following way:

$$P_{ij} = 1 - exp\left(-\gamma_{ij} \cdot T\right); R_{ij} = \sum P_{ij} \cdot P_j \tag{5}$$

The formalized methodological approach requires the following adjustments: when comparing the readiness coefficients of various transport hubs, it's necessary to take into account different volume of their operations; the minimization of critical failures risk causes the need to mirror the safety indicator in order to operate the developed model for general optimization – minimization; enhanced transport safety assessments require methodological expansion through the inclusion of additional criteria, i.e. transportation time and transportation costs.

The final step involves analysis of the constructed assessment table under conditions of uncertainty with the help of the following decision-making criteria [11]:

- Laplace criterion:

$$\overline{F} = F\left(\overline{X}, Y\right) = min_{1 \le i \le m}\left(\frac{1}{n}\right)\sum_{j=1}^{n} a_{ij} \tag{7}$$

Wald's criterion:

$$\overline{F} = F\left(\overline{X}, Y\right) = min_{1 \le i \le m} max_{1 \le j \le n} a_{ij} \tag{8}$$

Hurwitz criterion. "Optimism coefficient" a is within $0 \le \alpha \le 1$:

$$\overline{F} = F\left(\overline{X}, Y\right) = min_{1 \le i \le m}\left[\alpha min_{1 \le j \le n} a_{ij} + (1 - \alpha) max_{1 \le j \le n} a_{ij}\right] \tag{9}$$

Savage's criterion:

$$\overline{F} = F\left(\overline{X}, Y\right) = max_{1 \le i \le m} min_{1 \le j \le n} (a_{ij} - min_{1 \le i \le m} a_j) \tag{10}$$

The multimodal route, which appears most often, during using these criteria can be considered as the optimal one. By combining these two assessments, the method provides a holistic view on the transport safety in a multimodal transportation ecosystem.

3 Findings

This section presents results of transport safety assessment in case of multimodal transport ecosystem using the proposed algorithm. Three multimodal cargo transportation routes were considered to test the algorithm:

Multimodal route №1 (MR1): seaport of Houston (US HOU) → Marseille-Fos Port (FR FOS) → Marseille Provence Airport (MRS) → Rzeszów Airport (RZE) → warehouse (WH).
Multimodal route №2 (MR2): seaport of Houston (US HOU) → Port of Genoa (IT GOA) → Milan Malpensa Airport (MXP) → Rzeszów Airport (RZE) → warehouse (WH);
Multimodal route №3 (MR3): seaport of Houston (US NYC) → seaport of Piraeus (GRPIR) → Eleftherios Venizelos airport (ATH) → Rzeszów Airport (RZE) → warehouse (WH).

The transport hub's reliability assessment is based on the processing of statistical information on safety system failures of the correspondent hubs [12–17].

Table 1. Data on safety system failures by transportation hubs [12–17]

Transport hub	Operating incidents	Acts of unlawful interference	Other
US HOU	94	14	0
MRS	49	19	5
FP FOS	110	21	0
IT GOA	127	23	3
RZE	34	10	0
MXP	25	19	1
BTS	120	8	5
GR PIR	93	7	0
ATH	45	6	2

The evaluation process adopted a time unit of one day. The purposed method was tested on Rzeszów Airport (RZE). System failure rate (λ_s), mean time between failures, average recovery time and readiness coefficient equal (Table 1):

$$\lambda_s = 0.0186 + 0.0038 = 0.0225 \tag{11}$$

$$T = \frac{1}{\lambda_s} = 44.64 \approx 45(days);\ T_r = 12.167 \approx (12\,days);\ K_r = 0.7858 \tag{12}$$

The transition time of RZE is 75 days. The reliability of other transport hubs on the routes is calculated in the same way with the help of MatLab software.

The risk assessment is thereafter performed on the selected multimodal routes, using the statistical data on the number of vehicles involved in an accident on the routes [18, 19].

The probability of risk of an accident in sea transportation USHOU - FPFOS is calculated by the types of failures:

$$\gamma_{dmg} = \frac{N_{dmg}}{T_i \cdot S_T} = \frac{11234}{12745 \cdot 7} = 0.1259 \tag{13}$$

The probability of vehicle damage (P_{dmg}) in case of emergency and risk of its damage during transportation (R_{dmg}) are determined in the following way:

$$P_{dmg} = 1 - exp\left(-\gamma_{dmg} \cdot T_i\right) = 0.623; R_{dmg} = R_{exp} \cdot P_{dmg} = 0.00192 \quad (14)$$

Risk of vehicle destruction during transportation was calculated similarly. The risk of a transport accident along the USHOU - FPFOS route is determined by summing the values of critical failures in emergency situations:

$$R_1 = R_{dmg} + R_{dst} = 0.0011 \quad (15)$$

The next step is selection of the optimal route, based on various criteria. A weighting factor is implemented based on the turnover share of each point within the transport hub system. The comparative non-safety values for transport hubs are determined by subtracting the product of the hub's readiness coefficient and its weighting factor from one. Similarly, the comparative non-safety value of a multimodal route is derived as the average of these values across its transport hubs. The absolute values should be transformed into the relative ones (Table 2).

Table 2. Relative values of factors of multimodal routes assessment

Route	Time	Costs	Risk	Non-safety on TH
MR1	0.8953	1	0.8863	0.9944
MR2	0.9321	0.9500	0.8855	0.9931
MR3	1	0.9768	1	1

The following step is to analyze the formed table using the criteria of decision-making in conditions of uncertainty (Table 3).

Table 3. Results of the analysis by the criteria of decision-making in uncertainty

Criterion	MR1	MR2	MR3
Laplace's	1.2587	1.2536	1.3256
Savage's	0	0	0
Hurwitz's	−0.3204	−0.3219	−0.3837
Wald's	1	0.9931	1

According to the results of calculations, the multimodal route №1 is the optimal route from the point of view of transport safety: seaport of Houston (US HOU) → Marseille-Fos Port (FR FOS) → Marseille Provence Airport (MRS) → Rzeszów Airport (RZE) → warehouse (WH).

4 Conclusions

Globalization of the economy and evolution of modern supply chains lead to the development of different multimodal transportation routes. Regrettably, the matter of safety assessment for multimodal transportation has not been extensively explored.

The paper proposes a new holistic approach to safety assessment for multimodal transportation, addressing existing shortcomings in methodologies. This approach enables the evaluation of both transport hub safety and critical failures on transportation routes. By using this method, alternative multimodal transportation routes can be assessed based on selected criteria, allowing for improvements in transport safety during route design. This approach facilitates the identification of potential weaknesses and the development of strategies to mitigate risks, enhancing overall safety in multimodal transportation operations.

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Efficient Simulation of Aircraft De-Icing Safety Enhancement and Heat Load Reduction via Super Hydrophobic Coatings

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Abstract. The description, validation, and first application of a phenomenological model for efficient evaluation of the performances of modern super-hydrophobic surfaces for anti or de-icing operations is presented. Developed within the framework of IMPACT CleanSky-2 project, the procedure captures the different topologies of the water layer along the aircraft surfaces due to the different coating performances, including still-standing single droplets, moving ones, rivulets, and films. The results, in agreement with literature data, confirm that hydrophobic surfaces, while unable to provide a fully passive anti-icing device, offer a significant improvement in both energy efficiency of the thermal protection systems and safety enhancement, since quicker drainage of the runback water prevents unexpected ice accretion on downstream un-protected surfaces.

Keywords: IMPACT CleanSky-2 · superhydrophobic coatings · in-flight icing · modeling · safety · power reduction

1 Introduction

In-flight icing is still a major safety issue for aircraft operations. Proper knowledge of the involved phenomena, as well as an efficient approach to anti and/or de-icing procedures, has thus an appreciable impact on the aircraft performances. Beyond the obvious safety requirements, and the energy consumption associated with de-icing devices, in fact, accretion issues may define constraints on the maximum lift available from the different surfaces, with an influence on the global aircraft design options, thus playing a role towards flight sustainability. This become even more relevant in view of the energy transition, since the most reliable and efficient de-icing system exploits the waste heat from gas turbine engines, which would not be available anymore, as an example, for an electrical-powered aircraft. For these reasons, ice accretion modeling is getting fully integrated into the design procedure, rather than treated as an after-thought safety check. This is the approach followed in the CleanSky2 project IMPACT (GA no. 885052), focused on revising the aerodynamic and aero-structural design of the next-generation Short and Medium Range aircraft.

Several successful numerical simulation tools (see, as an example [1, 2]) can predict ice accretion on standard surfaces. Most of them follow the Messinger approach [3],

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implicitly assuming runback water as a continuous film. However, the development of reliable nanostructured, superhydrophobic surfaces, opened opportunities that cannot be described by such traditional models. Different coatings are available, from extreme hydrophilic, where the droplets spread on the surface quickly transforming into a continuous film, to extreme hydrophobic, where the droplets rest as spheres with a minimum contact area and are easily removed by shear or gravity. Hydrophobicity may delay the formation of continuous film and extend the droplet regimes, allowing for quick water drainage, either preventing the ice formation or at least reducing the heat load required for de-icing purposes. The simulation of such a regime requires proper modeling of the droplets' equilibrium and coalescence processes, as well as their development into rivulets and film. Within the above-mentioned IMPACT project, a hierarchical approach was followed: a campaign of high-fidelity simulations provided a sound statistical reconstruction of the average water layer parameters (droplet or rivulet size distribution, wetted area, water velocities, relevant heat transfer surfaces) and the relevant threshold criteria between static and running droplets, running droplets and rivulets, rivulets, and film regimes. The high-fidelity modeling is based on a phenomenological approach, which is way less expensive than a full VOF or similar full two-phase flow computation with the resolution required to describe each droplet. Integration of such results on a control volume offers an efficient model that, skipping the details of the smaller scale (single droplet), can be easily integrated within the standard CFD models. Here, we focus on the phenomenological model, its validation, and the analysis of an icing case which offers some hindsight on the possible scope and efficiency of hydrophobic surfaces in this field of application.

2 Mathematical Models

In-flight icing occurs when an airplane flows through a cloud of supercooled droplets, which can freeze on impact on the surface, or flow along it in the form of moving droplets, rivulets, or films which can freeze at some downstream location. Simulating such a phenomenon requires accurate modeling of the flow around the critical surfaces (wings leading edges, engine nacelles, tail planes), proper modeling of the interaction between the impinging droplets and the surface, the simulation of the water layer on the surface through all of its transformations: transition between still and moving droplets regimes, the onset of rivulets, their merge into continuous film, all in presence of phase change due to freezing and evaporation. Since the physical scale of the involved problems ranges from the micrometer scale of the impinging droplet radius to the multi-meter scale of the flow field around the whole wing or aircraft, the numerical workflow exploits a hierarchical suite of modeling tools starting from the droplet scale. The details can be found in [4], but the procedure is here summarized.

At the smallest scale, we do not model the single droplet growth and deformation via expensive CFD, but we assume them as independent individuals evolving according to simple rules (i.e., phenomenological modeling). As a first step, following [5], a correlation based on the local Weber number (ratio of the inertial to surface tension forces) checks whether the impinging droplets rebound (as with superhydrophobic surfaces and fast-coming droplets), while a model based on the local streamwise derivatives of the

shear stress offers an estimate of the distance at which the droplet hits the surface at a secondary impact location. These coupled correlations are used to correct the collection efficiency computed by standard approaches [1], which consider only the first impact. Numerical results show that the distance between first and secondary impact is usually quite small, so it plays a significant role only for very small elements, such as cables, while is negligible on the scale of the wing of a large airfoil. Once the collection efficiency, and thus the distribution of the impinging droplets on the surface, is defined, a Lagrangian model describes the time evolution of a population of droplets following their growth due to coalescences, movement driven by shear stress, transition to rivulets, coalescence of rivulets into a continuous film. The model was first developed to predict roughness evolution for rime ice [6] and later refined and applied to a wide range of droplet-related heat and mass transfer processes [7, 8]. Droplets are assumed as spherical caps subjected to aerodynamic drag, gravity force and surface tension forces. The latter are introduced through the hysteresis between advancing and receding angles, integrated along the contact lines [9, 10]. The droplet stands still if the surface tension forces are not overcome by shear and/or gravity. Transition to rivulets is defined by a balance of the same forces on half of the droplets, detecting the onset of droplet elongation [11]. The rivulet is modeled as a series of overlapping droplets: this allows the definition of the entrainment of individual droplets along the rivulet path with the same approach used for the droplet-to-droplet coalescence. Individual droplet velocities derive from a power balance, and rivulet and film velocities follow the assumption of constant shear stress along the water layer thickness. An instantaneous snapshot of typical results is presented in Fig. 1, for two surfaces hit by the same droplet mass flow and diameter. The hydrophilic surface shows larger droplets, still or moving (the latter identified by the dry surface left behind) and the onset of rivulets (identified as overlapping droplet clusters). The superhydrophobic surface offers smaller droplets, no rivulets, and clear traces (the strips at lower droplet density) of quick-running individual droplets.

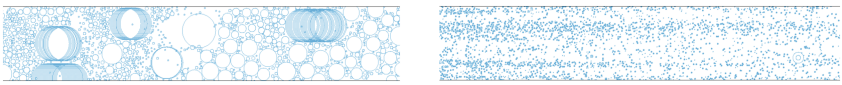

Fig. 1. Typical results obtained via the present model for droplet evolution on (left) hydrophilic and (right) superhydrophobic surfaces. Air velocity and drag forces from left to right.

At each time step, the energy balance equation for each individual droplet includes the convective heat transfer to the air, the heat flux provided by the de-icing heaters, the heat transfer related to phase changes (freezing on the solid-droplet interface and evaporation through the spherical cap surface exposed to the air). Freezing is not instantaneous but occurs after a short time lag due to the time required by the nucleating process to cover the whole contact area between the surface and the droplet [12]. Once the time lag has elapsed, an iced bead is formed and grows according to the freezing heat flux from the energy balance, until all of the volume of the parent droplet is frozen. Rivulets and film heat transfer follows the standard, Messinger based, energy balances, except for the correction (in the rivulet regime) due to the difference between the base area (where freezing occurs) and free surface one (where convective heat transfer takes place).

3 Validation

The experimental analysis of coating effects on ice accretion presented in [13] was chosen for a comprehensive validation of the above-described numerical modeling. In the cases chosen for the validation, a very small wind turbine airfoil (15 cm chord) is tested in an icing tunnel: free stream velocity is 40 m/s, liquid content LWC of the incoming flux of supercooled (−5 °C, 30 μm diameter) droplet is set to 2 g/m^3.

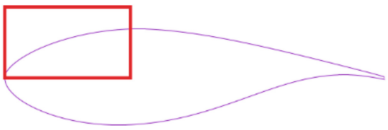

Fig. 2. Wind turbine profile Simulated surface within the rectangle

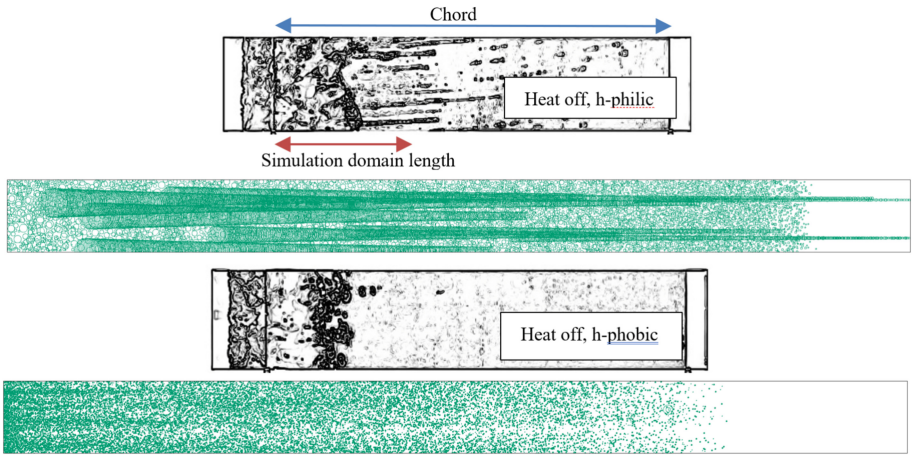

Fig. 3. Heater off; experimental images adapted from [13] and numerical results (green circles: iced beads and iced rivulets). Top, hydrophilic case, bottom, superhydrophobic case.

Two different coatings are considered, a hydrophilic one (advancing and receding contact angle 105° and 50°) and a super hydrophobic one (advancing and receding contact angle 159° and 154°). The airfoil profile is shown in Fig. 2: a heater covers 30% of the chord, starting from the leading edge. The simulation is performed on the small area inside the rectangle in the same Fig. 2. External airflow solution, shear stress and heat and mass transfer coefficients come from a CFD solution (SU2 code). Collection efficiency is evaluated via Lagrangian tracking of droplets within the CFD solution. It is important to note that the present model does not include the effect of geometrical shape deformation due to the accreted ice layer. Standard processes, as in [1], could be used to add this effect, but are beyond the scope of the present paper. Thus, the simulation is accurate if the accreted ice is relatively small. The comparison with the results shows that the qualitative behavior is well captured: switching off the heater we have ice accretion

on both the hydrophilic and hydrophobic surface, but the latter has a smaller iced area, no apparent rivulet, and a completely clean surface beyond the impinging zone, while the former presents, in both numerical and experimental results, iced streaks due to the freezing of rivulets. Switching on the heater, the hydrophobic surface is completely clean with a heat flux of 2.7 kW per square meter, while the hydrophilic coating, even at an heat flux of 3.2 kW, still produces significant ice accretion beyond the impinging region, due to runback water freezing (Figs. 3 and 4).

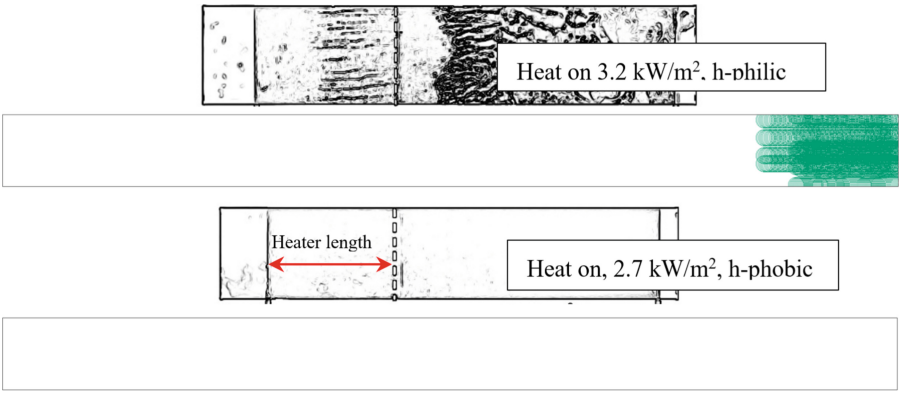

Fig. 4. Heater on; experimental images adapted from [13] and numerical results (green circles: iced beads and iced rivulets). Top, hydrophilic case, bottom, superhydrophobic case.

4 Conclusions

The proposed phenomenological model offers a relatively efficient (if compared to full two-phase flow computation at the high resolution required by the individual droplet scale) way of describing the performances of properly designed nanostructured, super-hydrophobic coatings in the field of anti and de-icing processes. The validation confirms that the simulation can capture the complexity and variety of different ice topologies produced by different coatings. Furthermore, the results, in agreement with the experimental data, show that super-hydrophobic coatings do not provide a full passive anti-icing device: in fact, typically at least the smaller impinging droplets will have a radius smaller than the threshold radius triggering the droplet movement; thus, small beads will appear progressively destroying the coatings effect (ice is super-hydrophilic, with contact angle close to zero). Nonetheless, coupled with thermal devices such coatings strongly reduce the required heat load, and offer inherently better protection from downstream runback water freezing, due to the quicker drainage of the small-hysteresis, tiny droplets. This is an important safety feature, since it prevents the possibility of unexpected ice accretion in non-protected, but possibly critical areas (sensors?) far away from the impinging zone.

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Integrating Human Factors and Neuroscience Research Through Neurophysiological Metrics Across Transport Modes

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Abstract. The application of neurophysiology to assess human cognitive processes has gained significant momentum in recent years across all transport modes. The present contribution reports the collaborative effort between Human Factors (HF) and Neuroscience research in aviation and automotive EU projects that has led to major advances in understanding human performance and neurophysiological assessment across transport modes. An overview of the current state-of-the-art, and related best practices, in terms of neurophysiological assessment of specific HF concepts to improve transport safety and efficiency is reported, as well as the insights for the design of user-centered and effective human-machine interfaces, adaptive automation, and the development of transparent AI systems.

Keywords: Human factors · Neuroscience · Human Performance · Neurometrics · Transport · Road Safety

1 Introduction

The increase in automation across transport modes is considered a promising mean to accelerate the shift to sustainable and smart mobility, thus contributing to a more affordable, accessible, inclusive, and connected transport system, and helping to achieve the United Nations (UN) Sustainable Development Goals 11 focused on sustainable cities.

Establishing connectivity between road users and automated systems through Human Machine Interaction (HMI) can indeed have a major positive impact on traffic safety, and flow efficiency, by assisting drivers/users to perform safe and effective operations in traffic, i.e., by sharing information and coordinating their actions accordingly. However, with the progress of automation, new forms of interaction where a human operator may be absent might confuse and/or stress users due to the uncertainty, e.g., whether the automated vehicle/system correctly detect them; what the intentions and future behaviours of the vehicle/system will be; or even the coordination between humans and artificial intelligence (AI) systems to perform operations (e.g., Reduced crew operations, Single pilot

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operations). In that sense, automation requires to be adaptive to the needs and requirements of the various users to efficiently communicate and coordinate. This concern is particularly relevant in the current transition scenario where we are still far from having fully autonomous vehicles and systems, therefore automation intrinsically implies a continuous interaction between the human and the machine that will alternately share/pass the leadership and control of specific tasks. It becomes crucial to make the machine aware of the psychophysical state of the user, i.e., situational aware, mental under- or overloaded, stressed, etc.

The present work, based on a neuroscientific approach to assess the user's state, aims at enhancing this innovation generating reliable measurement of HF concepts particularly relevant to monitor task in automated system, with a potential considerable innovation in the training activities (providing trainers with the possibility of monitoring the trainee response during simulations), in the design of new systems and in the development of technologies that have as an input the internal state of users.

2 Methods

The aim of this manuscript is to provide an overview of the current state-of-the-art of studies that use the present methodology, and the related best practices, in terms of neurophysiological assessment of specific HF concepts, i.e., the user's mental states. Therefore, this section is organized into three paragraphs, each one of them related to a specific topic of the methodological approaches deployed in this research field: 1) the sensors to get the neurophysiological data of interest; 2) how to process each kind of data; 3) how to neurophysiologically characterize a mental state and model it.

2.1 Neurotechnology and Sensors

During the last two decades, the scientific community achieved a high maturity in terms of computing, from human bio-signals, relevant neurophysiological indexes linked to the mental and emotional states [1]. In the described context of increasing automation, it would be extremely important to have information about the current state of the user, i.e., low or high vigilance or feeling stressed or having a low workload. Many studies have been interested in finding an unobtrusive, reliable, and real time assessment of such mental and emotional states. Traditional methods, such as behavioural and questionnaires (NASA TLX, SWAT, etc.) are not suitable for online seamless user's state monitoring. Most of these methods are not sensitive enough, are subjective, and do not provide information in real time, unless to become too invasive (e.g., instantaneous self-assessment) [2]. On the other side, modern neurotechnologies able to online record user's physiological activities allow to assess the user's cognitive and emotional states while performing any activity. The most used technologies, divided in terms of physiological activity, are the following ones:

Brain activity. Electroencephalography (EEG), for electrical cortical activity, and functional Near-Infrared spectroscopy (fNIRs), for brain oxygen consumption;

Heart activity. Electrocardiography (ECG), for heart electrical activity, and Photopletismography (PPG), for blood oxygen concentration variations;

Ocular activity. Electroculography (EOG), for the local (around the eye) electrical fields due to ocular movements, and Eye Tracking (ET, not properly a physiological activity) to track ocular movements and behaviour;

Skin sweating. Electrodermal Activity (EDA), to measure the skin conductance.

While brain activity is related to the Central Nervous System (CNS), the other physiological activities are regulated by the Peripheral, and in particular the Autonomic Nervous System (ANS). Depending on which branch it is investigated, different and complementary information can be obtained: in general, the CNS investigation provides direct access to the cognitive phenomena and its evolution over time, while the ANS analysis allows to obtain insights about unconscious body reactions, usually a consequence of the main cognitive phenomenon. For instance, increased visual attention is reflected by an increased brain activity over the frontal areas, and a consequent decrease of eye blinks rate [3]. At the same time, it is important to consider the quality of the used devices. On one hand, wearable and comfortable devices are compatible with real settings, on the other hand it is extremely crucial to guarantee the quality of the raw data. Any data processing algorithm will likely work independently from the quality of the raw data, it is just a matter of processing numbers, however a poor raw signal quality will dramatically impact on the reliability and robustness of results. In this sense, some works highlighted the limited reliability of wearable EEG systems for applications other than gaming and leisure [4]. The results presented in the following have been all obtained through high-quality devices, ranging from the initial laboratory-like systems [5], to the most recent wearable ones [6, 7].

2.2 Data Processing

The majority of the research conducted until 2000s' was performed in laboratory environments, i.e., in highly controlled conditions, with poorly realistic tasks and several constraints, e.g., the participants were asked to limit their movements. Such experimental settings are very far from real conditions; therefore, the validity of the results could be arguable. The technological progress, the development of highly realistic simulators, as well as of portable neurotechnologies [8], allowed to bring the research outside the traditional laboratories, so in conditions very close to real life, providing an enormous impact in terms of results relevance. Otherwise, this imply a critical data-related concern: even if using the highest quality devices, the collected data will be affected by a huge amount of noise, due to electromagnetic interferences, user's movements, other physiological data such as ocular blinking, and so on. An approach including "all the data" is therefore not acceptable. It is crucial to deal with artifacts, i.e., all those signal alterations affecting the collected data, through a robust data processing in order to obtain significant results. All the works cited in the results describe the data processing approaches employed to deal with this concern.

2.3 Neurophysiological Characterization and Modelling of a Mental State

Data processing is usually aimed to compute specific features, i.e., informative signal characteristics, which variations will be investigated with respect to the investigated mental state. Then, through specific computational algorithms, usually based on

machine/deep learning, these features will be combined into a "predictive function", i.e., the model. Unfortunately, sometimes the researchers could over-trust in these methods, using them in a naive way, e.g., without imposing some a-priori hypothesis on the data [9]. The common error is to employ all the available features (for instance including the brain activity without considering the single rhythms and cortical regions) for modelling a certain mental state. This will mean to include into the model phenomenon-unlinked data that would affect the model reliability [10].

It is therefore important to limit the datasets to those features demonstrated to be directly linked to the investigated phenomenon. For example, it has been suggested that in terms of EEG, the power spectrum of the brain rhythms in the frontal alpha band (8–12 Hz) are inversely related to the vigilance level [11]. The EEG frontal theta (3–7 Hz) and parietal alpha bands have been linked in several studies with mental workload variations [12]. Ocular activity, e.g., in terms of eyeblinks, can be used to monitor vigilance and workload as well [13]. Heart Rate and its Variability have been proved to be directly corelated to workload and stress variations [14]. As regards skin conductance (EDA), several studies demonstrated the link between arousal and stress levels, and the tonic component of the skin conductance [15]. All these assumptions should work as a-priori hypothesis before using any machine-/deep-learning model.

3 Results

One of the first experiences in the aviation domain was the NINA project (GA n°12–120610-C4). The Skills, Rules, Knowledge (SRK) model [16] was used to assess at which level of cognitive control the Air Traffic Controller (ATCO) was dealing with the considered task, demonstrating that specific brain features could characterize and discriminate the different SRK levels, so enabling an objective assessment of the degree of cognitive control [17]. EEG-based neurometrics for workload assessment, training evaluation, and cognitive control were therefore successfully developed. The real-time utilisation of workload neurometric enabled the implementation of adaptive automation, contributing to enhanced operational efficiency and human-machine interaction [18].

The STRESS project (GA n°699381) further improved the neurometrics of workload and successfully validated neurometrics for stress and vigilance evaluation in aviation [19]. The combination and fusion of multiple data and signals were investigated to enhance the accuracy and reliability of workload and stress assessment [20]. While the MOTO project (GA n°699379) focused on using neurometrics to evaluate the perception and interaction of different augmented solutions for remote towers in virtual and real environments. The application of neurometrics shed light on cognitive aspects related to the adoption of augmented technologies, facilitating the design of more intuitive and efficient systems for Air Traffic Control (ATC) [21].

Within the ALICIA project (GA n°233682), three different types of screens for helicopter pilots were evaluated by measuring their brain activity (EEG). The impact of the different technologies on mental workload was assessed during simulated missions to identify optimal display solutions that effectively support pilot performance, considering factors such as visual attention and information processing [22].

The ARTIMATION project (GA n°894238) aimed to evaluate the cognitive impact of various AI solutions and their transparency in supporting ATCOs' tasks. By using

neurometric measures, the research team gained insights into the cognitive processes involved in AI-assisted decision-making, facilitating the development of AI systems that align with human cognitive capabilities and support operators effectively [23].

In SAFEMODE (GA n°814961), an interdisciplinary project within the transport sector (aviation and maritime), HF were used to enhance human-machine interaction and operational safety, through reliable cognitive neurometrics.

Regarding the automotive domain, the mental workload EEG neurometric were deployed to assess the impact of the type of road and specific events during a driving task in real settings [24]. The workload measure was also used to evaluate the impact of Advanced Driver Assistance Systems (ADAS) on driving performance. Specifically, it was employed a multimodal approach (EEG, ET) to assess the perception and impact of using Adaptive Cruise Control (ACC) while driving, showing that the use of ACC caused an increase in mental workload and Perception-Reaction Time [25].

4 Conclusions

The joint work aimed at highlighting the maturity achieved by neuroscientific methodologies, that nowadays can be considered not only as a research tool but as an effective application enabling new forefront solutions that were not achievable by traditional approaches. Given the relevance of their applications, usually linked to safety concerns, it is mandatory to perform research in a robust and scientifically-sound way. It is crucial to deploy reliable technology and data processing methods, as well as the collaboration with psychologists and HF experts in order to get outcomes that are actually relevant and realistic in the target transport modes.

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Future Flight Operations: Communication, Collaboration and Resource Management

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Abstract. There is a continued lack of full understanding of the task distribution between human and non-human agents in teams and the implications for operational safety are far reaching. The state of the art in Socio-technical Systems (STS) modelling has yet to take full account of new teamworking and collaboration using non-human agents (Salmon et al. 2016), and yet, there is significant scope and opportunity to advance thi. With the adoption of Extended Minimum-Crew Operations (EMCO), Single Pilot Operations (SiPO) and further deployment of Artificial Intelligence (AI) it is prudent to ensure a thorough and accurate understanding of the wider socio-technical system (STS) so that new operational risks can be identified, and appropriate mitigation strategies be put in place. This paper outlines the open issues surrounding novel approaches in flight operations and suggests ways in which these may be addressed.

Keywords: Single Pilot Operations · Distributed Teams · Crew Resource Management · Operational Risk · Integrated Flight Concept · Data Governance

1 Introduction

With the implementation of Extended Minimum Crew Operations (EMCO), Single Pilot Operations (SiPO), flight operations will change dramatically. This will be more evident when fully-automated flights, fleet taxis, etc. come to fruition. Even with fully automated flight, humans will be required to manage parts of the system and yet there is a clear gap in our comprehension of the wider socio-technical system and how humans and non-human agents work together in teams. Understanding this is imperative if both are to function at an optimum level and paramount when considering safety critical systems. Neither technology nor AI function in a vacuum – they do so as part of a large and complex socio-technical system with human agents in distributed networks throughout. It is vital that these safety critical systems of systems are supported appropriately. Furthermore, for improved teamwork in complex safety critical systems, it is necessary to define an appropriate STS model throughout the design lifecycle (i.e. iterative design of technology, procedures, training, implementation and evaluation) (Roberts et al 2022).

Neither the human agents nor AI are intended to work in silos, therefore an integrated view of the human and non-human agents and their contribution to the overall

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operation/mission/system is required (McDonald et al. 2017a, 2017b, 2015). There is a continued lack of understanding of the distribution of tasks and collaboration between human and non-human agents in teams and the implications for operational safety are far reaching (Ulfert et al, 2023). The state of the art in STS modelling has yet to take full account of new teamworking and collaboration using AI (Salmon et al 2016). There is a wealth of research done on distributed situational awareness (Stanton et al 2006, Kay et al. 2008, Stewart et al. 2008) whereby the importance of recognising situational awareness at a systems level and not individual or team level has been amply demonstrated (Salmon et al 2016). An STS level approach to situational awareness should be a key requirement for further research in this area with respect to AI. Such approaches should consider all stakeholders in the STS. Indeed, recent reviews of shared mental models (Andrews et al, 2023) indicate that novel means of modelling and measurement of human-AI teaming is required if we are to fully benefit from their collaboration.

All stakeholders need to be represented and for future flight operations, this is not limited to the flight deck. There is now and will continue to be a much wider network of agents such as remote pilots and ground support with further distributed team members and networks of teams necessary to support the flight operations, air traffic, ground handling, airline and airport operations etc. It is therefore important to look at the teams and the roles that all agents (i.e. human and non-human agents) have. In terms of technical robustness, technical capability and functionality, some advances from AI cannot be denied, however, do such advances necessarily make the global sociotechnical system (which includes human stakeholders) safer or any more effective? Does increased speed of decision-making using AI naturally result in the best decisions being made? Does this equate to robust design or safe operations?

2 Data and Risk

It is necessary to ensure that ALL the good stuff is captured too, i.e. what goes right in the system – what operators do well day-in-day-out to ensure the safe functioning of the STS (Hollnagel 2016, Leveson, 2020). We require the ability to quantify risk, however, we also need the "how?" and "why?" things happen. Sociotechnical systems research has long been asking for different types of data to be included in risk and safety management (Rigner et al. 2009) and yet the push for greater amounts of solely quantitative data persists. A full understanding of the STS requires a full complement of data in order to make sense of operations. Aven (2022) presents a welcome call for future research on operational risk to provide an integrated picture of the STS. Future means of risk assessment should take into account the integrated or more global operational (team) performance rather merely a sum of its constituent parts based upon previous incident data where non-human team members were not operational. Such an approach would encompass assessment of likely "systems error" rather than "human error" (Salmon et al 2016). Previously termed "human error assessment" should now be considered at a systems level – indeed more aptly named "system error assessment" would be in-keeping with state-of-the-art modelling of STS (Salmon et al 2016). Indeed, prospective Risk analyses would benefit future flight operations with a view to improved whole STS design (Ward et al, 2022, Geary et al 2022).

Humans are still essential to safety critical systems. We must be cognisant of this and ensure that they can operate safely in a system that has been designed to support them. Humans continue to be used as a failsafe mechanism in STS. A whole socio-technical system design needs to take this into consideration to ensure the humans in the system can cope, not overloaded, not out of the loop, trained adequately to cope for being a main redundancy factor. This is linked directly to quantification of uncertainty with human as main redundancy factor for new technology designs using AI, Remote operations, Distributed teams, human-machine teamwork. Scenario-based modelling for such redundancy conditions is required to ascertain suitability for new procedures, communication and technology design using AI including but not limited to 1) Normal operations: fatigue, boredom, rest periods & breaks and 2)Non-normal operations: Incapacitation, Technology failure, Comms link failure, Cyber-Security threat.

3 Certification

The ways in which pilots communicate and collaborate are likely to change with EMCO, SiPO and the further introduction of non-human agents in distributed teams. The means of training and assessing crew competence to communicate, collaborate and manage crew resources such as LOSA (Klinect et al. 2003), LOFT (CAA 2002) and NOTECHS (Flin et al. 2003)) are based on two co-located human pilots and do not account for the new make-up of teams. Certification of crew competence requires updating to account for new means of communicating and collaborating with other team members i.e. both human and non-human team members. Harris (2023) rightly stresses the need to consider the role of Captaincy on board aircraft operating under SiPO, whereby each pilot – the sole pilot in command of the aircraft (i.e. aviate, navigate and communicate), the cabin crew, passengers and will have the responsibility of managing the often competing demands. Harris queries how pilots will gain sufficient airtime and experience of managing competing resources and demands on board without co-piloting with an experienced Captain over an extended period? This is yet to be determined and warrants additional research in this area as well as sufficient resources assigned by the industry for appropriate and strategic human resource management.

4 Data Governance

All use of AI, monitoring and data usage/storage must be in accordance with the EU's data governance framework – i.e. aligned with a clear and transparent data justice perspective. It is critical that it be made apparent to all human agents that their data will not be used for any purpose other than the greater good and will be treated as part of a just culture. Mindful governance models for managing information and strategic risk management are also welcome (McDonald et al. 2019). Models such as the Mindful Governance framework was developed in the FutureSkySafety (EU Grant Agreement: 640597) project in order to codify principles of resilience engineering (Hollnagel, 2016) and mindful organising (Weick & Sutcliffe, 2006) for the management of operational performance in complex systems (McDonald et al. 2019). It is built around the concept of obligation to act – a mutual psychological contract between diverse actors that assures

accountability for importance, efficacy, and viability in different stages of a project (from problem to solution to plan to implement and to verify). Implemented in the ARK platform (McDonald et al. 2021), Mindful Governance is supported by a comprehensive Socio-technical Systems analysis (STSA) methodology (the Cube STSA) and is linked to relevant data, analyses, risk assessments and documentation in a systemic knowledge graph environment that supports sophisticated knowledge management functions - user support, search, comparison, synthesis, etc. It has been developed as a tool that can effectively address the management of the role of human factors or human agents within the aviation socio-technical system across the system lifecycle building on the experience of reconciling the requirements of design with the complex experience of operations (McDonald et al., 2015, 2017).

In this context, mindful governance can play the role of a higher order qualitative reliability method – a governance framework for managing projects across stages and across multi-disciplinary stakeholders that provides accountability in transcending diverse interests, and assurance that the roles of human agency in the relevant socio-technical systems are effectively addressed. The issue of trust has become increasingly important in the development and deployment of AI systems. A Mindful governance framework, supported by the ARK platform can play a critical role on fostering trust in the models across the aviation lifecycle, providing a practical methodology for satisfying European requirements for Trustworthy AI.

5 Ethics and Trust

In addition to future flight operations being carried under the umbrella of a just culture, it should be noted that the requirement for ethical practice throughout the design lifecycle be upheld. This is in-keeping with the 7 key ethical requirements for trustworthy AI as adopted by EASA (2023) and are worthy of note: Human Agency and Oversight, Technical Robustness and Safety, Privacy and Data Governance, Transparency, Diversity, non-discrimination and fairness, Societal and environmental Wellbeing, and Accountability. All use of AI and ethical practice surrounding flight operations should be made transparent and traceable. All human agents must be made aware of how their data will be used for the greater good and how they will be protected for further progression within organisations, future recruitment etc. Furthermore, Transparency, Accountability, Justiciability, and Legitimacy are considered to be essential attributes in the prevention of institutionalised distrust in AI systems (Laux 2023). Further research in this area is warranted specific to human-machine teamwork.

6 Conclusions

Integrated approaches to STS modelling including strategic collation of risk data (and analyses) and a comprehensive review of how we train, evaluate and assess crew collaboration and resource management are welcomed.

The modelling of systems and requirements analyses of said systems should not solely be focussed on the procedural aspects of what the AI does, but how it impacts the human agent in terms of communication, collaboration, decision making, situational

awareness and trust. Future flight operations can only be made more adaptable and effective if all agents (i.e. human and non-human) are supported appropriately throughout the entirety of operations.

The significant investment in technology design should be matched by significant investment in training, research and thorough human factors evaluation of how all team members are supported for both normal and non-normal operations. Further implementation of AI will also have substantial impact on competence of organisations, i.e. training, selection and recruitment must adapt to new demands and skills bases required (Harris 2023). Strategic Human Resource Management for the foreseeable future should be cognisant of this. If a wider socio-technical system employs humans for the foreseeable future, it will benefit all to ensure that they are appropriately recruited, retained and supported appropriately. Regulatory and Legal support for training, selection, certification and simulation must be put in place to support all activities and future flight operations.

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Condition Monitoring of Railway Transition Zones Using Acceleration Measurements on Multiple Axle Boxes: Case Studies in the Netherlands, Sweden, and Norway

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Abstract. Railway transition zones connecting conventional embankments and rigid structures, such as bridges and tunnels, usually degrade much faster than other railway sections. Efficient health condition monitoring of transition zones is important for preventative track maintenance. In this paper, a methodology for monitoring railway transition zones using acceleration measurements on multiple axle boxes (multi-ABA) of a passing train is presented. To showcase its capability, the measurements in the Netherlands, Sweden, and Norway are analyzed and discussed. It is found that different bridges and transition zones exhibit unique characteristics including dominant wavelengths and energy distribution. Based on these unique characteristics, the geometry and support conditions at different locations of a transition zone can be evaluated. Higher train speed makes the characteristics more pronounced. The results demonstrate that the multi-ABA measurement has the potential to evaluate and thus monitor the health conditions of various transition zones.

Keywords: Railway Transition Zones · Condition Monitoring · Axle Box Acceleration · Onboard Measurement · Wavelet Analysis

1 Introduction

Railway transition zones are track segments connecting conventional embankments and other civil structures, such as bridges, tunnels, and culverts. Track conditions usually degrade much faster at transition zones than those at other locations due to significant variation in track support properties. For example, in the Netherlands, the maintenance frequency at transition zones can be more than two times higher than that at other track sections [1]. Such frequent maintenance is not only very costly but also largely reduces track availability. Therefore, effective monitoring of transition zones is important for preventative and efficient track maintenance.

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In the literature, to monitor the health conditions of railway transition zones, trackside measurement techniques are commonly used. Coelho, et al. [2] measured the passenger train-induced dynamic responses of a typical Dutch transition zone linking a conventional track and a concrete culvert. The track settlements and pore water pressures were monitored over one year. Stark, et al. [3] reported an instrumentation program which included the measurements of wheel and tie loads, and the permanent and transient vertical displacements as a function of depth at three bridge approach sites in a high-speed line in the United States. More measurements on transition zones can be found in [4–6]. In general, the track-side measurements can capture many details of the transition zones, thus giving specific solutions to the problems. However, such techniques are expensive when multiple transition zones at the network level need to be monitored.

Alternatively, onboard measurement methods, such as axle box acceleration (ABA) measurements, have the potential to enable more efficient condition monitoring of transition zones. The ABA measurement method was developed to detect track defects, such as squats [7] and joint bolt tightness [8]. These defects are generally with short wavelengths. In the present work, the ABA measurement method is extended to be applied to transition zones with relatively longer wavelengths. However, since the design and construction of different transition zones vary significantly, it is challenging to develop a robust method that is applicable to monitoring different transition zones. To achieve this, an in-depth understanding of ABA measurements at different transition zones is essential.

In this paper, we present a methodology for monitoring transition zones of railway bridges using acceleration measurements on multiple axle boxes (multi-ABA) of a passing train. The measurements in the Netherlands, Sweden and Norway are presented as case studies to show the potential of multi-ABA for evaluating the health conditions of railway transition zones.

2 ABA Measurement System and Data Analysis Method

The ABA measurement system consists of accelerometers on multiple axle boxes, a GPS antenna and a tachometer, as shown in Fig. 1. The GPS antenna is on the train roof to record the train's location. The tachometer records the train speed and also helps identify the train's position especially in mountainous areas.

Fig. 1. Multi-ABA measurement system (source of photos: TU Delft OpenCourse Ware)

The sampling frequency of the accelerations is set to 25.6 kHz to acquire sufficient information over a broad range of train speeds. In this paper, focus is on the sleepers, ballast layer and substructures at the transition zones in the low frequency range, usually below 200 Hz. The responses at a transition zone are highly location-dependent. Therefore, the continuous wavelet transform (CWT) method is employed to analyze the axle box accelerations. In CWT, the convolutions of an acceleration are calculated with a group of scaled and shifted wavelet functions. The wavelet coefficient of the acceleration signal $a_{w,r}$ from wheel w and rail r at location x and wavelet scale s ($s > 0$) is [7]:

$$CWT_{w,r}(x,s) = \sum_{n=0}^{N-1} a_{w,r}(n)\varphi^*\left(\frac{(n-n')\delta_t}{s}\right) \tag{1}$$

where φ is the mother wavelet and the Morlet function is employed here. * denotes a complex conjugate and φ^* is a family of wavelets derived from the mother wavelet by various translation and scaling steps. N is the number of points in the time series, $n = 0, 1, \ldots, N-1$. n' is the continuous variable for the translation, δ_t is the time step.

With multiple-ABA measurements, the acceleration signal $a_{w,r}$ is obtained by averaging the ABAs from 4 wheelsets. In this way, the uncertainty is much less reduced [9]. The wavelet power spectrum (WPS) is defined as the square of the absolute wavelet coefficient:

$$WPS_{w,r}(x,s) = \left|CWT_{w,r}(x,s)\right|^2 \tag{2}$$

A scalogram is used to visualize the WPS as a function of position and wavelength. The wavelength is obtained from the measured frequency and the train speed.

3 Case Studies

3.1 Measurements in the Netherlands

In the Netherlands, two measurement campaigns were conducted in 2019 between Dordrecht station and Lage Zwaluwe station. There are 9 bridges crossing over rivers and pavements between these two railway stations. More information can be found in the authors' previous work [9]. In the present work, the measurements at the transition zones of a typical bridge are introduced as shown in Fig. 2 below.

The bridge is about 28 m long carrying two ballasted tracks. One of the tracks, as shown with the dashed blue box in Fig. 2(a), is selected because the two measurements on this track are under different train speeds. It can be seen in Fig. 2(b) that, the ABA signals of the two measurements are generally quite similar in shape and trends, but the amplitudes are train speed dependent. The higher train speed results in the larger acceleration amplitude. The insulated joint can be identified.

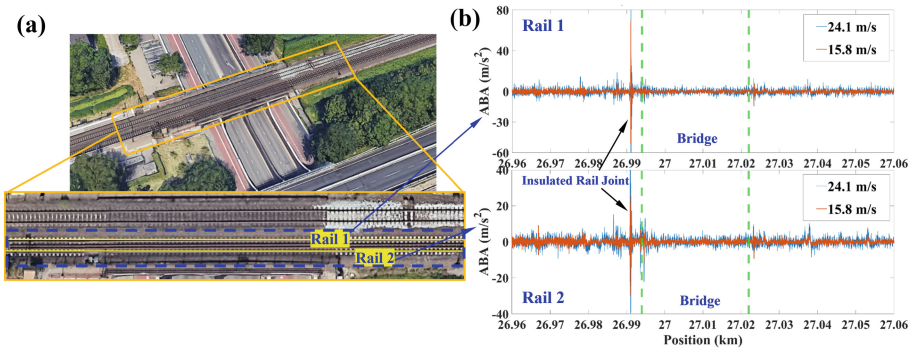

Fig. 2. Aerial photos of the transition zones and time histories of ABA measurements (source of aerial photos: Google Earth)

Figure 3 shows the corresponding WPS of the ABA measurements on the two rails at the transition zones. In Fig. 3, with wavelet analysis, the dominant wavelengths at the transition zones are visible at the high-energy areas. For example, the wavelength of about 0.6 m should be related to the sleeper interval. The sharp spike with broad short wavelength range is the impact induced by a local rail surface irregularity [10], such as an insulated rail joint in this case. The other strong responses with wavelengths longer than 1 m are probably related to the ballast layer and substructures.

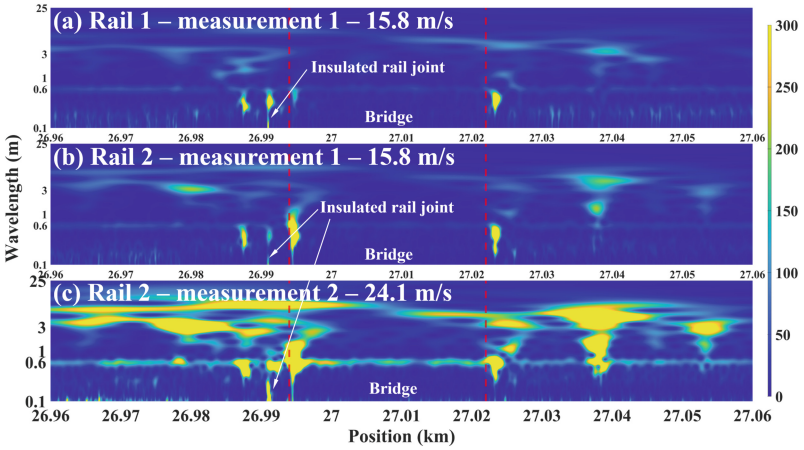

Fig. 3. WPS of the ABA measurements

It can be seen from Fig. 3(a) and (b) that, even though at the same track, the WPS of the measurements at the two rails can be slightly different in terms of the wavelength ranging from 1 to 25 m. It means that the ABA measurement is capable of identifying the slight difference of the supports at the two rails int terms of middle and long wavelength irregularities. With comparison in Fig. 3(b) and (c), it shows more clearly that train speed only affects the amplitude rather than the wavelength contents.

3.2 Measurement in Sweden

In Sweden, the ABA measurement was conducted in a mixed traffic line between Boden station and Murjek station. This railway line has only one ballasted track. As shown in Fig. 4(a), there is a culvert, with the length of 8.15 m in total, including a 4.2 m deck and two approach slabs at the two sides, each with the length of about 2 m. There were cracks found at the culvert abutment, so two steel beams were installed to help support the deck. The WPS of the ABA measurement over this culvert and the transition zones is shown in Fig. 4(b). It can be seen in Fig. 4(b) that, the effects of the welds can be easily identified. The sleeper interval related patterns are obvious. One unique characteristic is that quite strong response on the culvert is found, as shown with the large high energy areas both at rail 1 and rail 2 in wavelength range from about 3 m to 10 m. This is probably because of the dynamic characteristics of the degraded culvert structure. The origin of the dynamic characteristics can be verified by in-track tests, such as hammer tests.

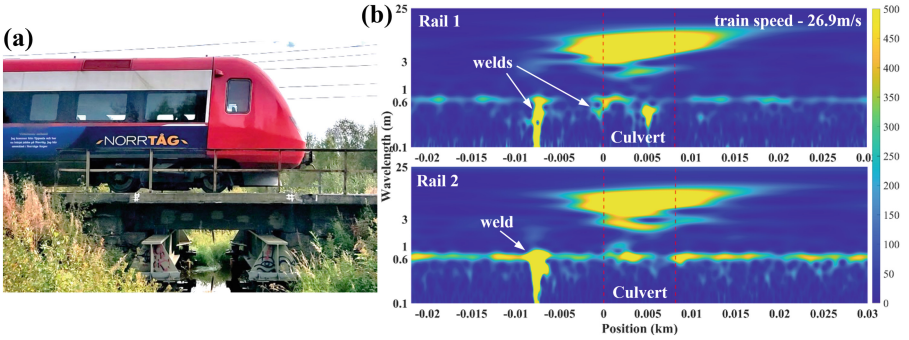

Fig. 4. ABA measurement at a culvert in Sweden

3.3 Measurement in Norway

In Norway, there is a concrete bridge with the length of about 53 m between Sosterbekk station and Katterat station, as shown in Fig. 5(a). At the transition zones, there was differential settlement due to the large variation in track support stiffness. In Fig. 5(b), at the abutments, as shown with the white dash box, high-energy areas with wavelengths about 1–10 m, are found due to the bumps caused by differential settlement. The sleeper interval-related patterns are still obvious but not so distinguishable from the patterns with shorter wavelengths, which is probably because of the short sleeper interval of 0.52 m, making the discrete rail support effect less pronounced.

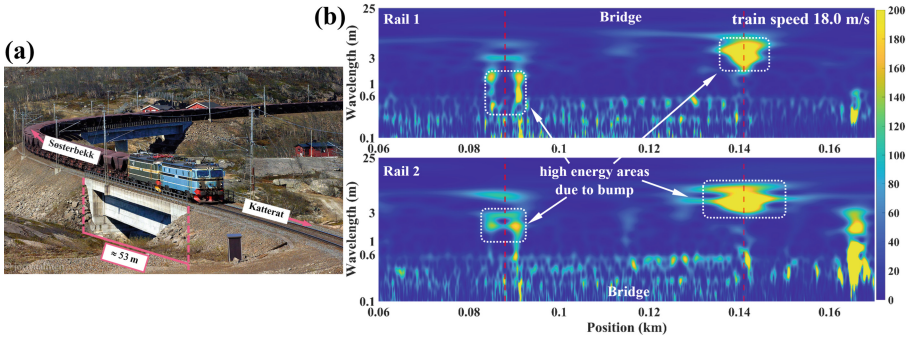

Fig. 5. ABA measurement at a bridge in Norway (source of aerial photos: https://www.arctictrains.com/Ofotbanen/i-DgW4F7N)

4 Conclusions and Future Work

In this paper, using multi-ABA measurements for health condition monitoring of transition zones is introduced and showcased with measurements in the Netherlands, Sweden and Norway. It is found that different bridges and transition zones exhibit unique characteristics including dominant wavelengths and energy distribution. Based on these unique characteristics, the geometry and support conditions at different parts of a transition zone can be evaluated. Higher train speed makes the characteristics more pronounced. These results demonstrate that the multi-ABA measurement has the potential to evaluate the health conditions of different transition zones.

In the future, local dynamic tests and numerical studies can be conducted to further interpret the ABA measurement results thus to make the multi-ABA measurements more applicable for the health condition monitoring of railway transition zones.

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MagRail Technologies to Secure Heavy Freight Activities in Alpian Mountains: A Driverless Perspective

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Abstract. Maglev-derived systems (MDS) are guided transportation systems containing a propulsion which is independent of any frictional interaction between wheels and the infrastructure. The current study investigates the specific friction mode safety cases in order to illustrate how a safety increase with the help of MagRail Boosters can be demonstrated using CSM (Common Safety Method). MagRail Booster is a transportation system in which rolling stock and railway infrastructure are retrofitted by equipping them with a linear motor propulsion and other necessary subsystems (power electronics, signalling, communication) to increase the capacity and extend the functionalities of legacy railway systems. The reasoning is illustrated referring to the alpian railway line of the Cluse Valley, providing a representative industrial example of freight traffic. The potential contribution of the considered technology to the safety demonstration of a driverless freight train is discussed at the end of the paper.

Keywords: MagRail Booster · railway operational safety · driverless train operations

1 Introduction

The aim of the current paper is to introduce first design elements for safety files of Maglev Derived Systems. Maglev-derived systems (MDS) are guided transportation systems containing a propulsion which is independent of any frictional interaction between wheels and the infrastructure. Moreover, the current study focuses on guided transport systems operating on wheels. The proposed methodology is to analyse the existing system moving on wheels as it is. Then, taking this system as a reference, the use of "non friction propulsion technologies" is considered for a potential increase of safety and/or level of service.

There were five operating Maglev lines in 2016:

- Linimo (Tobu Kyuryo Line, Japan, started in 2005).
- Shanghai Maglev Train (China, started in 2003), High speed (430 km/h).
- Daejeon (South Korea, started in 2008).

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- Incheon Airport Maglev (South Korea, started in 2016).
- Changsha Maglev (started in 2016, China).

There was an operating line in Germany, but the commercial exploitation was stopped in 1991. A consequence of this matter of fact is that we identified no scientific works dealing with safety methodologies to assess MDS in Europe.

Using non-frictional forces for train traction is a small revolution in a railway system (ERTMS curves explicitly involve friction forces [1]). The presented work is only illustrative and aims at demonstrating a technical potential on a particular use case. The proposition is not a generic methodology.

The paper focuses on a critical railway freight activity: crossing a steeply inclined ramp where the trainset risks getting stuck due to insufficient locomotive traction, effectively in the slip condition.

In any case, there is a significant decrease in line capacity and an increase in operating costs. This issue is particularly relevant due to the presence of multiple lines with high inclination sections across Europe and the ever-increasing demand for efficient freight transportation in these corridors or areas, including in the alpine valley of Cluses, the third biggest industrial zone in France.

The following paper will discuss the potential of introducing MagRail Booster technology as a potential solution to the posed problem by investigating several relevant case studies [2]. Particular focus is put on operational safety aspects in the inclined tracks scenarios. Conclusions will be drawn in order to assess the general viability of implementing the proposed solution.

2 Safety Framework and Specific Accident Contexts

Risk management process and independent assessment (see European implementing regulation no. 402/2013 [3]) use the principle that the existing risks associated with driving a train are covered by the proper application of procedures described in the main line drivers reference book in France (RCL 2008, see [4]). Then we are going to focus on differences introduced by the use of the new technology for the proper execution of the requirements of the reference system.

Definition from [3]: *'reference system' means a system proven in use to have an acceptable safety level and against which the acceptability of the risks from a system under assessment can be evaluated by comparison.*

The current technical proposition is combining linear motor propulsion and classical traction creating the movement by the mean of friction forces. The following section mentions several safety cases, corresponding to freight alpian lines, where the Maglev booster technology will increase the safety.

2.1 Friction Forces Are Safety Critical

Let us focus on critical events related to friction forces:

- If the braking force is greater than the grip of the rail, wheels do not turn anymore but trains are still moving. In this paper, it is called sliding.

- If the tractive effort is greater than the grip of the rail, wheels turn while sliding and the train does not move. In this paper, it is called slipping.
- In both cases, violent behavior may occur when the sliding effect stops, providing a sudden mechanical efforts reallocation. As evidence, as the force needed to start sliding is greater than that needed to continue sliding, it induces a behavioral discontinuity. In this case, train coupling breaks may happen. Coupling breaks in slopes can be dangerous scenarios, when the lost part of the train is not well braked (let us consider the scenario of Morlanwelz in Belgium that occurred the 27th of November 2017 where two workmen were killed[1]).

The general causes for poor adhesion can be:

- Atmospheric conditions (rain, freezing fog, snow, etc.).
- Pollution (deposits of fatty substances, leaves).
- A grease hose may leak (e.g. overgreasing).

The slipping consequences can be:

- Serious damage to the rail which can lead to breakage. Rail braking may lead to derailments.
- Flattening of wheels.
- Serious damage to the engine (destruction of the traction motors, etc.). It is to remark that a defense against slippage is sandblasting (automatic or not), but this is prohibited around the point areas.

The reporting of sliding and slipping is a regulatory obligation. However, the transmission of information is often done in a deferred manner: in the absence of an available telecommunications system, the driver will issue a report at the next station.

For a slide, the potential consequences at the system level are greater: non-compliance with braking distances that can cause collisions by overtaking or nose-to-nose, derailment following overspeed, or interlocking track device engagement. As an illustration, we can consider the overspeed example of Fontpédrouse (66) – 25/01–2021 – derailment of a train on the Villefranche - Latour-de-Carol line[2].

2.2 Anticipating Leads to Static Solutions

Because of these corelative dangers, Art D24.04 of [4] provides a set of recommendations for "driving on a lane where grip may be abnormally low ".

A summary of these recommendations could be: "use the available knowledge and your own know-how for anticipating".

Then a paradox arises: how can we anticipate an event which dynamic is higher than the duration of a railway travel?

[1] https://www.railjournal.com/passenger/main-line/belgian-accident-leaves-two-infrabel-staff-dead/

[2] https://www.bea-tt.developpement-durable.gouv.fr/fontpedrouse-66-25-01-2021-deraillement-D-un-train-r318.htm.

A natural answer is to put some margins assuming that the event will happen even when the probability is low. A direct consequence is a global cost increasing and a global capacity decreasing.

As an example, during a six-month period of the year (i.e. half of the time), it will be assumed that snow will fall in the French mountains and that the adherence of the rolling stocks will decrease. As a consequence, it will be a problem in many heavy slopes and in many cases two locomotives instead of one will be used. As there is a lack of train drivers in France, the proposed solution would rather be to decrease the global weight of the train by decreasing the number of wagons. The more the transported material are heavy, the more they are impacted by this measure. In the Cluse valley, which is a national leading area of steel industry, the potential impact is significant.

3 Boosters Are Static Solutions that Are not Related to Adherence Values

3.1 Description

MagRail Booster is a transportation system in which rolling stock and railway infrastructure are retrofitted by equipping them with a linear motor propulsion and other necessary subsystems (power electronics, signaling, communication) to increase the capacity and extend the functionalities of legacy railway systems (Fig. 1). The system combines two features – automated traffic and electrification – functionally simplifying both by using a single device, the linear motor. Booster vehicles' propulsion is fully controlled by a master controller in a ground control station.

3.2 Failure Modes and Synthesis on Safety

Weather events such as freezing smog, rain and snow decrease the efficiency of friction forces at a level that may impact safety. Nevertheless, specific failure modes are related to MagRail Booster technologies and a closer analysis should consider combinations between friction force failure modes and linear motor failure modes. As evidence it is mandatory to investigate the existence of common modes of failure.

The current study aims at establishing that in heavy freight alpian railway lines, MagRail Booster technology provides functional solutions increasing the average level of safety, without considering black swans: a deeper scenario-based analysis is still needed.

4 Discussion on a Prospective Driverless Train

When a train is stopped in an incline, a hill start can be extremely difficult to perform. For this, the driver must compress the trainset first. Mechanical stoppers are put to the last wagon and the train is allowed to roll down slightly, loosening the couplers. When later pulled, the wagons start moving one after another, and the tractive forces delivered by the locomotive can be increased progressively rather than having to be available at once.

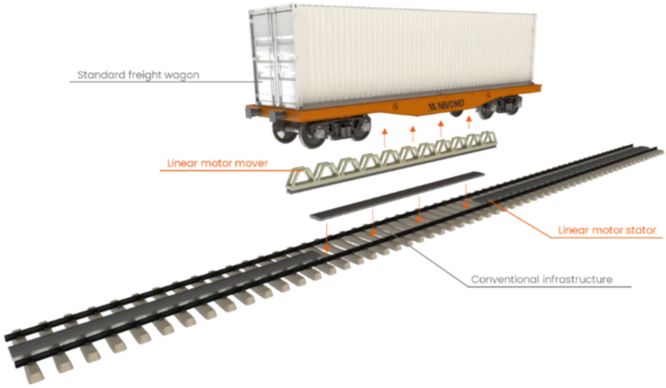

Fig. 1. MagRail Booster system components (provided by Nevomo society).

However, when the couplers are not loose, the needed tractive effort to start the whole train at once is very high. Moreover, in conditions specific to the discussed alpine areas, the inclination of the tracks (reduced pressure force of the locomotive – perpendicular to rails) and detrimental weather conditions (reduced friction coefficient due to snow and ice) inherently reduce the tractive effort available. Some of the hazards that can result from insufficient pulling forces include breaking of the couplers under maximum load or just inability to put stoppers in the tracks for driverless locomotives. The identification of these safety cases was made in the context of the TCRAIL project involving Railenium and SNCF (among others) [5, 6]. To ensure safety in operation, trains that use steeply inclined tracks are traditionally pulled by an additional locomotive or they would have to carry severely reduced loads. Alternatively, a pushing locomotive service may be purchased by the railway undertaking that operates a given connection.

MagRail Booster may be an alternative to the above policy for avoidance of couplings-broken and train getting stuck in slopes. Today in Europe, autonomous freight train is still a challenging objective. Enriching the set of potential technical solutions with MagRail Booster is reasonably to be considered in the critical zones.

5 Conclusion

The current paper proposes an upgrading of the tracks on inclines with the linear motor and adapting conventional freight wagons with movers will allow for achieving higher tonnage of the trains using their full allowable lengths, boosting the capacity on the line, and termination of additional pushing locomotive services, while ensuring safety of transport in both manned and driverless operations.

A safety framework was presented. It proposes to use the existing system as a reference while using the Common safety Method [3]. Applying this methodology, safety cases corresponding to real accident scenarios were analyzed with regard to the classical technology and their genericity was discussed. Then the booster solution using linear motor rather than friction forces was presented. Their potential contribution when the

friction forces are reaching their limits, because of common weather event happening in alpian mountains, are highlighted.

In the context of Maglev Derived System safety, the main perspectives of the current paper are to propose a generic methodology, assessing a safety reasoning on the basis of high-level concepts [7–9], proving iso-functionality while using technological diversity, applying a Swiss cheese strategy.

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GNSS-Based Performance and Railway Operating Rules

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Abstract. Railway environment produces local effects for GNSS use for train localisation. This technological context is discussed with regard to the state of the art. Then, the daily management of disturbances and parametric variation by railway driver is shortly presented in order to share a vision concerning the potential industrial use of the considered technology.

Keywords: Operating rules · railway safety · localisation · GNSS

1 Introduction

GNSS (Global Navigation Satellite System) is now identified as a realistic and serious game changer for the future of the ERTMS (European Rail Traffic Management System). But the environmental conditions of track and surroundings configuration, i.e., tunnels, dense urban areas or vegetation. often degrade positioning performance and thus its efficiency and safety. For its part, an experimented driver will extract from environmental conditions some predictions to adapt its driver's behaviour. This knowledge is part of the driver skills. As an example, after the theoretical training, the French process of a new driver's qualification ends with a supervised period with an experimented driver who advises the young driver. The experimented driver has the responsibility to decide when the young one is able to operate on the line, when he is efficient enough and when he acquired the needed specific knowledge of the line.

In this context, we investigate how the use of a GNSS-based train positioning device can be integrated in the global needed knowledge of a specific line. If the on-board GNSS is used to eliminate track devices, GNSS information becomes safety critical. But if tailored actions can preserve the global safety, these actions just have to be added to the set of needed knowledge. This paper discusses how the variable positioning performance knowledge can be integrated into an efficient operational railway system as a whole.

2 GNSS-Based Localisation in a Railway Environment

All GNSS users have already experienced loss of accuracy or availability when travelling in dense urban cities or inside tunnels.This will also be the case for

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a GNSS-based train locator. Indeed GNSS-based positioning solutions can be seriously impacted by the track surroundings as they can generate multi-path, NLOS (Non-Line-Of-Sight) and interferences inducing inaccuracy, unavailability and lack of integrity.

2.1 GNSS Principles in Presence of Local Effects

Satellite-based positioning techniques rely on Time-Of-Arrival measurements. Each of the worldwide GNSS constellations (GPS, Galileo, GLONASS and Beidou) are composed of non-geostationary satellites that broadcast continuous signals, that are received, decoded and used by the receiver to estimate their propagation time. These times multiplied by the speed of the signal (i.e., the speed of light for GNSS) will represent the emitter-to-receiver distances, called pseudo-ranges. The reception of n (at least four) satellites will allow the receiver to benefit of n observations to solve the system of n equations where the unknowns are (x,y,z,δt); (x,y,z) being the antenna position and δt the clock bias coming from the user and satellite clock offsets. The system resolution is classically performed with a Least Square (LS) estimator or a Kalman Filter. The different GNSS can be used independently and with interoperability but whatever the constellation used, their positioning performances are strongly related to measurement accuracy, as well as to the satellite distribution around the reception antenna. The straighter the path of the signal between the satellite and the receiver is, the more accurate will be the satellite-receiver distance estimation. Unfortunately, for land transportation users, measuring the propagation time of the direct signal can be a challenge because of obstacles that can reflect or block satellite signal reception and then degrade the measurement accuracy. These local effects are called multi-path and non-line of sight (NLOS). Multi-path refers to the phenomenon that a signal reaches the receiver after reflections or diffractions that are combined with the Line-Of-Sight (LOS) signal. Each received path is called an echo. Its delay and phase depends on the surface characteristics and geometry of the scene. Multi-path will distort the shape of the correlation used by the receiver to extract the pseudo-range information. Its impact on the position will depend on the distortion of the correlation. The NLOS label is used when the direct signal cannot be received because of the presence of a masking obstacle (Fig 1). Then, the correlation output is always characterised by a delay on the pseudo-range estimation caused by the absence of the direct path that will induce positioning error in the estimation step. These phenomena can vary very quickly along the train path depending on the its speed and on the topology of the track.

2.2 State of the Art of GNSS-Based Solution for Rail

When addressing safety-critical applications, GNSS-based solutions must prove their performances in terms of availability, accuracy and integrity and their compatibility with RAMS [1]. Integrity, in the GNSS domain, is defined as the measure of trust that can be placed in the correctness of the information supplied

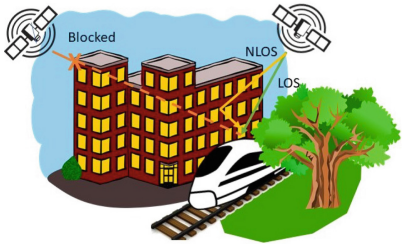

Fig. 1. Environment impact on GNSS signal reception (Source: Author's own work)

by a navigation system. It includes the ability of the system to provide timely warnings to users when some system anomaly results in unacceptable navigation accuracy.

The on-going developments of GNSS-based localisation units anticipate the consequences of these harsh conditions of reception and will rely on a series of barriers aiming to prevent or mitigate them when possible. A first objective is to develop a solution that will reach the railway requirements in terms of accuracy and availability. Most promising solutions will rely on hybrid solution embedding GNSS and an IMU (Inertial Measurement Unit) [2] at least, completed with fault detection and exclusion (FDE) processes [3]. But some residual or unexpected errors will remain. The FDE is developed with some integrity monitoring concepts that intend to bound errors and avoid critical errors of the system. Some solutions are today in a development phase such as in the TRENI project [4] that intends to embed most of the latest technologies. Predictive studies may also help to anticipate dynamic losses of GNSS-based solution performance, that can be based on track characterization as proposed in [5] in the ERSAT-GGC project, multipath error mapping [6] or in a statistical basis as well as with training methods [7].

On the other hand, and independently, meteorological conditions are also environmental conditions impacting the train operation on the line. The presence of leaves on rails or snow on track for example will request the driver to modify the train speed and its driving behaviour.

3 GNSS Integration and Railway Operating Rules

3.1 Safety Rules, Principles

Scientific literature dealing with building and managing safety rules is not very extensive [8]. One of the most relevant contributions concerning the way of making rules is constituted by Hale's publication in 2003: "Management of safety rules: the use of railways" [9]. However, this publication itself mentions the few existing works available in the literature of this area. A rule is based on collective knowledge to define safe behaviours and equipment and implement them [10].

If the knowledge is collective, it is then appropriate to collaborate with the different holders of a piece of this knowledge for building and validating a rule. Indeed, a rule is based on the perception and representation of the system of the rule maker. Therefore the matching between the system and its conceptual model is critical, assuming that a model is an abstraction of the real system. This abstraction is built using a specific point of view, allowing to skip many non-needed details [11].

3.2 Contextual Actions

A security rule is a set of actions to be implemented to bring all operations to an acceptable level of security. Let us present it as a triple:

- a context of application (place, time, type of intervention, nature of agents),
- conditions and constraints validating the application of the rule,
- a list of actions to implement.

Rules can be built, based on preliminary risk analysis or based on gap analysis using a Common safety method comparing with a reference system (CSM-2, see [12]). Fundamentally, the idea is that it is not possible to wait for the occurrence of accidents to integrate them into a common knowledge: it must be therefore anticipated in order to avoid operating with a base of rules whose relevance is proven for a system which no longer exists [13]. There is therefore a need for a predictive approach [14]. This last consideration brings up a new challenge. Indeed, a declarative text naturally describes knowledge, but the predictive approach relies on logical or functional links whose textual representation is much more delicate. There is therefore a need to structure this knowledge since it must be interpreted to make a prediction.

3.3 Barriers and Protections

Let us consider two types of security rules:

- The first ones apply a measure intended to prevent the occurrence of an accident: this is the concept of the barrier.
- The second ones promote the non-occurrence of accidents (for example staff training), or reduce the severity (for example lower speed). This is a protection strategy.

Preventing hazard occurrences seem to be the most definitive strategy. However, building a barrier can be not achievable:

- preventing that infrastructure will disturb GNSS signal reception is not realistic,
- change of meteorological conditions are also environmental conditions impacting the train, but they can not be prevented.

Concerning the protection function, the latter being integrated into a general process aiming at achieving a satisfactory level of safety, it is sometimes triggered during a transient mode specific to a failure. The question is then: who will certify that changing the type of a rule does not degrade the overall security of the system. A general study at the highest level of responsibility is a satisfactory response from a functional point of view. Nevertheless, it is more efficient to only validate the subsystem that is directly impacted by the modification.

3.4 Driver Operating Rules

In the framework of the TCrail project [15], some expert drivers have been interviewed in order to check if the delay introduced by a remote operation may have a severe safety impact. As a matter of fact, train drivers daily managed with rain, smoggy weather, obscurity, leaf in autumns, etc. Most of this common variations impacting safety do not appear in the driving reference book [16]. They are handled locally, as behavioural local adaptation on a given railway line. A driver must know his line, and this required knowledge includes anticipation of smog on a bridge over a river, leaf inducing sliding during Autumn, and probably future satellite disturbances at a given point of the infrastructure.

Let's consider braking performance as an example. Braking performances are completely modified when the rail is wet compared to nominal behaviour. It is then susceptible to evolve all along a run, as GNSS performance may do. We can then wonder if GNSS disturbances will impact driving conditions more than braking performance diversity that freight drivers manage everyday. For braking, the use of mathematical models of context-based disturbances allows to anticipate the evolution of the knowledge of the system. Inspired by such models, future investigations will then concern context-based models for GNSS performances to be integrated in the global system knowledge.

4 Conclusion and Perspectives

This paper develops a pragmatic analysis of future GNSS exploitation challenges in future of railway signalling, integrating main railway environmental constraints and local effects producing GNSS disturbances. These considerations are explained and discussed with regard to the state of the art. In a second step, the daily management of disturbances and parametric variations by the railway driver are shortly presented to share a vision concerning the potential operational use of GNSS. Future work will discuss the level of management to be involved to manage future GNSS disturbances, regarding potential system impacts.

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On-Board Train Integrity: From Concept to Field Testing

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Abstract. On-Board Train Integrity (OTI) project provided requirements specifications for on-board train integrity detection and safe train length determination. On this basis, simulation activity and performance analysis provided guidelines for tuning three demonstrators before field testing. Identified solutions allow reducing the cost of the infrastructure and enables virtual and moving blocks for capacity increase. Finally, migration strategies and standardization proposal have been defined.

Keywords: Railway · On-Board Train Integrity · train length determination · European Train Control System (ETCS) · safety · infrastructure cost reduction · capacity increase

1 Introduction

Safe train separation requires trains' position, integrity, and length determination. Current technologies are based on track circuits and axle counters that imply high infrastructure costs and capacity limitations due to fixed blocks. OTI project provided train integrity and length determination at on-board level thus allowing infrastructure costs reduction and line capacity increase by enabling virtual and moving blocks.

2 On-Board Train Integrity and Train Length Determination

OTI project [1] provided requirement specifications [2, 3] for train integrity monitoring and safe train length determination. The train length is determined before starting train mission and provided to the ETCS onboard to avoid manual data entry errors from the train driver. The determined safe train length is considered by the Radio Block Centre to assign movement authorities for the preceding train. According to the safety analysis proposed in [5], the safety integrity level SIL 2 is required for OTI and SIL 4 is required for safe train length determination.

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Three main OTI product classes have been identified for different applications. In product class 1, the integrity evaluation criterion consists in checking the liveliness of communication between head and tail in trains equipped with a wired communication network. Product class 2 uses kinematic data exchanged over radio link to check coherence movement of head and tail. Finally, product class 3 detects separation between adjacent waggons and determines completed train composition in freight applications.

As part of validation and verification (V&V) approach, simulation activities have been performed before the field-testing to identify proper values for integrity criteria parameters and false alarm filtering. Two complementary approaches are described in the following.

The Railway Advanced Navigation Simulation System (RANSS) developed by CEIT [6] simulated the behavior of HITACHI demonstrator for product class 2 in the line selected for the field-testing, focusing on kinematic data used for OTI evaluation criterion. Features of the train and topology of the line have been inserted within the simulator with the objective of identifying the most appropriate value for OTI FSM parameters for loss of integrity detection and false alarm rejection.

Other V&V activities consist in using formal methods techniques to analyze the OTI performance and the OTI Finite State Machine (FSM) parameters in relation to the different communication solutions adopted in the three product classes. OTI FSM has been modelled by RAILENIUM with UPPAAL [7] and its behavior has been evaluated in different situations using One Factor at a Time (OFAT) sensitivity method.

Guidelines from simulation activities constituted a reference to configure the demonstrators with timers and threshold values respect to performance objectives.

3 On-Field Testing

Three demonstrators have been implemented and tested on-field for three different product classes. In product class 1, the train integrity criterion consists in head-tail communication liveliness through wired on-board network. AZD implemented this demonstrator with OTI devices deployed in all waggons and connection over an Ethernet on-board network in a passenger train and field testing has been executed in Czech Republic in August 2022 (Fig. 1).

Network topology discovery allows determining train composition and train length. More specifically the OTI device installed in each waggon hosts configuration parameters data including waggon identifier and waggon length.

Equipment installation was simple, and the testing activities executed successfully included length determination, integrity monitoring and joining-splitting procedures (Fig. 2).

The HITACHI demonstrator for product class 2 [9] consists in two OTI devices installed at each train end connected to ETCS equipment. An Adaptable Communication System (ACS) over cellular public networks allows Train-to-Ground (T2G) communication for configuration phase and Train-to-Train (T2T) during train mission. The configuration phase consists in a pairing procedure between head and tail, based on train composition data acquired from Traffic Management System (TMS) by means of Integrity Layer [8] and common data repository enriched with train composition data

Fig. 1. Line in Czech Republic for experimental testing (left) and experimental train (right).

Fig. 2. Ethernet plug installed in the train (left) and OTI dashboard inside the cabin (right).

consisting in OTI identified installed at each train end. Train length is calculated by acquiring a balise with ETCS at head and tail and measuring the travelled space. Train Integrity is determined by acquiring train speed from ETCS at head and tail, exchanging acquired values over radio and comparing them. If the speed difference between head and tail stays below a defined threshold, the train is considered integer.

The experimental equipment includes balise antenna, wheel sensors, ACS Gateway, Global System for Mobile (GSM) communication antennas and ETCS On-Board installed in shadow to the existing Automatic Train Protection (ATP) system installed on two coupled ALn668 locos at Sulmona depot. The T2T and T2G communication is realized by using two independent mobile network operators (Fig. 3).

Field-testing has been executed in shadow to the passenger service in Abruzzo and with dedicated testing session during the night along the Adriatic line between Pescara and Ortona. Main phases of the OTI FSM for product class 2 includes head-tail pairing by interacting with TMS, train length determination and on-board train integrity monitoring. The coverage with two public cellular networks is depicted in Fig. 4 with green markers for nominal coverage, red markers for poor coverage and no markers inside not covered tunnels. According to Change Request 940 [4] when the radio connection is not available, integrity is unknown, and train virtual occupation is increased.

For costs optimization the OTI software can be hosted in a safe elaboration unit within ETCS platform, independently from the ETCS core logic. Proposed technical approach is applicable to trains without any wired on-board communication network, variable composition and ETCS installed at each train end.

Fig. 3. Experimental train with Aln668 locos (left) and cellular network antennas (right).

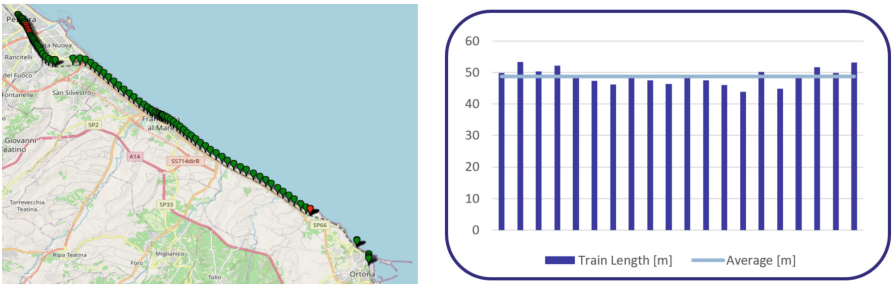

Fig. 4. Cellular network coverage (left) and train length measurement (right).

In product class 3, the OTI system determines train length based on network topology discovery techniques and detects separation between adjacent waggons by using multiple sensors in each waggon and radio communication. INDRA implemented it for freight trains [10] by using ZigBee and 6LowPan wireless communication between OTI devices and Received Signal Strength Indicator (RSSI), Inertial Measurement Unit (IMU) and Global Positioning System (GPS) sensors.

Interaction with TMS is also used to compare train composition discovered from OTI System. Field-testing executed in United Kingdom (UK) in April and October 2022. Figure 5 depicts the line selected for field-testing in UK, the train intentionally split during train mission and the OTI dashboards showing the detection of loss of integrity.

Network Rail provided support for installation and site testing with a freight train equipped with OTI system and a special separation device able to split intentionally the train while running. OTI Dashboard installed in the cabin shows train composition determined with network topology discovery technique and compared with train composition provided by TMS. The technical solution developed by INDRA and tested in UK with Network Rail is suitable for freight trains with fixed train composition.

4 Migration Plan

DLR developed an optimization model [11, 12] that allows economic optimization of OTI migration in terms of determining the order to equip the trains by optimizing removal of trackside equipment for train integrity verification within a network.

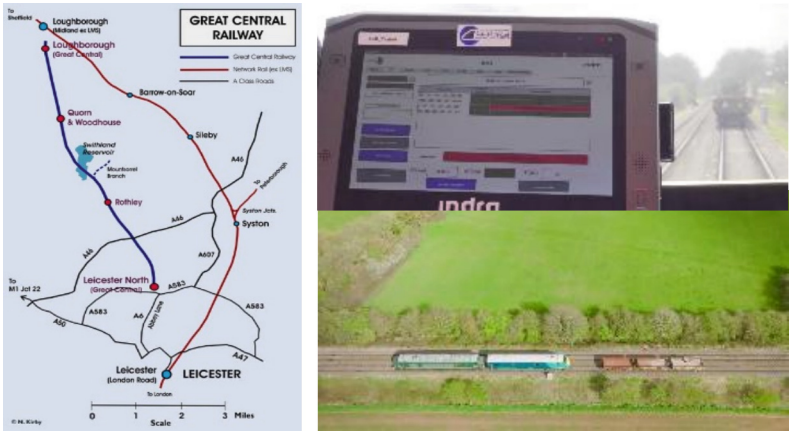

Fig. 5. On-field testing in UK (left), loss of integrity (right-down), OTI dashboard (right-up).

The objective consists in minimizing the network-wide sum of trackside train detection elements over the years under the following assumptions: (i) the necessary workshop capacity for all trains to be equipped is available; (ii) differentiation between train categories has been set according to regular maintenance intervals; (iii) removal of trackside elements only when all trains on the line are equipped; (iv) the model has been developed for line optimization so far, not considering nodes. Figure 6 depicts an example with gradual removal of trackside detection system over a period of 8 years.

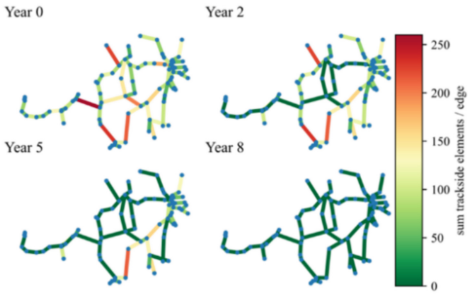

Fig. 6. Gradual removal of network-wide trackside elements.

The results of the optimization model consisted in defining the equipment order with OTI technology for the considered fleet of trains in the analyzed network to ensure early removal of the trackside train detection elements and thus reducing infrastructure cost.

5 Results, Conclusion and Future Works

The experimental train for class 1 showed results of network topology discovery and communication liveliness over Ethernet network installed in each wagon of a passenger trains. Alternative approach for class 2 exploited a multi-bearer communication system

based on cellular public networks. This solution avoids modifying the train couplers to wire each wagon with a bus. Class 3 is proposed for freight trains and uses a network of wireless sensors to discover train composition and to detect its integrity.

In conclusion, the OTI project provided requirements specifications, developed and tested technological approaches for different type of trains, and defined a migration strategy. Further evolution of the work could refer to automatic couplers for freight trains and standardization of proposed specifications [13].

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Use of Video Records for Evaluation in Service of Innovative Equipment for Train Passenger Doors

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Abstract. The development of new anti-drag devices appears as an efficient solution to reduce the risk of dragging a passenger caught outside the train during passenger door closing sequence.

Where train doors are only by the driver operated, the expected improvement of safety, offered by a new device must be evaluated and balanced with possible impacts on train regularity, particularly for urban areas with high density traffic.

To test such solution under real conditions, without running the risk of disrupting the day-to-day operation of commuter trains, the implementation of a test in commercial service enabling video recording of the contexts in which a passenger access door anti-drag seal is triggered seemed particularly appropriate.

By providing unprecedented information on detection situations, this experiment demonstrated the expected performance of the product, and made it possible to assess its impact on rail operations, which could be transposed to larger-scale equipment.

1 Introduction

The introduction of innovative technical solutions, on rolling stock intended for intensive commuter operations, needs a particularly cautious analysis of benefits and risks: Where such innovation may affect traffic flow, it is essential to assess its impact on the regularity of operation under real conditions.

The technical solutions applied in the three last decades on large commuter trains fleets, to manage safely the door closing operations, had drastically reduced the numbers of incidents, in comparison with the previously known situation.

The current situation could be considered mature, with acceptable operating regularity and a very low number of incidents. Nevertheless, even though the number of door-related incidents is now much lower than before, they have unfortunately not completely disappeared, and railway operators are still looking for solutions to reduce them further. The use of Anti-drag door seals has been evaluated as an appropriate solution to achieve this target.

In the reflection process for future rolling stock, for Paris commuter trains, the operating department had asked for a test in commercial service of one of the most recent designs of "anti-drag" door seals, with an important expectation on the evaluation of the potential impact on train operation regularity.

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2 Method/Experimental

2.1 Previous Technical State of Art

First applied in the 1980s, active sensitive seals on the leaves of external passenger access doors offer new capabilities for detecting small objects while the doors are closing, and even when they have already reached their closed position.

This new technical capability was seen as an interesting way of avoiding the rare but sometimes dramatic situations in which passengers trapped by closing doors are dragged onto the platform outside the train.

After early attempts on metros, large range application of such solution did not come until now in France, for many technical, or industrial reasons, some of them based on facts, and some supposed, such as a possible impact on trains regularity, when the train could not depart in case of false detection.

On request of the operating department, the Rolling Stock Engineering departments of SNCF Voyageurs proposed to perform a test in commercial service, to evaluate in real service on an existing train, an "anti-drag" door seal coupled to a monitoring video recorder, implemented as a fully passive system.

This testing conditions offers a means of evaluation of the context where the sensitive edge is activated, such as the situation in station, the door position when detection occurs, and the relative position of passengers.

2.2 Mains Characteristics of the Test in Commercial Service

The commercial service test was carried out on two Z5600 series double-deck trainsets (also known as Z2N).

These units are operated without staff on board, except the driver, who supervise, by means of a rear-view equipment, of the whole door closing sequence. For this purpose, the driver has door closing controls and "closed door signaling lamps" which enable him to close and then check that all the doors are closed before starting traction. On this type of trainset, it is technically impossible to trigger the train traction command with the "closed door" signal lamp switched on. If an obstacle is trapped in the doors: the train driver notices that the "closed door" signal lamp is still illuminated despite the door closing command lever being held in the closed position. He then can release the closing of the doors and restart a sequence after a few seconds to give a third-party time to free the obstacle trapped in the doors.

During their overhaul associated with a major refurbishment, the access doors on 4 separate platforms of each electric multiple units were fitted with anti-drag seals. (16 doors spread over 8 platforms, 2 coaches per trainset).

For each door equipped, a video monitoring system has been set up to track events when a seal detects an object.

The eight platforms were fitted with the following devices:

- Two pairs of anti-drag seals (one per door) in place of the existing door seals
- Two cable holder chains, placed in the door mechanism, enabling the cable of the male seal to door movements.

- Two seal control units, placed above the platform, to interpret and process the signals sent by the seal.
- Two video cameras, located in the door mechanism, to film the seals and door environment during commercial service.
- A management unit comprising a recording system and a data transmission system via GSM network.
- A GPS/GSM antenna for data transmission

The top cover protecting the door mechanism allowed the installation of an overhanging camera, allowing video to be captured of the joints and the exterior environment of the door (Fig. 1).

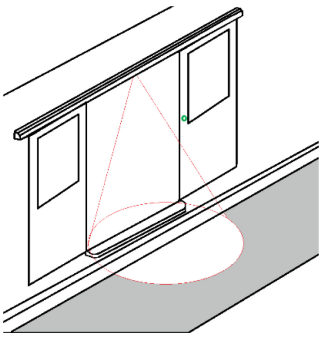

Fig. 1. Camera focus

On each equipped door, the installed camera process continuously the video signal, which is record in an internal system memory.

Each time the door seal is electrically activated, when a door closing command is present, then a video sequence is triggered, to isolate a 70 s sequence recorded by the camera, which starts 10 s before the seal activation, and ends 60 s after. This sequence is then transferred by means of a mobile data exchange system.

$$\textit{Door closing command} + \textit{Detection by the seal}\ (t) = \textit{Video recording}\ (t - 10s\ \textit{to}\ t + 60s)$$

To demonstrate that the existing dispositions had not been degraded by the implemented tested components, and make transparent the experimentation for the train operation, and especially the drivers, the tested doors seals have had been particularly designed to offer the strictly same obstacle detection performances as the original seals, in order to fit with the existing door mechanism with the same adjustment's parameters (Fig. 2).

3 Results andDiscussion

3.1 Observed Results in Train Operation

By considering the various uncertainties and disparities in the operation of the trains, and the variable availability of the information transmitted by the equipment, it has been possible to estimate the average number of detections of the anti-drag seal.

Fig. 2. Z5600 door equipped with the anti-drag device and the camera. The door is a sliding door with an external mechanism (Source / SNCF Voyageurs)

It appears that the frequency of detection by the anti-drag joints is relatively low. When you consider a passenger access door individually, the transmission frequency of a recording occurs on average every 20 days. However, this frequency would represent, on a large fleet scale, like Z2N, a few hundred detections a day (Fig. 3).

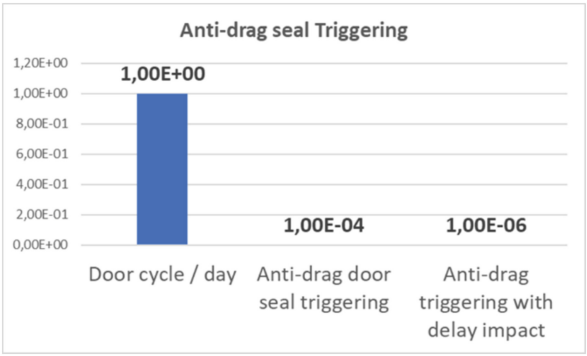

Fig. 3. Anti-drag seal triggering

As well as counting the number of detections, these recordings allow us to understand the context in which the door seal was activated and to assess the possible impacts:

- Was the joint activated prior or after the doors were closed (detection of a dragged object)?
- Would the triggering of the detection have caused a longer time on the train's departure procedure, if the detection had been used to reopen the "door closed" safety loop?
- Would the anti-drag seal have covered a risk identified by the video recording?

3.2 Analysis of the Observed Detection Cases

Video recordings have given us a better understanding of the conditions in which passengers can be hit or trapped by the door when it closes.

Four main contexts had been identified:

- Late boarding attempts: This context is characterized by boarding (or attempting to board) the train while the procedure for closing the doors has been initiated.
- Late attempted descent: This type of event occurs when a passenger attempts to get off the train while the door closing sequence is in progress.
- Closing on passenger flow: This type of event generally occurs during peak periods, at station stops where passenger exchanges are important.
- Other cases: Voluntary obstruction of the door closure by a passenger (not boarding or alighting) (Fig. 4).

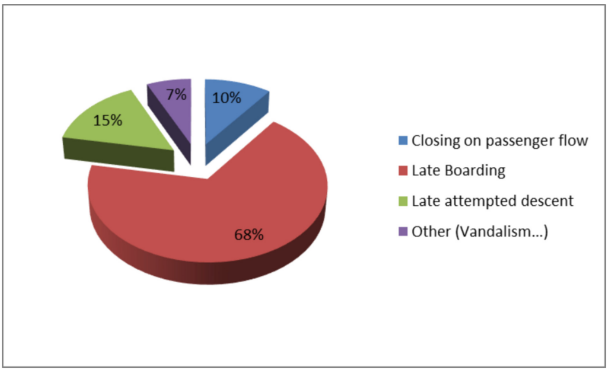

Fig. 4. Detection case analysis.

4 Conclusions

4.1 Safety Perspectives

The purpose of the test of the anti-drag door seal was to assess the potential benefits of this technical solution, without modifying or degrading the level of safety offered by the provisions currently fitted on Z2N trains.

The video recordings showed that:

1. The detected cases were always appropriate, and no disturbance or wrong detection have been observed during the test.
2. In some cases, the closure of the doors presented significant potential risks, which the current arrangements have fully controlled.

The video recordings shed valuable light on the context of these incidents and highlighted a number of key facts:

- When passengers trapped outside the door maneuver to free themselves, there is a risk of the closing limit switch switching from “open” to “closed” (This risk occurs when the passenger trapped outside turns their foot or hand to free themselves.)

– The closing sequence, performed under the control of the driver, is sometimes not interrupted as quickly as it should when a passenger is stuck outside the doors.
– Thin objects, undetectable by the current provisions, have been trapped, and accurately detected (without any consequence on safety or traffic regularity).

When analyzing the risk of a passenger being dragged along, the test in commercial service had shown that the use of an anti-drag seal would provide far superior mastering:

1. It would make it possible to detect the presence of a thin object trapped outside after the door was closed.
2. It would provide an independent device to prevent the possible consequences of a failure of the limit switch or a drift in the door setting.
3. It would enable the detection of a passenger being struck by the door during closing; this signal could usefully be provided as additional information to the driver.

4.2 Regularity of the Test

As the anti-drag seal was tested passively with respect to train and door operation, no impact on availability or related delay in operation during the test had been observed.

However, the video recordings for the most part of highlighted situations where contact between the seal and passengers resulted in an increase in the time taken to close the doors and in the length of time spent in the station.

In the case where the anti-drag seal would had been used - for example - to reopen the door safety loop after closing, less than 1 per cent would have led to an interruption in the train's departure procedure, associated with a longer stop in station.

The characteristic videos of these cases were:

– Where a passenger, after closing the door, extracts a paper bag trapped in the seals.
– Where a passenger, after closing the door, extracts a section of his jacket, held in his hand.
– When after door closing, a user removes his hand and mobile phone trapped in the door for long seconds.

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Using Safety Performance Indicators to Support and Monitor Road Safety Policies – The Role of Trendline

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Abstract. Trendline is a project funded by the European Commission for developing and applying a common methodology for the collection of safety performance indicators (called 'KPI') in the EU. 25 EU countries are fully engaged in the project; four more European countries act as an observer. Trendline starts from eight KPIs which have been defined by the European Commission. These concern speeding, driving under the influence of alcohol, distracted driving, wearing helmets, wearing seatbelts and using child restraint systems, vehicle safety, safety or roads, and post-crash care. Moreover, within Trendline some new indicators have been identified and have been tested out predominantly in the course of 2024. This set includes safety indicators on driving under the influence of drugs; enforcement of traffic regulations, red-light negation and share of 30 km/h streets in urban zones. For all KPIs, international Key Expert Groups (KEGs) have been created for developing common methodological guidelines and monitoring their implementation. Within Trendline, particular attention will be paid to policy integration. Trendline is the biggest international effort for promoting the use of performance indicators within road safety policies. Most of the data has been collected in 2024 and results have become publicly available in earlt autumn 2025.

Keywords: Road Safety · Safety Performance Indicators · Policy; Europe Union

1 Background

The Communication of the European Commission (2018) confirmed the EU's long-term goal of moving close to zero fatalities in road transport by 2050.

In order to gain a much clearer understanding of the different issues that influence overall safety performance, the Commission has elaborated, in cooperation with Member State experts, a first set of key performance indicators (KPIs) (European Commission 2019); these are listed in Table 1.

The Commission Implementing Decision C(2021)5763 final of 5.8.2021, concerning the adoption of the work programme for 2021–2023 and the financing decision for the implementation of the CEF (Connecting Europe Facility), foresaw a technical assistance action for the collection of Key Performance Indicators for road safety in

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EU Member States. The action builds on a previous CEF support action in 2020–2022 which established the Baseline project to collect and analyse data for 8 road safety Key Performance Indicators (KPIs) in 18 EU Member States (website: www.baseline.vias.be and final conclusions in Silverans and Vanhove (2023)). On the 10th of August 2022, the European Commission published a call for "Technical Assistance for the development and collection of Road safety Key Performance Indicators (KPI)". A grant was awarded to a consortium of 25 EU Member States which had proposed the "Trendline" project to continue and elaborate the work on key performance indicators". The Trendline project (www.trendlineproject.eu) officially started on the 15th of October 2022 and will last for 3 years.

2 Key Performance Indicators

2.1 What Are SPIs/KPIs?

Performance indicators are numeric values that provide useful information about the performance or quality of a process or service. In the field of road safety, performance indicators can be used for gaining a better understanding of causes of injury crashes and the effectiveness of the implementation of measures that have been taken in order to prevent these road casualties. Such indicators are often used (Road) Safety Performance Indicators; the European Commission uses "KPIs" (Key Performance Indicators (European Commission, 2019).

KPIs/SPIs can be used, among other, to (European Commission 2022):

- set targets to be achieved in the medium and long term
- monitor progress towards targets
- identify policy measures that need to be taken
- assess whether the policy measures implemented have led to the desired results
- monitor changes in contributing factors
- detect emerging trends at an early stage.

If the methods for data collection and calculation of KPIs are identical in different geographical areas (regions, countries), KPIs can also be used for benchmarking.

2.2 Eight Original KPIs

At the core of Trendline project are eight KPIs, which are listed in Table 1. These 8 KPIs are listed in a document of the European Commission (2019). The selection of these indicators was made following a long consultation process, involving road safety and SPI experts from the EU Member States. The EC document (2019) also includes minimum requirements that need to be when collecting data for these KPIs.

For each of these KPIs, a methodology for data collection and analysis was initially developed in the Baseline project. These methodologies have been reviewed and somewhat adapted during the early stages of the Trendline project and are publicly available (www.trendlineproject.eu). When developing these guidelines, the minimum requirements specified in the EC document (2019) were taken as a starting point – such as

which vehicle categories and road users, and which road types needed to be incorporated and at which moments the observations should take place. Within Baselin and Trendline, for most behavioural KPIs (distraction by phone, helmet wearing, use of seatbelt, …) the minimum number of observation locations was set at 30 (10 for urban roads, 10 for rural roads and 10 for motorways) and the minimum overall sample size at 2000 observed vehicles or road users. For several KPIs, more than one methodology and/or KPI formation was accepted. It is up to the Member States to define their national methodology in line with the common requirements specified by the Trendline methodological guidelines.

Table 1. Eight original KPIs within Trendline.

Area	Definition
Speed	Percentage of vehicles travelling within the speed limit
Safety belt	Percentage of vehicle occupants using the safety belt or child restraint system correctly
Protective equipment	Percentage of riders of powered two wheelers and bicycles wearing a protective helmet
Alcohol	Percentage of drivers driving within the legal limit for blood alcohol content (BAC)
Distraction	Percentage of drivers NOT using a handheld mobile device
Vehicle safety	Percentage of new passenger cars with a Euro NCAP safety rating equal or above a predefined threshold
Infrastructure	Percentage of distance driven over roads with a safety rating above an agreed threshold
Post-crash care	Time elapsed in minutes and seconds between the emergency call following a collision resulting in personal injury and the arrival at the scene of the collision of the emergency services

2.3 Practical Considerations

One of the aims of Trendline is to ensure comparability between KPIs from different Member States, the comparability cannot be fully achieved. This is linked to several factors, including:

- Some Member States have a long tradition of collecting and analysing data for road safety KPIs. The methodologies used often deviate somewhat from the Trendline requirements, but in order to maintain historical timelines and comparability with KPI values obtained in the past, some Member States prefer to stick to their original values.
- As stated before, for some KPIs, more than one methodology is accepted. A clear case in point is the KPI “Driving under the influence of alcohol”. The prime methodology

is based on random selection of drivers by the police. However, in some countries, the police is legally forbidden to undertake such random controls. Hence, an alternative method needs to be chosen.
- The road categorisations used in the different Member States may not fit very well with the categorisation used within Trendline.

Although such issues make it more difficult to make accurate statements about differences in road safety performance across Member States, they remain useful when making comparisons across countries.

2.4 New Experimental Indicators

In Trendline some new experimental indicators and complementary methods have been identified, following a consultation process involving all Member States. These experimental indicators are listed in Table 2.

Table 2. Additional KPIs considered within Trendline (provisional name)

Driving under the influence of drugs
Share of 30km/h road lane lengths in urban zones
Red-light negations by road users
Compliance with traffic rules at intersections
Helmet wearing of PMD riders
Self-reported risky behaviour
Attitudes towards risky behaviour
Use of lights by cyclists in the dark
Enforcement of traffic regulations
Alternative speeding indicators

Also for all these indicators, international KPI Expert Groups have been established and methodological guidelines are being developed. Based on draft versions of these guidelines, Tests have been undertaken in 15 countries to assess the feasibility, relevance and cost of data collection and analysis.

2.5 Policy Monitoring

The Trendline project will put emphasis on the effective use of the KPIs in policy monitoring activities. A Policy Integration Advisory Committee (PAC) has been established that is reflecting on how KPIs could be used in the policy process, will collect best practices, and will formulate recommendations to the European Commission and the Member States.

A survey on the use of KPIs within national road safety policies has been conducted, showing great variation across Member States, but also the beneficial effect of the funding

made available by the European Union, in particular in Member States with little or no past experience with KPIs.

3 Project Organisation

3.1 Partnership

Trendline brings together 25 (of the 27) EU Member States as partners as well as 4 European countries as observers (Estonia, Malta, Norway and Switzerland) (Fig. 1).

Most project partners are ministries of transport, but there are other types of organisations such as road safety institutes, universities, and transport research institutes. The participating ministries delegate or subcontract often most of the activities to road safety and/or transport research organisations.

Fig. 1. European countries participating in Trendline. Observers are marked in light green.

3.2 Project Coordination

The project is supervised by the General Assembly of project partners. It is coordinated by SWOV Institute for Road Safety Research (The Hague, The Netherlands). Some support for coordination and project management is provided by CDV (Brno, Czech Republic), NTUA (Athens, Greece) and Vias institute (Brussels, Belgium). Together they form the Trendline Coordination Team. For scientific coordination, a Technical Committee has been established, consisting of experts of the same organisations. Other important international groups within the project are Key Expert Groups ("KEGs") for each of the KPIs considered, a committee of statistical experts and the Policy Integration Advisory Committee (PRAC). The organisation chart is shown in Fig. 2.

3.3 Schedule and Current Status

At the moment of submitting this paper, the methodologies for the eight standard KPIs in Trendline have been published, data collection is going on and the feasibility tests for the new experimental indicators is going on. Most EU Member States will deliver values for 5 to 7 of the original KPIs and two thirds will test one or more experimental indicators. Most of the measurements and observations took place in autumn 2023 and spring 2024. Public reports were available in early autumn 2025.

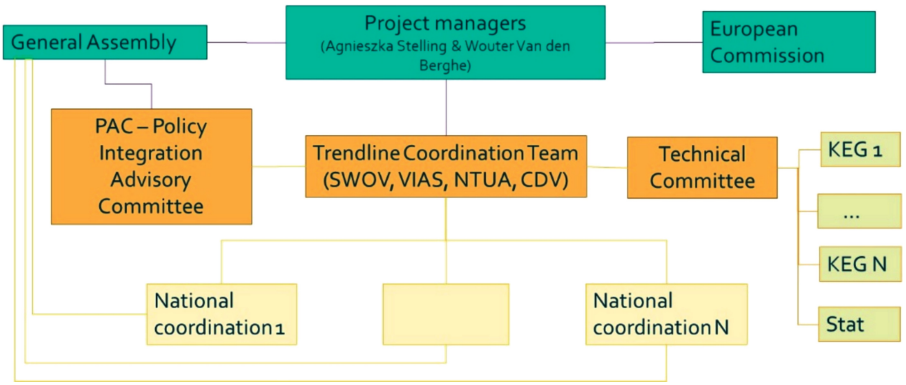

Fig. 2. Organisation of the Trendline project.

4 Conclusion

The Trendline project show that it is possible to develop and apply methodologies for road safety performance indicators that are common, transferable and comparable across different countries in Europe. The data collected is a basis for monitoring and evaluating the road safety progress at national and EU level over the decade 2021–2030. It will also facilitate the formulation of targets at European and national level and will support decision makers in deciding on the most appropriate measures to be taken to improve road safety.

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Examining the Influence of Traffic Enforcement on the Development of Traffic Safety Culture

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Abstract. This paper aims to investigate the impact of traffic safety culture elements on the probability of road crash involvement, focusing on traffic enforcement aspects.

Focus is on car drivers and motorcyclists in touristic and non-touristic areas in Greece. A questionnaire survey was conducted among car drivers and motorcycle riders in Athens and the on island of Rhodes. The survey included questions on background variables, national and local traffic safety culture (referring to the road user behaviours that respondents expect from other drivers in their own country or municipality), paternalism, experience of road safety enforcement, road risk attribution and previous involvement in road crashes. Five binary logistic regression models were developed in an effort to find differentiations and common road safety culture elements between car drivers and motorcycle riders, but also drivers in Athens and drivers in Rhodes, in relation to road crash risk. Results indicate that drivers probably understand the importance of more intensive traffic enforcement as a means of traffic crash reduction; the development of a common traffic safety culture in the island of Rhodes in contrast to Athens and the importance of factors such as driving frequency, age and experience on traffic crash probability.

Keywords: Road safety · traffic crash involvement · traffic safety culture · traffic enforcement

1 Introduction

Worldwide, about 1.35 million road users are killed annually resulting to a devastating social and economic cost (W.H.O, 2018). Greece scores the 6th worst performance in the European Union as far as road fatalities per million inhabitants are concerned (CARE – Eurostat, 2022). Nævestad et al. (2012), highlight the importance of traffic safety culture studies as a means of improving road safety level. Morimoto et al. (2022) also point out the necessity of constructing a Safe System tailored to the traffic safety culture of each country, utilizing comparisons and ratings based on common road safety metrics, in order to implement road safety measures at a national level.

Traffic safety culture studies in Norway and Greece (Nævestad et al., 2021), show that a common safety culture exists in Norwegian provinces, while in Greek provinces

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there is a statistically significant differentiation. The importance of traffic safety culture as a behavioral pattern indicator is highlighted while the correlation between it and traffic crash involvement is proved. With that in mind, a similar research (Nævestad et al., 2022) has shown that risky behavior endorsement can increase road crash probability.

Based on the findings of the ESRA study (Meesmann et al., 2022), the enforcement level declared by drivers is adversely proportional to traffic violations. Moreover, drivers' opinions concerning traffic enforcement as well as their or other drivers' risky behaviors, could be an important predictor of traffic violation probability (Tan et al., 2022). In Greece, it has been found (Yannis et al., 2007) that the level of enforcement and road crash number varies significantly from region to region in Greece.

The main objective of this paper is to investigate the impact of traffic safety culture elements with focus of traffic enforcement aspects, on the probability of road crash involvement. Car drivers and motorcyclists in touristic and non-touristic areas in Greece constitute the target groups of road users.

To achieve this, a drivers' behavior questionnaire survey was conducted among 503 private car drivers and motorcycle riders who live in Athens and Rhodes areas. Questions serving the objectives of this study were selected and the respective answers were statistically analysed. Five binary logistic regression models were developed using road crash involvement as the dependent variable.

2 Methodology

2.1 Data Collection

Data used in this paper were initially collected within a research project titled "Safety culture in private and professional transport: examining its influence on behaviours and implications for interventions" undertaken by the Norwegian Institute of Transportation Economics (TØI) and the National Technical University of Athens (NTUA). One of the main goals of the project was the comparison of transport safety culture between Norwegian and Greek drivers.

A questionnaire survey was conducted among private car drivers and motorcycle riders sampled in two different areas, namely Athens (N = 321) and the island of Rhodes in Greece (N = 182). The survey included questions on background variables like age, experience as a driver, gender, kilometers driven with a car or motorcycle in the last two years, frequency of driving and type of vehicle. Additional questions concerned measuring national and local traffic safety culture (referring to the road user behaviours that respondents expect from other drivers in their own country or municipality), paternalism, experience of road safety enforcement, road risk attribution and previous involvement in road crashes. Questions selected for the analysis described in this paper and alternative answers are listed below:

- **General**: gender, age (<26, 26–35, 36–45, 46–55, 56+), for how long have you had your driver's license? (0–5 years, 6–10 years, 11–15 years, 16–20 years, 20+ years), What is you highest education? (primary school, high school, lyceum, professional school/technological university, university), area (Athens, Rhodes), type of vehicle (car, motorcycle)

- **Expected driving behaviour (country level/municipality level):** When driving in my country/municipality, I expect from other drivers to respect and follow traffic rules (none/very few, less than half, about half, more than half, nearly all/all)
- **Expected driving behaviour (peers):** How many of your friends who regularly drive a car do you think they respect and follow traffic rules (none/very few, less than half, about half, more than half, nearly all/all)
- **Acceptance of traffic enforcement:** The fact that crashes still happen in traffic, shows that the authorities should control road users' behaviour to a greater extent than they do today (totally disagree, disagree somewhat, neither agree or disagree, agree somewhat, totally agree), The authorities should make it more difficult for people to engage in risky behaviour in traffic (totally disagree, disagree somewhat, neither agree or disagree, agree somewhat, totally agree),
- **Traffic enforcement experience:** In the course of the two last years, approximately how often have you seen a police inspection along the road? (never, hardly ever, 5 times or fewer, 10 times or fewer, 20 times or fewer, more than 20 times)
- **Road risk attribution:** In your opinion, is lacking police enforcement of traffic rules an important cause of traffic crashes in Greece? (unimportant, of little importance, neither important /nor unimportant, somewhat important, very important)
- **Involvement in road crashes:** During the last two years, have you been involved in a traffic crash while driving? (No, Yes)

2.2 Descriptive Statistics

More than 2/3 of the sample comprises men, while the majority of the questioned drivers are aged between 26 and 45 years old. Most of the drivers and riders (69%) have had their driving license for more than 10 years, while about 9 out of 10 drivers drive every day.

Some quantitative findings include that only 33 to 42% of the drivers expect other drivers to follow traffic rules, regardless of the reference level (friends, municipality or country). The current insufficient level of enforcement in Greece is indicated by the fact that 55% of the drivers have seen less than 5 police checks over the period of the last 2 years. The majority of drivers deem the lack of enforcement as a very important cause of traffic crashes.

2.3 Statistical Analysis

For the analysis of the data, five binary logistic regression models were developed:

- An overall model for drivers of private cars and motorcycles in Athens and Rhodes
- One model for drivers of private cars and motorcycles in Athens
- One model for drivers of private cars and motorcycles in Rhodes
- One model for drivers of private cars in Athens and Rhodes
- One model for drivers of motorcycles in Athens and Rhodes

In all models the dependent variable was the involvement in a traffic crash. The selection of the independent variables inserted in each of the above models is the result of many trials with several different independent variable combinations, out of which

the models with the best statistical fitment were extracted. Statistical checks require an independent value significance level of less than 0.05, a Hosmer-Lemeshow value significance greater than 5% and an R^2 value as close to 1 as possible.

3 Results

Model 1: Drivers of private cars and motorcycles in Athens and Rhodes

Results show that those who expect less than half of their friends to follow traffic rules are 39.3% less probable to being involved in a crash. This, maybe, shows that they consider others' behavior dangerous for themselves too and, as such, they make safer decisions. It is also important to notice that those who declare that the lack of enforcement is not an important cause of traffic crashes are 2.5 times more probable to being involved in a traffic crash. This could be attributed to the fact that these drivers do not prefer stricter enforcement, because they obtain risky behaviors that also result to higher crash involvement. Finally, driving frequency and age are also important. Those who drive every day are more probable to crash involvement, due to their greater exposure to everyday risk. Drivers over 55 years old are also at greater risk compared to younger drivers.

Model 2: Drivers of private cars and motorcycles in Athens

In Athens, drivers' behavior in the municipality plays a statistically significant role when it comes to traffic crash involvement. In particular, those who expect less than half of the drivers in their municipality to follow traffic rules, are 64% less probable to being involved in a crash (similarly to Model 1). Moreover, gender plays a statistically significant role, as women are less probable to being involved in a crash by 42.9% compared to men.

Model 3: Drivers of private cars and motorcycles in Rhodes

Contrary to the drivers in Athens, those who expect less than half of the drivers in their municipality to follow traffic rules are 6.5 times more likely to being involved in a crash. This is likely attributed to the fact that in a small and secluded society, like the island of Rhodes, the local social environment has a strong influence on behavior, causing drivers to follow social trends (in this case not following traffic rules) in order to avoid standing out or being considered irregular.

Model 4: Drivers of private cars in Athens and Rhodes

Declared police enforcement frequency is statistically important among car drivers, as those who have reported infrequent checks are 49.2% less probable to being involved in a crash. A likely explanation is that the lack of enforcement forces drivers to adopt safer behaviors, as they feel exposed in a low-level enforced driving environment.

Model 5: Drivers of motorcycles in Athens and Rhodes

Experience – and not age group – is a statistically significant variable among motorcycle riders. That been said, it is observed that riders with less than 5 years of experience are the least likely to being involved in a traffic crash. A possible contributing factor could be that motorcycle riding requires more skills than car driving and, thus, less experienced riders tend to be more careful on the road.

4 Discussion

The main objective of this paper is to investigate the impact of traffic safety culture elements with focus of traffic enforcement aspects, on the probability of road crash involvement. The study was focused on car drivers and motorcycle riders as well as on drivers in touristic and non-touristic areas.

The findings of this study can provide useful insight to road safety stakeholders and particularly to local authorities and high-level police officers who decide on and design enforcement activities with regards to the interaction between road safety culture and enforcement. Specifically, how enforcement is perceived by road users, is accepted or not and what impact it has on road safety culture and consequently on road safety outcomes.

The main conclusions of this paper are included in this chapter, taking common elements and differentiations between the models into consideration. Starting from the common elements, there are two common statistically significant variables across all models. These were driving frequency, which is proportional to the traffic crash probability and lack of enforcement being considered an important cause of crashes. The latter shows that drivers who perceive that there is a lack of enforcement, adopt less dangerous behaviors due to the insecurity caused by the above finding. They also understand that traffic enforcement is a key factor towards making roads safer, demanding its intensification.

Concerning age and experience, it is found that older drivers (55+ age group) or, in the case of motorcycle riders more experienced ones (20+ years of experience) are more prone to being involved in a crash, compared to all the other groups. This might show that age or experience comes at the cost of obtaining riskier driving habits.

Friends' behavior is only statistically significant when it comes to smaller social groups, like drivers in Rhodes and motorcycle riders. This might show that bigger social groups, like car drivers or drivers in Athens, are not greatly influenced by their peers.

As discussed, driver-declared behavior of other drivers in their municipality has a positive impact on drivers in Athens, yet a negative one on drivers in Rhodes. Thus, a common safety culture among drivers in a secluded touristic area is likely developed.

On the other hand, driver-declared enforcement frequency is only significant when it comes to car drivers, indicating that they are worried about low enforcement level and, because of that, they take fewer risks. Finally, gender is only significant among drivers in Athens, showing that women have a lower risk of being involved in a crash.

The following proposals, which are based upon the discussed conclusions, aim to generally improve road safety level in Greece. Particularly, an increase of the enforcement level could be useful, provided that it is focused upon the main crash causes, such as speeding, alcohol violations and seatbelt/helmet usage. Establishing local road safety observatories in areas with low road safety levels such as the Greek islands, could also prove very useful. Those observatories could gather and analyze specific crash data from these areas and provide solutions which are tailored to their unique needs.

Future research proposals include expanding the specific study into areas that have a discrete traffic safety culture, so that comparison studies can become available. A research expansion among different islands (i.e. in the Mediterranean) would also enlighten some interesting safety culture aspects. Frequent research repetition and an expansion among different European countries could as well provide a firm European

traffic safety culture database. Finally, the inclusion of additional survey questions or different analysis methods could further enlighten traffic safety culture.

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Powered Micromobility on the Edge: The Reality of Critical Interactions with Other Road Users

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Abstract. The growing popularity of electric personal vehicles has led to new challenges and an increase in accidents. This study aims to analyze risky situations among e-scooter and e-monowheel users by examining perceived, observed and measured data to gain a comprehensive understanding of safety issues. Over two months in the South region of France, the daily trips of 25 e-scooter and 5 e-monowheel drivers were recorded using smartphones, including vehicle dynamics data and video footage. The participants could report critical events in real-time. The experiment recorded 1559 trips and 115 critical events. Most interactions occurred on the road, involving motorists and pedestrians, often at intersections and during daylight. Drivers attributed responsibility as follows: 20% to themselves, 65% to others, and 15% shared, with 9% of traffic offenses reported. Causes primarily revolved around non-compliance with traffic regulations, failure to signal driving intentions, and right-of-way violations. Video and measured data accurately captured 80% of events, with 77% of them matching the declared emergency maneuvers, typically hard braking and/or avoidance. 10% of the critical events were classified as very serious and 21% as serious. Some differences emerged between e-scooter and e-monowheel users' critical events. Similar naturalistic driving studies in Lyon and Paris will provide valuable additional data.

Keywords: Mobility · Safety · New Power-Assisted Personal Mobility Vehicles

1 Introduction

The introduction of electric Power-assisted personal Mobility Vehicles (e-PMVs) has significantly transformed the way people move around. However, the growing popularity of these vehicles, alongside conventional modes of transport, has resulted in new challenges, such as sharing street space, increasing traffic offenses, and creating higher-risk situations [1]. The latest statistics from the French road safety observatory on road accidents [2] indicate a substantial increase in e-PMV accidents in France.

Some authors have studied reported crash data to describe crash patterns associated with the use of electric scooters [3]. However, accident data is scarce and often lacks

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detail. Few studies have explored the interactions between e-PMVs drivers and other road users in natural environments [4]. A recent naturalistic driving study involving 50 shared electric scooters was conducted by Virginia Tech [5]. This study detected safety-critical events, including crashes and near-crashes, using a combination of criteria based on vehicle dynamic data. The approach used in our study is similar in terms of instrumentation, but critical events are first identified based on the driver's perception and assessment, with the driver reporting the incidents in real-time. Additionally, the driver answered a questionnaire about each event, which complements the vehicle dynamic data recorded throughout the trip, along with video contextualization of the scene ahead. To date, no comprehensive naturalistic study specifically focusing on e-monowheel driving has been found in the literature, probably because e-monowheel driving is a relatively recent and less prevalent mode of personal transportation when compared to the more widely adopted e-scooters and e-bicycles.

This study aims to understand the risky situations and near-misses experienced by users of e-scooters and e-monowheels. It seeks to identify interactions perceived as dangerous, analyze them, and see how these subjective data are corroborated or not by objective measured and filmed data. The aim is also to see how the combination of these three types of data enhances situational risk comprehension.

2 Material and Methods

Over a two-month period, a fleet of 25 e-scooter and 5 e-monowheel drivers was observed in the South Provence-Alpes-Côte d'Azur region of France. Daily trips were recorded using a smartphone as a data logger, installed on each vehicle with the help of a custom 3D-printed support (Fig. 1).

Fig. 1. Instrumentation of e-scooter and e-monowheel. Photos by LMA, G. Eiffel University.

The smartphone is equipped with an application specifically developed for capturing vehicle dynamic data, including accelerations in three directions (longitudinal, lateral, and vertical), rotation rates in three axes (roll, yaw, and pitch), GPS speed and trajectory information, and video footage of the road ahead. Participants could report risky situations by pressing a button on the recording system interface during the trip, and at the end of the trip or later, they were invited to complete a questionnaire to provide further

details on the critical situation encountered: location and frequency of circulation, road configuration, other users involved, responsibility, causes, emergency maneuver, traffic violation, frequency and severity.

3 Results

Overview. The experiment enabled the recording of 1309 e-scooter trips, covering a total distance of approximately 2600 km, and 250 e-monowheel trips, covering around 700 km (Table 1, Fig. 2). In total, 115 situations were reported by drivers with a fully completed form, with 104 from e-scooters and 11 from e-monowheels.

Table 1. Characteristics of experiment and reported events.

	No. of drivers	No. Drivers with events	No. of trips	Distance (km)	No. of events (No. of accidents)	No. of events in intersection
E-scooter	25	20	1309	2609	**104** (1)	50 (47%)
E-monowheel	5	4	250	689	**11** (2)	4 (36%)
Total	30	24	1559	3298	**115** (3)	52 (45%)

Context. The other road users involved in these situations were mainly motorists (49%) and pedestrians (17%). In 13% of the cases the user was alone (Fig. 3). These interactions primarily occurred on the road (61%), followed by cycle lanes (17%), with significantly fewer events occurring on sidewalks and other facilities like soft paths, meeting zones, bus and tram lanes. In 45% of the cases, the events took place at intersections (Table 1), while 47% occurred at locations the driver frequented on every trip. Most of these incidents occurred during the day (83%), with 13% at night and 4% at twilight.

Examples. Figure 4 displays three driver-reported events (two e-scooters, one e-monowheel), with curves representing longitudinal acceleration, yaw, and roll rates during these situations, marked by yellow (freeze frame) and red (reported moment) cursors.

Accidents. Among the 115 reported situations, three were in fact accidents (Table 1), involving collisions with others, or a fall to the ground. According to the drivers, these accidents were not serious enough to cause any injury or material damage.

Responsibility. Users acknowledged being responsible for a risky situation in 20% of the cases, attributed responsibility to another party in 65%, and reported shared responsibility in 15%. They declared having committed traffic offences in 9% of the cases. However, video observation revealed that some users routinely break traffic regulations, like wrong-way driving, using sidewalks, and weaving between lanes.

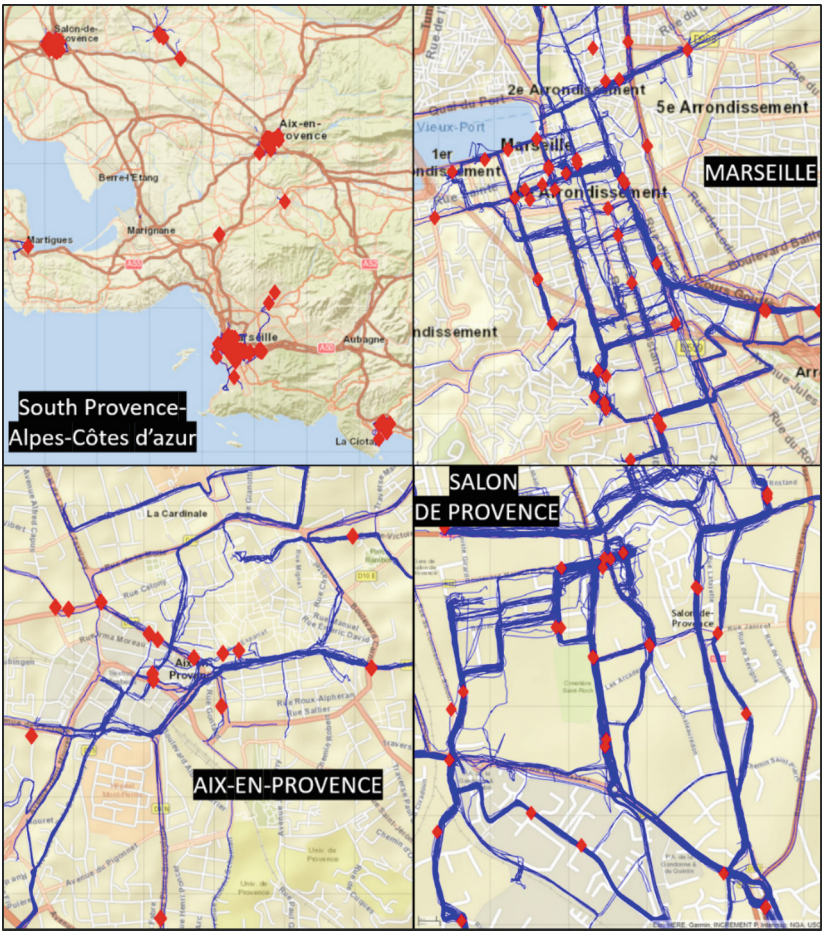

Fig. 2. Maps of trajectories and event triggers. Created using MATLAB R2023a.

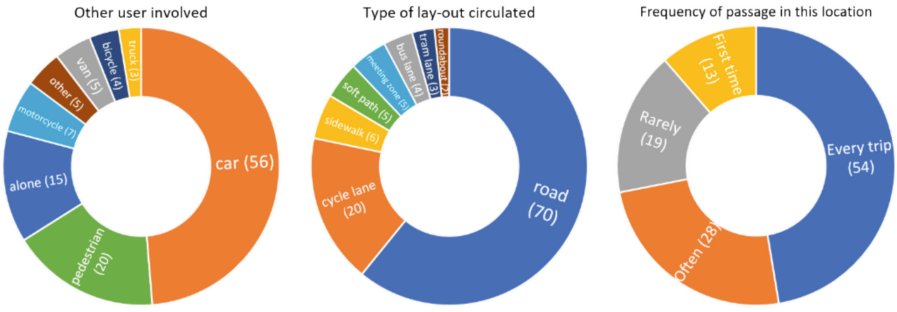

Fig. 3. Context of events.

Fig. 4. Examples of risky situations reported by e-scooter and e-monowheel drivers.

Causes. The triggering factors of reported interaction situations (Fig. 5) were estimated based on user responses in questionnaires, observed elements in videos, and recorded speed data. Some factors may be underestimated, especially speed. There is a predominance of factors related to non-compliance with road rules, including failure to signal driving intentions. A substantial number of instances where the other user violated the right of way were observed and reported by drivers. There are also problems associated with road layout (e.g., end of cycle path) and poor road conditions (e.g., potholes).

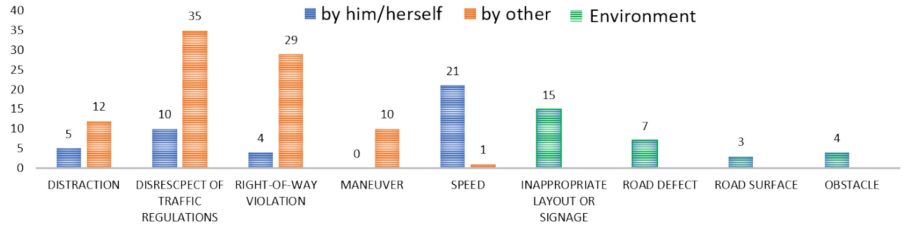

Fig. 5. Estimated causes of events (multiple possible choice for each event).

Emergency Maneuvers. In 80% of cases, the event could be traced to the video data with correctly recorded vehicle dynamics. In 77% of these cases, at least one declared emergency maneuver corresponded to that observed in the measured data. The most common emergency maneuver is hard braking, followed by avoidance, and a combination of both (Fig. 6). Observed and declared emergency maneuvers generally align, but participants tend to report more 'emergencies' than external analyses consider urgent.

Frequency and Severity. The drivers rated the frequency and severity of critical events on a scale of 1 to 6. 26% of the events were considered to occur very rarely, and 2% very frequently (Fig. 7). 28% of the events were classified as serious (5), 21% as moderately serious (2), and 20% as medium-serious (4). Additionally, 10% of the incidents were classified as very serious (6), the three actual accidents not rated at this severity level by the drivers (one rated severity 2, and 2 rated severity 5).

E-scooter Versus E-monowheel. Figure 8 illustrates key differences in the critical events between e-scooters and e-monowheels. On average, e-scooter drivers reported

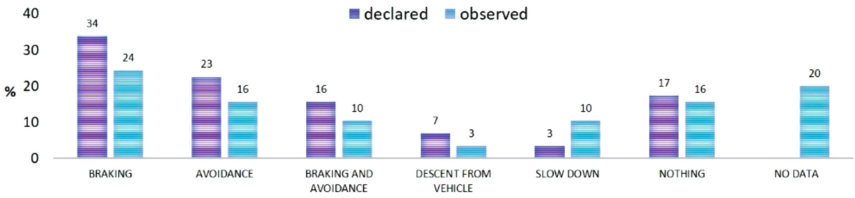

Fig. 6. Emergency maneuvers (%).

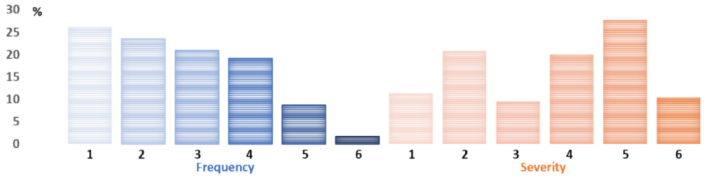

Fig. 7. Declared frequency and severity of events.

4 events, while e-monowheel drivers reported 2. Of the 25 e-scooter drivers, 5 had no events. These users drove an average of 66 km, compared with a general average of 104 km. Of the 5 e-monowheel drivers, only 1 had no incidents. This driver drove 61 km, compared with an average of 138 km for e-monowheel users. E-monowheel incidents occurred more frequently when drivers were alone and less frequently on the road. These differences should be confirmed with a larger e-monowheel sample.

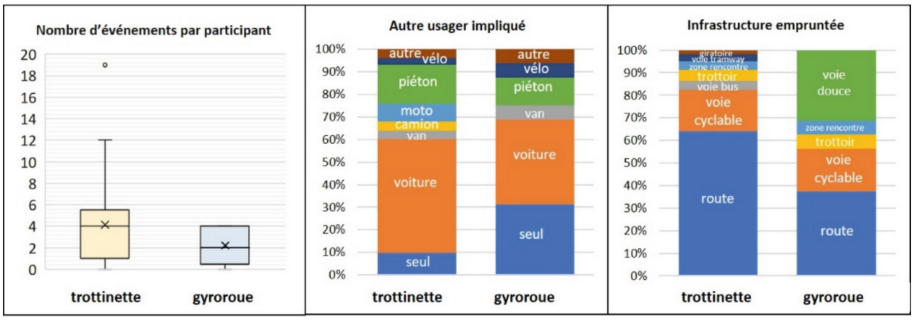

Fig. 8. Differences in critical events between e-scooters and e-monowheels.

4 Conclusion

The study highlights the various at-risk interactions of E-PMV users, and underlines the value of cross-referencing reported and measured data to create a detailed overview of interactions. The study also involved interviews with participants and a self-confrontation with the risky situations they reported. An in-depth analysis of these interviews is

planned, which may reveal potential inconsistencies between the participants' statements and the questionnaire responses. Upcoming experiments in Lyon and Paris with 60 participants will offer valuable data and insights into critical situations for e-scooter and e-monowheel users, advancing our understanding of road safety for all road users.

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A Naturalistic Study of Personal and Free-Floating Electric Scooter Users: Profiles and Behaviours

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Abstract. The development of electric vehicles has made it increasingly difficult to share urban layout facilities. The purpose of this study is to understand the profiles of personal and free-floating electric scooter users, their behaviours and their risky situations. Forty-one users of e-scooters were recruited, and three data collection methods were combined during one month: 1) recordings of all their routes using a camera fixed on the chest, 2) completion of a logbook describing each route and critical situation, and 3) an interview per week based on the logbook and the video recordings to deepen the user's behaviours. Results showed that even if the distance traveled for personal e-scooters users is double the distance traveled by free-floating e-scooters users, the routes are relatively short for both users. There were a couple of differences in terms of usage: type of route, wearing of safety equipment, and relation to the rules. One hundred and twenty-six risky situations were collected during a month. Participants mainly considered other road users responsible for the risky situations, particularly car drivers (44%). The riskiest layouts are the bike lanes on the road (26%) and the shared road (24%). The most frequently risk scenario encountered by these users is «encroachment of another user on a lane or presence of a stationary user» (29% of all critical situations). These data are necessary for the formulation of public policies in order to promote, supervise and design urban layouts and facilities including those for e-scooters users.

Keywords: Electric Scooter users · Behaviour · Risky Situations

1 Introduction

Urban mobility is being changed by environmental awareness and the growing commitment of planning policies to 'clean' cities. This translates into the development of active mobility offers and electrical Power-assisted personal Mobility Vehicles (e-PMVs) with low environmental impact, like e-scooters. These vehicles are subject to a new mobility organization called 'shared mobility'. The multiplication of these new mobilities leads to new mobility situations: new users, new behaviours, new risky situations. The latest

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data showed that the number of seriously injured e-PMVs users has been rising steadily since 2019 with a strong increase in 2021 [1]. In view of these figures, the multiplication of these vehicles is a source of concern for the public authorities in terms of interaction and management difficulties. These concerns are even pressing as it appears that the development of these active mobility modes is not a trend. A new way of sharing lanes, either authorized or imposed by the users themselves, is being defined and needs to be understood.

A naturalistic approach has been chosen for this investigation based on a conceptual framework at the intersection of the French-language ergonomics approach and the critical incident method [2]. This approach aims to report on human activity by considering it as a complex whole integrating emotions, perceptions, interpretations, actions and communications. It allows us to consider the activity as 'situated' because it is closely linked to the 'context' in which it takes place [3]. It also focuses on the collection and exploitation of verbal data. The critical incident method is an interview technique that facilitates the study of significant events identified by the person involved in them, as well as the way in which they are managed and their effects in terms of perceived affects.

This article presents the results of a naturalistic study conducted in Paris and Lyon (France) that sought to understand the profiles of personal and free-floating electric scooter users, their behaviours and their risky situations.

2 Data Collection

Forty-one users of e-scooters were recruited for one month (average age = 32; 12 women and 29 men): 17 with personal e-scooters and 24 with free-floating ones.

Three data collection methods were combined: 1) recordings of all their routes using an on-board camera fixed on the chest with an integrated GPS sensor, 2) completion of a logbook describing each route and critical situation, and 3) an interview per week based on the logbook and the video recordings to deepen with the user's behaviours.

Two types of data were analyzed: position data (distances covered, average speeds and routes durations) and interview-logbook data. The participants' speeches were transcribed providing an overall view of their responses. A processing grid was then constructed, incorporating analysis categories (actors involved, scenarios, etc.). Once the categories of analysis had been set, the corpus was coded using the comments of the participants. Afterward, descriptive statistical analyses were carried out.

3 Results

3.1 Use and Difference Between Personal and Free-Floating E-Scooters Users

The study allowed to record 214 trips, 1443 km traveled and totaling 5445 min.

Data showed that the average distance traveled is relatively short for both types of users, although the average distance traveled by personal e-scooters is twice the one traveled by free-floating e-scooter users (4.1 km versus 2.1 km). Then, data highlighted a couple of differences in terms of usage. Firstly, for personal vehicles, routes are more oriented towards daily commuters (70% of the time). Free-floating e-scooter users took

more leisure trips (69%). The number of routes made per week by personal e-scooters is also slightly higher (on average, 3.5 per week for personal e-scooters users compared with 2.5 per week for free-floating users). Secondly, safety equipment is worn more by personal users (47%) than free-floating users (4.5%). They considered it inconvenient for their use because they did not plan the use of an e-scooter in advance. So, users are not planning any special equipment. A reason for wearing safety equipment by personal e-scooter users was raised: it allows them to follow the codes of motorists and be more respected and different from free-floating users who, in their view, are less respectful. Personal e-scooter users seem to perceive a difference in their relationship to other road users when they wear equipment or not. Thirdly, the link with the rules also seems to differ between personal and free-floating scooters: 71% of personal e-scooter users said they were familiar with the rules, compared with 18% of free-floating e-scooter users.

3.2 Risky Situations

One hundred and twenty-six risky situations were collected: 89 from personal e-scooters users and 37 from free-floating e-scooters users. In over half the cases (56%), participants said that another user was the trigger (59% for personal e-scooter users and 31% for free-floating e-scooter users). The next highest proportion of responsibility was attributed to inadequate layout (14%).

Almost half of the road users involved in these risky situations were car drivers (44%). They were the most involved users for both types of e-scooter users (47% for personal e-scooters and 32% for free-floating e-scooters). Then, there were many pedestrians (13%) and pickup vans (13%).

Two types of lanes were particularly concerned by risky situations: bike lanes on roads (26%) and shared roads (24%). This can be related to the number of users involved and their interactions with motorized users.

Figure 1 illustrates that the main risk scenarios encountered by users include. The most common risky situation is the encroachment of the lane by another user or the presence of a stationary vehicle (29%). This scenario includes all situations where another user, moving or stationary, has occupied the space on the lane where the participant was initially located. We then find the denial of priority from another user (21%). It represents all situations where the participant had the priority but this has not been respected by another user. And finally, the third most encountered risk scenario is the inappropriate layout (12%). It concerns all situations where the participant has judged the layout to be unsuitable for their user (inappropriate design, lack of signage or information, etc.).

Depending on the mode of transport used, the order of these scenarios was not exactly the same. For personal e-scooter users, the first two scenarios were the same, followed by non-compliance with lateral and longitudinal safety distances (7%). For the free-floating e-scooter users, inappropriate layout was the most frequently encountered scenario (30%), followed by the encroachment of another user on a lane or the presence of a stationary user (14%).

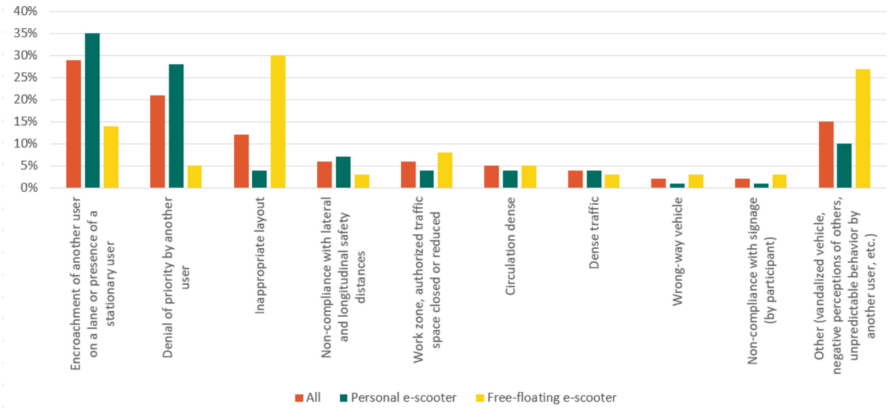

Fig. 1. Distribution of risk scenarios (as a percentage).

4 Discussion

Few studies exist on the real use of electric scooters, which makes comparison difficult. However, regarding the existing literature on similar soft mobility modes (bike, e-bike), we can see that the risks encountered are relatively similar. The shared road and car drivers were the layout and users most involved in incidents [4]. Concerning risk scenarios, two of the three scenarios most frequently encountered in this study (encroachment of another user on a lane and failure to give way) were also most common in the COCY project (2021) and the COFACY project (in progress).

The results of the study can also be compared with those of the ELMOS project [5], which converge in the same direction. In terms of use we find 76% of ELMOS project respondents use their electric scooter daily or almost daily. This trend is even more pronounced among users with their own scooter, where the proportion rises to 87%. In terms of mode of use, work or study-related travel is also the main reason, reported by 90% of respondents. Additionally, there is a higher prevalence of trips for leisure activities among users of shared services. The ELMOS project also found that helmet use was highest among users of personal electric scooters (27%), while a proportion described as 'extremely rare' was observed among users of shared services. Furthermore, one observation corroborates that made in our results, where users of personal electric scooters wear safety equipment to distinguish themselves from users of shared services. Indeed, users of electric scooters themselves report that users of shared services are a risk factor and are particularly disrespectful of traffic rules. In terms of responsibility in the event of risky situation and the user involved, the results are also consistent with those of the ELMOS project, where in 78% of Personal Mobility Device (EDP) accidents, another vehicle is involved, and in two out of three accidents, it involves a conflict with a car.

Furthermore, an unexpected result showed that this increase in the use of soft mobility leads to group effects. Users feel a certain sense of belonging, enabling them to feel safer from other users because they are more numerous and therefore 'more imposing'.

However, it also means that the facilities are too small, which can cause tension between vulnerable users.

This study may lead to the development of a number of suggestions for adaptations based on experience in the field and the practical difficulties experienced by e-scooter users. Results showed that there is a need for improvement in urban traffic in order to reduce the risks associated with interactions between users, improve lane sharing and facilitate the day-to-day use of e-scooters in terms of comfort and navigation. We can imagine the creation of an awareness campaign on the risks generated by certain behaviours identified as problematic, the addition of signage to draw attention to the presence of potentially vulnerable road users, and the coloring of cycle layout to reduce the presence of pedestrians. Also, it would be relevant to make it easier for users to plan their itinerary, the installation of traffic light systems to free up the flow of vehicles, etc. These data are necessary for the formulation of public policies aimed at promoting, supervising and designing urban layouts and facilities including those for e-scooter users, especially given the increasing popularity of e-PMVs and increasing frequency of accidents.

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Gamified Smartphone App Engagement: Comparative Analysis of Belgian and UK Car Drivers in the i-DREAMS Project

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Abstract. The i-DREAMS project introduced the concept of a 'Safety Tolerance Zone', i.e., a context-aware safety envelope designed to assist drivers in maintaining self-regulated control within the boundaries of safe operations. Using an ecosystem of sensors, i-DREAMS technology continuously monitors factors determining driving task complexity and available coping capacity and calculates risk levels in real-time. Based on this information, both real-time and post-trip interventions are tailored to keep drivers from getting too close to the boundaries of unsafe driving. Real-time interventions are provided via in-vehicle display, while post-trip interventions are delivered via a smartphone app (and web-dashboard) with provisions for gamification. This study focuses on post-trip interventions, specifically user engagement with the i-DREAMS app.

Data from 49 Belgian and 51 UK car drivers over a 10-week period showed a steady decline in drivers' engagement following the first day of app activation. However, when gamification features were activated, user interaction increased, suggesting they re-engaged users. UK drivers exhibited higher engagement than Belgians. Trips, scores and goals were the most visited features in both countries, while the leaderboard was popular among UK drivers only. Analysis showed a dose-response relationship, with intensive app users demonstrating better improvement in driving performance than less frequent users.

Keywords: i-DREAMS · Safety Tolerance Zone · Gamification · Smartphone intervention · User engagement · Dose-response analysis

1 Introduction

Europe has achieved intriguing progress in reducing road fatalities and injuries. The EU member states have, however, faced a slowdown in reducing crash-related fatalities recently [1]. To deal with stagnation in road safety improvement, researchers and

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policymakers are looking for new and innovative solutions, such as smartphone applications with the incorporation of gamification elements [2–4]. The i-DREAMS[1] was a European project funded by the EU's Horizon 2020 research and innovation program. It introduced the 'Safety Tolerance Zone' (STZ) concept, a context-aware safety envelope designed to prevent drivers from getting too close to the boundaries of unsafe driving via both real-time and post-trip interventions. The i-DREAMS platform accounts for driver background factors and real-time risk indicators associated with driving performance as well as driver state and driving task complexity indicators to monitor and determine continuously in real-time if a driver is within acceptable boundaries of safe operation. In-vehicle interventions inform or warn drivers in real-time (nudging), and post-trip interventions inform them after driving through an app-based (and web-based) gamified coaching platform to improve driving behaviour (boosting). More in detail, the smartphone application was developed to provide feedback to drivers about important driving behaviour variables once a trip was completed. Major functionalities included trip-related information, scores, forums/messages, pros-cons, tips, goals and badges, and leaderboard (see Vanrompay et al. [5]). This study focuses on the post-trip interventions.

2 Objectives

The primary aim of this paper is to report on user engagement with the i-DREAMS app. Moreover, this study examines the potential dose-response relationship between the level of engagement with the i-DREAMS app intervention on the one hand and the level of improvement of driving performance on the other hand. We hypothesize that more user engagement leads to better (i.e., safer) driving performance.

3 Methods

Part of the i-DREAMS project was a longitudinal field operational test conducted in a real-world setting, comprising four phases: phase 1: Baseline measurement with no intervention (4 weeks), phase 2: real-time intervention only (4 weeks), phase 3: real-time intervention + post-trip feedback (4 weeks), and phase 4: real-time intervention and post-trip feedback + gamification (6 weeks). The participants were selected based on several inclusion criteria to ensure a diverse and representative group. These criteria included factors like driving experience, road exposure, age (minimum 18 years), balanced representation of gender, vehicle type (to accommodate the i-Dreams technology), smartphone usage, multi-driver access (i.e., one vehicle, many drivers), etc. Data used for this study comes from 49 Belgian and 51 UK private car drivers and covers a 10-week period (i.e., phase 3 and phase 4, where participants were using the app). Data analysis for this study was done in two stages. In the first stage, user engagement data with the app was analysed (1) to determine how frequently drivers used the app, (2) to identify the most popular app functionalities, and (3) to determine how user engagement evolved over 10 weeks, over days in the week, and over hours in the day. In the second stage, we performed a dose-response analysis to check the impact of interventions, specifically

[1] For details, please check i-DREAMS project website: https://idreamsproject.eu.

app engagement, on driving performance. More in detail, participants were divided into low and high-engagement groups based on their app use. Next, a generalised linear mixed effects model (GLMM) was utilised to analyse the impact of app engagement on driving behaviour. The GLMM was chosen because it facilitates the simultaneous analysis of repeated measures in a longitudinal design, and yields more precise estimation of changes in outcomes over time [6]. The dependent variables were the average total number of risky events per 100km observed during four distinct phases, whereas the independent variables were level of engagement (high- and low-engagement group, with low-engagement group as reference) and the four phases of the field trial: phase 1, phase 2, phase 3 and phase 4. Phase 1 served as the reference point for time comparisons.

4 Results

4.1 User Engagement

Table 1 provides details of app visits of i-DREAMS participants in Belgium and the UK. The average daily visits were higher in the UK (51.3) than in Belgium (39.5). However, the average daily users were higher in Belgium (18.4) than in the UK (17.6).

Table 1. Total app users, total visits, and average daily app users and visits

	Belgium	UK
Total # of users	49	51
Total # app visits	2768	3594
Av. # visits per day	39.5	51.3
Av. # users per day	18.4	17.6
Av. # visits per user per day	2.1	2.6

A more detailed frequency analysis indicated that ‘trip’ was the most intensively visited functionality in both countries. For Belgium, following the ‘trip’ menu, users often visited the ‘scores,’ ‘goals,’ and ‘fact’ menus, while in the UK, the ‘leaderboard’ and ‘scores’ were particularly popular. As for the evolution of app engagement over time, Fig. 1 shows the total daily app visits, and demonstrates how app use varied during the trial period. The app was not active for the initial eight weeks and only commenced on day 57.

In both Belgium and the UK, drivers exhibited increased app usage during Phase 4, following the introduction of gamification features. However, the level of app engagement differed between the two countries. During Phase 3, Belgian drivers had higher usage, while in Phase 4, UK drivers showed higher use. In both countries, there was a notable spike in app usage at the beginning of each phase, gradually decreasing as the phase continued. Further analysis showed that, in Belgium, app usage was higher during midweek days, whereas in the UK, the proportion of visits remained relatively consistent throughout the week, with minor variations. Regardless of the country, there

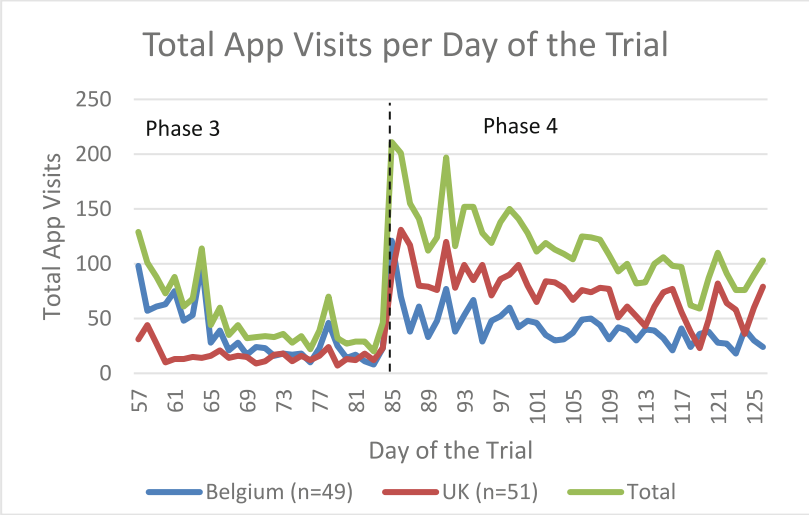

Fig. 1. Total app visits per day of trial by country and for combined sample

were three distinct peaks in app usage at 7 AM, noon, and 9 PM. Interestingly, these peaks coincided with the times when participants received push notifications aimed at encouraging app use.

4.2 Dose-Response Relationship

Tables 2 and 3 present findings of the GLMM examining the impact of the real-time interventions alone (i.e., phase 2), and of app engagement (i.e., phases 3 and 4), on the average frequency of total events per 100km for the entire sample and the UK sample. There were no significant results for the Belgian sample, most likely because Belgian trials started when some COVID-19 restrictions were still in effect. These restrictions eased during the trials for some users, resulting in fluctuated traffic density, which would have caused a more complex environment than experienced in the initial phases.

For the combined sample, the high-engagement group demonstrated a notable improvement in driving performance compared to the low-engagement group. On average, the high-engagement group had 0.458 fewer risky events per 100 km ($\beta = -0.458$; $p < 0.001$) than the low-engagement group. The difference in event rates per 100km between the high- and low-engagement groups increased from phase 1 to phase 4 with the former showing more reduction in event rates per 100km than the latter, which indicates better driving performance in the high-engagement group[2]. There were reductions of 1.41%, 2.54%, and 3.16% in event rates per 100km within the high-engagement group compared to the low-engagement group during phases 2, 3, and 4, respectively[3]. This underscores the positive impact of higher app engagement on driving performance.

[2] Analysis results not provided due to page limit constraints.

[3] **Total users**: percentage decrease in risky events per 100km for high engagement vs. low engagement groups (P_{2-1}: 4.70% vs. 3.29%, P_{3-2}: 4.67% vs. 2.13%, and P_{4-3}:5.94% vs.

Table 2. GLMM results for both countries

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	5.481	0.086	63.498	<2e−16	***
Phase 2 vs Phase 1	−0.039	0.023	−1.687	0.09162	
Phase 3 vs Phase 1	−0.074	0.023	−3.170	0.00152	**
Phase 4 vs Phase 1	−0.129	0.022	−5.529	3.23E−08	***
Cluster 2 vs Cluster 1	−0.458	0.115	−3.968	7.25E−05	***

For UK drivers (Table 3), both high- and low-engagement groups consistently exhibited better driving performance. However, on average, the high-engagement group had 0.498 fewer risky events per 100km ($\beta = -0.498$; $p < 0.001$) than the low-engagement group. Regarding within-group differences, the high-engagement group saw reductions of 2.48%, 0.91%, and 2.19% in event rates per 100km compared to the low-engagement group during phases 2, 3, and 4, respectively[4].

Table 3. GLMM results for the UK

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	5.605	0.104	54.057	< 2e−16	***
Phase 2 vs Phase 1	−0.086	0.031	−2.798	0.00514	**
Phase 3 vs Phase 1	−0.135	0.031	−4.394	1.11E−05	***
Phase 4 vs Phase 1	−0.184	0.031	−5.979	2.25E−09	***
Cluster 2 vs Cluster 1	−0.498	0.15593	−3.193	0.00141	**

5 Discussion

Considering the positive impact of app engagement on driving performance, enhancing driver intervention adherence and engagement can be considered as critical. Several recommended approaches to achieve this are outlined in the existing literature. Firstly, tailoring the intervention content to participants' individual preferences is essential. Secondly, priority should go to usability and user experience. Previous studies in other fields, such as mHealth, have underscored the importance of perceived usefulness and a user-friendly experience in enhancing engagement, e.g., see [6, 7]. Another strategy to boost driver engagement could be to offer timely and personalized feedback.

2.77%), where P_{21} means the difference (%) between phase 2 and phase 1 and so on for P_{32} and P_{43}.

[4] **UK users**: percentage decrease in risky events per 100km for high engagement vs. low engagement groups (P_{2-1}: 9.35% vs. 6.86%, P_{3-2}: 4.79% vs. 3.88%, and P_{4-3}: 5.57% vs. 3.38%).

Unavoidably, this study was subject to certain limitations. First, the study sample predominantly consisted of men who were highly educated, employed, and experienced drivers. Therefore, caution should be exercised when generalising the results to a broader population. Secondly, it is essential to acknowledge the presence of potential measurement biases in assessing driver engagement. Moreover, the app functionality was considered visited when clicked, but there was no verification of the actual engagement with the functionality. This merits further research.

6 Conclusion

This study reported on user engagement with the i-DREAMS app, how it evolved during the field trial period and how it impacted the driving behaviour. It also informed about the most popular app functionalities and the differences between Belgian and UK car drivers regarding app use. Results indicated that app use increased when gamification features were unlocked. App engagement was highest during the mid-week days than on Monday, Friday and the weekend. The provision of push notifications influenced app use positively. Most importantly, findings revealed a positive dose–response relationship between user engagement with the smartphone app and safe driving behaviour.

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Development of New Road Traffic Safety Assessment Methodology

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Abstract. The methodology of traffic safety evaluation in Slovenia is currently based mainly on recording the data about past traffic accidents, measuring their count and an often superficial evaluation of their consequences. Technical and societal aspects are usually only considered to a limited extent, mostly as infrastructure data and measurable physiological properties of the persons involved in accidents. Providing a comprehensive evaluation of the traffic events, which also enables a more detailed determination of their causes, their prediction and proposal of measures for limiting their consequences, requires acquisition, storage, processing, and analysis of other available and accessible data related to traffic safety. We present the activities of the project initiated and funded by the Slovenian Traffic Safety Agency and co-funded by the Slovenian Research Agency, targeted to address these issues. The first part of the paper includes the overview of the relevant research in the field, lists the traffic-safety-related data available in Slovenia, and outlines the methodology of their acquisition and storage. The practical aspects of data manipulation are summarised in the presentation of the developed administrator and end-user tools. In the second part we present the progress on development of the new methodology of traffic safety analysis and evaluation, based on readily obtainable, measurable and comparable data. In the discussion we highlight the possibilities and challenges of using this approach, evaluate its suitability for use on general traffic systems and provide and insight into planned further research.

Keywords: road safety methodology · road data · data analysis · database

1 Introduction

Currently the evaluation of traffic safety in Slovenia is based on recording traffic accidents, measuring their number, and assessment of their consequences. Inclusion of technical and socioeconomic aspects and data is currently severely limited and only includes infrastructure parameters and measurable accident participant physiological properties. These data are publicly available in the web application of the Slovenian Traffic Safety

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Agency, which interactively shows a map of the traffic accidents occurred on the road network of Slovenia [1].

A comprehensive treatment of road traffic incidents, which will enable a more precise determination of their causes, their prediction and the proposal of measures to limit them, requires the collection, storage, processing and analysis of other available traffic related data. The project entitled *Development of New Safety Assessment Methodology in Road Traffic* (Slovenian: *razvoj nove Metodologije merjenja Varnosti v Cestnem Prometu* - MVCP)[2] was set up to address these issues.

The project is composed by three main, related and complementary parts: i the first part dealt with the preparation of, a detailed review of the results of research on available data and methodologies that can be used for the evaluation of traffic safety. The central part of the project consists in the preparation of an up-to-date methodology for the evaluation of traffic safety, which should elaborate measurable and easily comparable indicators based on the set of concretely accessible data.

2 Methodology

In order to propose a methodology able to comprehensively evaluate the level of road safety, during the first part of the project a four-step procedure was followed. Firstly, a review of already completed projects [3–11], publications [12–18], strategies [19–21] and databases [22, 23] both at national and international level, has been worked out to understand, which are the main data considered, and what methodologies are already in use. After that, the existence and availability of datasets related to road safety in Slovenia have been checked, asking to the main leading institutions in Slovenia to provide the type of data stored in their databases, the technical characteristics of the database itself, and the level of accessibility of the data. Based on these first two steps, a selection of useful inputs for the developing methodology has been prepared and a road safety assessment methodology with its pros and cons has been proposed to the Traffic Safety Agency.

The review of already developed projects about road safety assessment has shown that some general concepts defining road safety management do exist and are widely accepted by the most well-recognised institutions, like the World Health Organization, the World Road Association PIARC and the International Transport Forum OECD/ITF [18, 20, 21]. These institutions agree on the concept of the road safety hierarchical pyramid, which does not consider only collisions as core elements in road safety, but it recognizes three levels [19, 20]. Similarly, they also give a lot of attention to road safety data: they underline the importance of being aware of what data are available, what are their strengths and their weaknesses and whether there are openly available databases [18–20]. They also highlight the importance of data standardization.

These publications suggest to apply two kinds of data: on one hand the ones, that are directly related to road collisions, on the other hand, the ones, that are not directly related to traffic accidents, but that can describe the road system and the issues in road safety [20].

Several projects have been developed to record and store data in accordance to PIARC indications: among them there are EU-IDB [22], DaCoTa project [5], EUROSTAT database [23], IRTAD database [21], the “Fatal Accident Database” and the “Accident Causation Database”. A comprehensive database about traffic and road collisions

has been created in the framework of SafetyCube project [10]. This reports, among the others, data about human factors, factors leading to road collisions, data about naturalistic studies, risk exposure data, and data from questionnaire about behaviour in traffic. Additionally, the database contains specific information about road collisions, infrastructural data, data about vehicles, in-vehicle technologies and vehicular damage. More recent projects regarding road safety also highlight the need for another group of data, that plays a central role in road safety assessment: human factor data. Among the projects mentioning these data, there is project MEDIATOR [8], which has considered many variables related to the driver's condition, but also information about the feeling of comfort, driver's emotions, and trust in the system. Drive2thefuture [6], the aim of which is to identify different driver behavioural patterns, to model possible behaviours of autonomous vehicle's drivers, used mainly data obtained by questionnaires and interviews with technicians, focused on road safety and security, human factors, inclusion, sustainable mobility and innovation [14]. Project i-DREAMS [7], with the aim to develop and test a system to keep drivers within their "Safety Tolerance Zone", also created a huge set of data covering aspects regarding the driver's status, their behaviour in traffic and the driving context. An interesting project when it comes to road safety data, is uDRIVE [4]: it developed the first wide naturalistic study in Europe, involving car drivers, truck drivers and powered-two-wheeler riders. One of the project's results is a large database with the information collected during the developed naturalistic study [3]. In the end, it should be mentioned that there are other openly accessible databases [9].

2.1 Data Collection

The research of the available traffic related data has revealed that the amount of the data being collected is very large and the data diversity, regarding formats and access options, very high. The data is mostly either available in on-line databases or as an off-line service on request. Because of this, the short-term solution is to set up a local database with a pilot dataset. The list of the available databases is shown in Table 1. Once the pilot dataset will have been used and verified in data analysis and safety assessment models, a framework for acquiring the required data directly from their providers will be developed.

On the basis of the information obtained by the Slovenian road safety and road management institutions, a selection of the available data, which can be fruitfully used for the development of the road safety assessment methodology, has been proposed. As the starting point for the new database, the existing traffic accident database has been utilised as it provides data storage in the required formats, geolocation facilities and management of time-dependent data history. The individual datasets are stored in the relational database in individual tables.

2.2 Proposed Traffic Safety Assessment Methodologies

As it is supported by the overview of the already developed projects regarding road safety level assessment, there are two complementary approaches that should be considered, when proposing such a methodology: on one side, there is the reactive approach, that uses accident data to elaborate analyses and statistics related to already happened road

Table 1. Overview of available databases.

Database	Status, access
Statically obtained HGV weights	active, restricted
HGV weights obtained in free traffic flow	active, restricted
Data from traffic counters	active, restricted
C-ITS traffic counter data	active, restricted
Database of traffic accidents and offenses	active, data available on request
Automatic traffic accident data transfer	active, data available on request
Interactive map of traffic accidents	updated periodically, public unrestricted
Database of vehicle technical inspections	active, data available on request
Registry of driving schools	active, data available on request
Police database of traffic accidents	updated periodically, publicly available
Database of infrastructure data	active, restricted
Database of road data	active, unavailable to general public
Driving dynamics data	active, available to researchers on request

collisions. Though this approach tackles an extremely important aspect of road safety, such analysis is not enough to describe the whole level of safety of a country's road network. Therefore, it should be taken into account also the proactive approach, whose aim is to act before coming to tragic road events. This is also what is stated by (Network Wide Road Safety Assessment – Methodology and implementation handbook), promoted by the European Commission and followed by MVCP project.

The main idea followed by MVCP project is to develop two ranking scales with each of the considered approaches and to calculate the final road safety score on the basis of a matrix reporting both obtained scales. The reactive approach will be applied to calculate widely accepted road accident metrics, and to rank different road sections on the basis of these calculated metrics and of already accepted thresholds. Both the metrics and the thresholds are calculated applying the method presented in the (Road Safety Manual). In this way, a reactive road safety ranking scale will be obtained. The proactive approach will be applied from an infrastructural point of view. On the basis of the available road geometry data, road characteristics that are better or worse than the standard ones, will be listed, and reduction factors will be defined for each of them. These reduction factors will be then applied to calculate the proactive road safety score. In the end, the comparison of the two road safety ranking scales, would lead to the definition of the final road safety level.

3 Results and Discussion

At the time of submission of this paper the MVCP project has reached its first milestone at which the developed database framework has been filled with the pilot data. Reaching this milestone has proven significantly more difficult than anticipated at the time of

defining the project tasks. As a matter of fact, the thorough research in the initial project activities has revealed that the pool of the institutions that collect and/or process the traffic safety related data is unexpectedly large and heterogeneous. On one hand this ensures a large amount of useful data but on the other hand it presents a hurdle in their collection and efficient inclusion in the analyses. Additionally, while the large majority of the queried institutions have shown a high level of agreement to cooperate by providing the data, once it came to the realization of this premises, they failed to provide the adequate support to successfully transfer their data to our database.

4 Conclusion

The project's final aim is to develop a comprehensive methodology to assess the road safety level on Slovenian road network, considering not merely road accident data, but also other indicators, which can give a more exhaustive representation of the whole road safety situation. At this point, the first four main tasks of the project have been completed: reviewing other similar research works, that could help in posing the basis for the proposing methodology, collecting data from leading institution within the country, developing the framework for the new database and proposing the first draft of the methodology to assess road safety. The collected data collection and the developed storage facilities are a useful tool for traffic safety data management. Additionally, the models for traffic safety analysis, that will be detailed in the next project phase and based on the stored data, will provide a proof of concept on how to utilise those data for an advancement in traffic safety analysis methods. All the tools developed, as well as the project deliverables will be publicly available. By achieving these results, the project can be considered completed and its objectives satisfied. Nevertheless, beyond the mere project goals, there is the will of developing a central Slovenian traffic safety data hub. This is one of the research directions that the researchers involved in the project would like to pursue in the near future.

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Differences in Drivers' Attitudes and Behavior Towards Ambulances and Police Vehicles

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Abstract. Emergency driving entails challenges, one being the interaction with other road users. Drivers' attitudes towards Emergency vehicles (EVs) may affect their willingness to move over. Previous research has suggested that attitudes towards the different emergency response organizations may differ, but no previous research has compared the driver behavior aspects associated with the two organizations. The purpose of the present study was to examine drivers' attitudes and driving behavior around approaching ambulances and police vehicles. A total of 110 drivers participated in a driving simulator study where they were approached by emergency vehicles three times. After the drive, they were asked about their typical driving behavior and attitudes towards ambulance and police. No difference in driving behavior when interacting with either an ambulance or police vehicle was seen in the simulator data. There was a difference in expressed attitude towards the organizations. Drivers reported that they felt a higher level of stress, and were more aware of their driving when approached by a police vehicle compared to when approached by an ambulance. The participants stated that it is important to move over regardless of EV type.

Keywords: Ambulance · Police · Attitude · Driving behavior

1 Introduction

Emergency vehicles (EVs) are crucial to ensure the best possible assistance for all citizens. However, driving an EV can be hard and sometimes even dangerous. The EV operator (EVO) is under pressure to arrive at the incident scene as soon as possible but must do so without imposing an undue risk to the people in or around the vehicle. Unfortunately, interaction with civilian road users may result in both fatal and nonfatal accidents [1]. Drivers' attitudes towards EVs may affect their willingness to move over. In Alwidyan et al. [2] the Jordanian public's perceived appropriateness of ambulance lights and sirens was examined through a survey study. The results indicated that a majority believe that the use of lights and sirens is important to the functionality of the emergency medical response system. Furthermore, the participants reported that not yielding to an approaching ambulance was deemed unethical and those who chose not to move over should be punished. Even though the participants in Alwidyan et al. [2]

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were mostly positive about the use of lights and sirens in ambulances, there were concerns. One was the stress caused by being approached by an ambulance, another was the overuse of lights and sirens. It was suggested that excessive use of blue lights and sirens can reinforce negative perceptions of the legitimacy of EVs and ultimately reduce willingness to move over [2].

Terry et al. [3] found that road users adjust their speed when approaching a police vehicle. It, therefore, seems like the presence of the police vehicle affects driver behavior. However, the public's opinion of the Police may differ from the attitude toward the emergency medical services. There might be differences in how drivers behave around the two EV organizations. In a survey by The Swedish Civil Contingencies Agency, Swedish road users were asked to estimate how long they thought the response time for an ambulance and a police vehicle would be. The participants in general assumed that the Police would have a longer response time [4]. These results indicate that drivers may have different expectations of emergency organizations.

The active choice to not move over when an EV is approaching could have fatal consequences because it might cause delays for the emergency responders. It is therefore important to examine what attitudes drivers have toward the need to move over for EVs and if the attitudes are reflected in their driving behavior. Moreover, previous research has indicated that attitudes towards the different emergency response organizations may differ, but no previous research has compared the driver behavior aspects associated with the two organizations. Hence, the purpose of the present study was to examine drivers' attitudes and driving behavior around approaching ambulances and police vehicles.

2 Method

This research complied with the American Psychological Association Code of Ethics and was approved by the Swedish Ethical Review Authority. Informed consent was given by each participant. The method consisted of a simulator study and two questionnaires, which are described below.

A total of 110 drivers aged 18–61 years, $M = 38.23$, $SD = 15.16$ years, whereof 60 men and 50 women participated. All participants had valid driver's licenses for regular passenger cars. They had had their driver's license for 0–42 years ($M = 16.15$, $SD = 15.53$) and drove 0–1 250 km per week ($M = 249.53$, $SD = 259.50$). All participants were recruited through advertisements on social media.

A fixed-base simulator with two screens was used. A siren sound was presented when the EV was five seconds from passing the participant's vehicle. Blue lights were presented by two LED strips placed behind the participant to create a reflective effect on the front screen. The blue lights were visible five seconds before the EV was expected to pass the participant's vehicle. The intensity of the blue lights and the volume of the sirens increased as the EV approached the participant's vehicle.

Two questionnaires were included in the study, one pre- and one post-questionnaire. In the pre-questionnaire, the participants were asked about their driving experience and demographics, such as age, gender, and educational level. The post-questionnaire was divided into two parts. Firstly, the drivers were asked to report their self-reported driving behavior when approached by either ambulance or police vehicles in a real traffic

scenario. For instance, if they immediately try to move over or feel stressed when an EV approaches them. Secondly, they were asked to describe their attitudes regarding the traffic behavior associated with the police and ambulance organizations. All questions in the post-questionnaire were measured on a seven-degree Likert scale (1 = Strongly disagree, 7 = Strongly agree). The participants received all questions twice, with the question either being about ambulances or police.

The participants were welcomed and informed about the procedure of the study, that they would remain anonymous, and the infection control precautions (due to the ongoing COVID-19 pandemic). They then completed a consent form and a pre-experiment questionnaire. The participants were then seated in the simulator and instructed to drive as they would normally do in real traffic. The participants were not told that EVs would be included in the experiment. The main drive scenario consisted of a 30-min drive on a three-lane highway. The density of traffic was high in the right and middle lanes. The surrounding cars would on average maintain a lower speed than the participant, leading the participant to prefer the left-most lane. All participants had three EV events at 11, 19, and 27 min into the scenario. Either by two police vehicles and one ambulance, or one police vehicle and two ambulances. The EV would approach them in the leftmost lane, with lights and sirens engaged, and stay behind the participant's vehicle until they moved over. After the drive, they were asked to fill out the post-experiment questionnaire. Before they left, they were given a gift card and informed about the purpose of the study.

2.1 Design and Analysis

A within-subjects design was used to measure the potential difference in move-over behavior in the simulator. The participants were approached by EVs, with lights and sirens engaged, three times. There were two different orders of EV types. Either ambulance, police, ambulance, or police, ambulance, police.

A dependent variable of "EV hinder"-time was used to examine if, and for how many seconds, each participant hindered the EV from maintaining its preferred speed (165 kph). The EV hinder-time was calculated by examining how many seconds the EV would have to decrease its speed due to the participant blocking its path. By not moving over, but instead remaining in the left-most lane the participant would hinder the EV causing a longer "EV hinder"-time. If the participant moved over in time, thereby not delaying the EV the hinder measurement would be zero. A repeated measures ANOVA was used to explore the difference in EV hinder-time and EV type.

To examine the results of the pre-questionnaire descriptive statistics was used. For the post-questionnaires, the mean difference in the participants' attitudes was examined through paired t-tests. Cohen's d was used to indicate effect size.

3 Results

In the results section, the analysis from the simulator data is presented first. Followed by the results from the two parts of the post-questionnaire. The first questionnaire part concerns the self-reported behavior and experience around ambulances and police vehicles and the second part concerns the attitude towards the behavior of the ambulance and police vehicles.

3.1 Simulator Results

The repeated measures ANOVA did not indicate a difference in hinder time between ambulance and police vehicles. On average the participants hindered the ambulance for 3.40 s ($SD = 3.6$ s) and the police vehicle for 3.42 s ($SD = 4.32$ s), $F(1,59) = 0.00$, $p = .996$.

3.2 Questionnaire Results

The results presented in Table 1 show that drivers feel more stressed when a police vehicle is approaching them, compared to when an ambulance is approaching them. The participants also believed that they feel more aware of their driving when approached by police, compared to an ambulance. Furthermore, the participants report that they adjust their driving to surrounding traffic if approached by an ambulance to a larger extent compared to when approached by a police vehicle.

As displayed in Table 2, the participants reported that they thought it was more important to move over for ambulances, compared to police vehicles. Furthermore, they believed that the matters of the ambulance were more important than the matters of the police. They also reported that, according to them, the police to a larger extent drive with blue lights even when it is not urgent compared to the ambulance.

4 Discussion

The purpose of the present study was to examine drivers' attitudes and driving behavior around approaching ambulances and police vehicles. The results of the present study suggest a difference in attitude, but not a difference in behavior, toward ambulances and police vehicles. All participants in the present study moved over for the EV. Regardless of if it was an ambulance or police vehicle. Because no previous study has examined the behavioral effects when interacting with different types of EVs in traffic, it is not possible to contrast the lack of behavioral differences found in the present study with previous research. However, it may be when driving in the simulator the participants perhaps realized that no amount of unlawful driving would result in legal consequences. It may be that drivers when driving in real traffic, are aware of the possible repercussions of misbehaving near a police vehicle. Another explanation may be that it was difficult to distinguish the EV type when it was approaching in the simulation. To further investigate the drivers' visual scanning when approached by an EV, future studies should include eye-tracking.

Table 1. Self-reported behavior and experience around ambulance and police vehicles

	Self-reported behavior and experience around ambulance and police vehicles						
	[Emergency vehicle]			Comparison			
	Ambulance	Police		Ambulance vs. Police			
				95% CI of the difference			
	M ± *SD*	*M* ± *SD*	*df*	*Lower*	*Upper*	*t*	*d*
I feel stressed	3.69 ± 1.84	4.15 ± 1.89	105	−.709	−.216	3.72**	1.281
I become more aware of my driving	4.5 ± 2.04	5.48 ± 1.68	104	−1.348	−.614	5.30**	1.896
I adjust to how surrounding vehicles act	5.60 ± 1.59	5.21 ± 1.57	102	.183	.594	3.75**	1.05
I wait until [EV] is near before I move over	1.51 ± .88	1.67 ± 1.03	105	−.299	−.022	2.30*	.719
I move over, even if it means breaking laws	4.69 ± 1.57	4.43 ± 2.07	100	.053	.482	2.48*	1.085
I immediately try to move over	6.28 ± 1.28	6.03 ± 1.57	99	−.020	.520	1.84	1.359
It is difficult to know how to move over when [EV] is approaching	2.52 ± 1.74	2.70 ± 1.87	104	−.360	−.017	1.80	.975

** $p < .001$, * $p < .05$

The participants reported different experiences and behaviors when they were approached by an ambulance or police vehicle. They indicated that they felt a higher level of stress, and were more aware of their driving when approached by a police vehicle compared to when approached by an ambulance. They reported that they were more likely to adjust their driving according to the surrounding traffic when approached by an ambulance.

There was a difference in participants' attitudes towards the ambulance and police organization. For instance, they believed that the matters of the ambulance were more urgent than the matters of the police. It may be that the mission of the ambulance is more closely connected to life-or-death situations. Which leads to a higher willingness to move over for ambulances. Sometimes the police will, due to ongoing crime, turn off their lights and sirens in an attempt to not be discovered by the suspects [5]. It may be

Table 2. Self-estimated attitudes toward the driving behavior of the ambulance and police

	Difference in attitude toward ambulance vs. police						
	[Emergency vehicle]			Comparison			
	Ambulance	Police		Ambulance vs. Police			
				95% CI of the difference			
	M ± *SD*	*M* ± *SD*	*df*	*Lower*	*Upper*	*t*	*d*
[EV] should be allowed to break traffic laws, e.g., surpass the speed limit, run red lights, etc.	6.84 ± .60	6.77 ± .68	106	.018	.132	2.60*	.298
I think it is more important to move over for [EV] than [EV]	3.24 ± 2.40	2.26 ± 1.76	103	.646	1.316	5.80**	1.724
I believe that the matters of the [EV] are more urgent than the [EV]	3.09 ± 2.27	2.09 ± 1.40	103	.673	1.327	6.06**	1.684
I believe that [EV] often drive with blue lights when it is not urgent	1.33 ± .90	1.66 ± 1.23	91	−.534	−.140	3.39**	.952

** $p < .001$, *$p < .05$

that the police's driving behavior in those situations is experienced as reckless by the public. Because they are not aware of the importance or urgency of the situation. The seemingly unnecessarily reckless driving behavior might negatively affect the public's attitude toward the police.

The participants in the current study did not state that the ambulance or police services drive with blue lights when it is not necessary. This finding is different from Alwidyan et al. [2], where more than half of the participants believed that the ambulance service overused lights and sirens. It is difficult to know why the findings of the two studies are different, but it may be due to cultural differences.

Even if there was a difference in attitude towards the two EV organizations the participants in the present study still agreed that it is important to move over for EVs, whether it is an ambulance or police vehicle. They also believed that both ambulances and police vehicles should, if needed, be allowed to break traffic laws. The EV types included in the present study were ambulances and police vehicles. However, there are

other types of EVs. Future studies should include fire engines to explore the possible differences in driver behavior and attitudes toward the fire brigade.

5 Conclusions

Previous studies have indicated that the difference in attitude towards approaching emergency vehicles may affect the willingness to move over. However, no previous study has measured the behavior when a driver is approached by EVs from different emergency response organizations. The results indicate that the attitudes toward ambulances and police vehicles in traffic differ. However, the difference in attitudes did not result in a difference in willingness to move over when approached by an ambulance or police in the simulator. Instead, the time it took for the drivers to move over was almost identical regardless of the type of EV approaching them.

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Outcome Evaluation of i-DREAMS (H2020 Project) Interventions: Multi-country Comparison of Driving Behavior

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Abstract. The i-DREAMS project introduced the concept of a 'Safety Tolerance Zone,' i.e., a context-aware safety envelope designed to assist drivers. Using an ecosystem of sensors, i-DREAMS technology monitors factors that determine driving task complexity and coping capacity and calculates risk levels. Real-time and post-trip interventions are tailored to keep drivers from unsafe driving. Real-time interventions are provided via in-vehicle display, while post-trip interventions are delivered via a smartphone app with gamification provisions. This study focuses on the effectiveness (i.e., outcome evaluation) of real-time and post-trip interventions that involve 4 phases, including the baseline measurement phase.

The paper presents a comparative analysis using the data collected from car drivers from three countries: Belgium (n = 48), the UK (n = 49), and Germany (n = 25). Overall, drivers showed a reduction in events per 100 km after exposure to the i-DREAMS technology. So, there was an improved safety outcome. However, differences were found between the countries analyzed. The highest number of events per 100 km was noted for UK drivers, with the reduction pattern consistent across 4 phases. The interventions were more promising for 'road sharing' and 'speeding' events for Belgian and German drivers. Driver-level analysis revealed that two-thirds of drivers in each country showed a consistent decrease in events/100 km.

Keywords: i-DREAMS · Safety Tolerance Zone · Outcome evaluation · naturalistic driving data · multi-country comparison

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1 Introduction

In the era of digitization, rapid steps in transport automation bring new challenging conditions, transforming the framework of operator/vehicle/environment interactions and the need for an increased understanding of the human factors affecting the behavior of operators/drivers. Simultaneously, technological advancements make vast and in-depth operator performance data easily accessible (e.g., new in-vehicle sensors that record precise driving behavior and contextual data, increased driver adoption and usage of information technologies, Internet of Things). This opens up new possibilities for detecting and designing tailored interventions to continuously and dynamically reduce hazards, raise awareness, and improve performance [1–3]. Two viewpoints for safety management (i.e., local and general) were offered by [3]. The local or "in real-time" perspective denotes a closed-loop procedure of sampling, evaluating, and responding to actual occurrences. The 'generic' perspective is founded on the holistic notion that a driver's response in a real-world scenario depends on variables that are more constant over time (such as personality, driving experience, safety attitudes, etc.). The i-DREAMS project introduced the 'Safety Tolerance Zone' (STZ) concept, a context-aware safety envelope designed to prevent drivers from getting too close to the boundaries of unsafe driving via both real-time and post-trip interventions. The formal working definition of STZ adopted within i-DREAMS is as follows: **"the time/distance available [for vehicle operators] to implement corrective actions safely [in the potential course towards a crash]"** [4, 5]. In-vehicle interventions inform or warn drivers in real-time (nudging), and post-trip interventions inform them after driving through an app-based (and web-based) gamified coaching platform to improve driving behavior (boosting).

This paper addresses the effectiveness (i.e., outcome evaluation) of real-time and post-trip interventions developed within the i-DREAMS project. Moreover, this study presents a comparative analysis of the intervention effectiveness based on the on-field trials conducted in the UK, Belgium, and Germany.

2 Methods

Part of the i-DREAMS project was a longitudinal field operational test conducted in a real-world setting, comprising four phases, as given in Table 1. The participants for the field trials were selected based on several inclusion criteria to ensure a diverse and representative group. These criteria included factors like driving experience, road exposure, age (minimum 18 years), balanced representation of gender, vehicle type (to accommodate the i-Dreams technology), smartphone usage, multi-driver access (i.e., one vehicle, many drivers), etc. To ascertain effective participation, an incentive of 250€ was paid to each driver incrementally during the data collection. More information on the experimental protocol can be found in [6]. The naturalistic driving data collected in i-DREAMS concerns various data about safety promoting goals (SPG) and performance objectives (PO). Table 2 defines these SPGs and POs and their inter-relationship.

According to the STZ, a driver can be in three different stages: 1) Normal Driving, 2) Danger (medium severity level), and 3) Avoidable Accident (high severity level). No real-time interventions are necessary if a driver is within the first stage (i.e., normal

Table 1. Phases and their definitions

Phase	Definition
1	*The baseline Phase* corresponds to the initial monitoring period after the installation of i-DREAMS technology when interventions were not active) – Duration: 4 weeks
2	Phase 2 corresponds to the monitoring period when only real-time interventions were active within a vehicle- Duration: 4 weeks.
3	Phase 3 corresponds to the monitoring period when in-vehicle real-time interventions were active, and drivers also received feedback (scores and events per trip) on their driving performance through the app; duration: 4 weeks.
4	Phase 4 corresponds to the monitoring period when in-vehicle real-time interventions were active along with feedback, but at the same time, gamification elements were also active. Duration: 6 weeks

Table 2. SPG and PO and their inter-relationship.

Safety Promoting Goals (SPG)	Performance Objectives (PO)
Vehicle Control	Acceleration, Deceleration, Steering control
Speed Management	Speed
Road Sharing	Headway, Illegal Overtaking, Lane Discipline, Forward Collision Warning, and Pedestrian Collision Warning
Driver Fitness	Fatigue and handheld mobile phone use (during driving)

driving). On the contrary, an alert is offered if a driver is within the stage of danger. In contrast, in the avoidable accident stage, an intrusive warning signal (either or not accompanied by an instruction) is offered. The device developed in i-DREAMS issues warnings on the following risk indicators: Headway, Speed, Fatigue, illegal overtaking, Lane departure, and Pedestrian collision [7]. Within post-trip interventions, more details are given to the driver with the help of a smartphone application [8]. This smartphone application features general driving performance scores and gamification elements like a leaderboard, goals, and pros and cons for certain driving behaviors. Data used for this study comes from 48 Belgian, 49 UK, and 25 German car drivers and covers around 4.5 months. The analysis is based on determining changes in a number of normalized events (i.e., events/100 km) for the two highest risk stages of STZ (i.e., danger stage and avoidable accident risk stage). The analysis method includes comparison using descriptive statistics and standard statistical tests (repeated measures ANOVA (in case the data is normally distributed), and an equivalent non-parametric test is used (such as the Friedman test)). Results of the Generalized Linear Mixed Model (GLMM) estimated for total events/100 km are also provided. Additionally, individual driver-level analysis is performed to investigate the differences which are not detectable in group-level analysis.

3 Results

Table 3 provides the general idea of the effectiveness of the interventions as total events/100 km occurred in danger and avoidable accident stages are indicated along with the standard deviation. UK drivers generate more events/100 km, with a consistent reduction pattern compared to other countries. This is mainly due to higher urban trips that may have resulted in higher vehicle interactions.

Table 3. Total events/100 km concerning intervention phases

Phase	Belgium (n = 48)		UK (n = 49)		Germany (n = 25)	
	Events/100 km	St. Deviation	Events/100 km	Std. Deviation	Events/100 km	St. Deviation
1	180.8	94.5	275.3	249.6	152.2	153.7
2	185.7	97.5	261.3	223.8	151.0	114.7
3	188.0	107.0	251.0	225.2	137.3	123.6
4	177.2	105.6	240.7	219.2	149.6	126.2

Table 4 provided the events/100 km for each phase for each SPG (especially Vehicle Control (VC), Road Sharing (RS), and Speed Management(S)). Driver fitness-related events/100 km were relatively lower compared to other SPGs. The UK's statistical test results show improved behavior in almost all SPGs, with Belgian drivers showing better results for RS-type events. For German drivers, results do not seem promising. However, it was noted that German drivers' speeding events/100 km belonging to the avoidable accident stage decreased consistently, which is statistically significant.

Additional statistical analysis was carried out on the combined countries' data (BE, GER, and UK) using GLMM analysis, as this allows for the analysis of data when (a) random effects are present (e.g., the case of repeated responses from study subjects/participants or multi-level data structure), and (b) it has a non-normal distribution. Negative binomial (NB) GLMM was applied to the data since the independent variable (events per 100 km) is a count variable exhibiting overdispersion. Table 5 provides the results of the GLMM, where total events/100 km, only danger STZ, and only avoidable accidents STZ) are considered as the dependent variable. Phase (Phase 1 as reference) and Country (BE as reference) are considered independent variables.

For the combined case of 'total' events, the expected log count of events per 100 km decreases from Phase 1 (baseline) to each of Phase 2, Phase 3, and Phase 4 (indicated by the -ve sign of the estimates). The country variable estimate suggests there were more events in the UK compared to Belgium for all cases. The variance between drivers was found to be more for avoidable accidents than for the danger stage. Because of the large variance in the data, it is useful to analyze differences between drivers. The average number of total events per phase was calculated for each driver, and drivers who showed overall improvement from Phase 1 to Phase 4 are labeled as Type A, and other drivers are labeled as Type B. For Belgium and Germany, around two-thirds of

Table 4. Events/100 km concerning intervention phases

SPG	Phase	Belgium (n=48)		UK (n=49)		Germany (n=25)	
		Events/100 km	test Significance	Events/100 km	test Significance	Events/100km	test Significance
VC	1	101.5	0.070	136.7	0.060	96.8	0.691
	2	107.9		131.7		94.1	
	3	109.9		130.7		89.5	
	4	102.7		130.6		97.3	
RS	1	65.4	0.017	119.7	<0.001	N/A	
	2	62.3		113.8			
	3	61.8		106.0			
	4	59.4		96.2			
S	1	13.9	0.122	18.8	<0.001	55.8	0.218
	2	15.5		15.8		56.8	
	3	16.2		14.3		47.9	
	4	15.1		13.9		52.3	

Table 5. GLMM estimation results

Fixed Effects	Combined (danger + Avoidable accidents)		Avoidable accidents STZ		Danger STZ	
	Estimate	p-value	Estimate	p-value	Estimate	p-value
Intercept	5.114	<0.001	3.652	<0.001	4.835	<0.001
Phase 2	-0.026	0.277	-0.055	0.064	-0.019	0.433
Phase 3	-0.071	0.003	-0.140	<0.001	-0.045	0.072
Phase 4	-0.116	<0.001	-0.195	<0.001	-0.088	<0.001
GER	-0.316	0.020	0.058	0.725	-0.457	0.001
UK	0.234	0.039	0.140	0.308	0.264	0.002
Random Effects: Variance User_ID	0.281		0.445		0.294	

drivers showed improved outcomes after exposure to the technology, but in the UK, this figure increased to three quarters (see Table 6). Type A and Type B drivers were further analyzed regarding demographic and other characteristics; in all three countries, Type B drivers were more confident.

Table 6. Drivers type and summary statistics

Country	Type A (Events/100 km Decreased)		Type B (Events/100 km Increased)	
	No. of Drivers	Percentage Decrease	No. of Drivers	Percentage Increase
BE	31 (65%)	−17.0%	17 (35%)	26.1%
UK	37 (76%)	−23.5%	12 (24%)	10.8%
GER	16 (64%)	−26.4%	9 (36%)	22.2%

4 Discussion and Conclusion

When data was combined for Belgium, Germany, and the UK, events decreased statistically significantly from Phase 1 to Phase 4. This was for both medium and high severities, for 'total,' 'vehicle control,' 'speeding,' and 'road sharing' events. This suggests that the i-DREAMS system positively impacted the measured safety outcomes and kept drivers in the first level of the STZ for more of their journey. The most significant results from Phase 3 to Phase 4 were seen in the combined data. This suggests that adding the gamification elements significantly impacted safety outcomes and supports the conclusion that the system provides the most effective results. Looking at the different safety-promoting goals, the interventions appeared to have the most significant and consistent impact on 'road sharing' events. However, these data were only available for Belgium and the UK, so it would be helpful to collect further data for other countries to support this finding. 'Vehicle control' events were least significantly impacted, which could be because there are no real-time warnings about this SPG. There were little demographic differences between the two types of drivers, and where there were differences, they generally were inconsistent across countries. There is some data to suggest the drivers who worsened were more confident than those who improved, so it is possible they had less desire to change their behavior, though this cannot be concluded. Further work is needed to understand why the system has varied effects on drivers.

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Education and Traffic Safety Among Young Drivers with A-Tractors in Sweden

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Abstract. In the new proposal of the Driving Licence Directive in the EU, a new B1 driving licence category are discussed, where Member States can extend driving rights of young driving licence holders (from 16 years of age), to drive vehicles with a maximum speed of up to 45 km/h. Sweden have had A-tractors (a slow-moving vehicle) for many years, which is a standard vehicle and originally built and used by farmers. However, after the Swedish authorities introduced new rules, the A-tractors have become very popular among young people. The purpose of the study was to gain better knowledge into the use of these vehicles and the drivers' perceptions of road safety. A survey and interviews were carried out with young drivers. Unique knowledge has been gained about where, how and why young people use A-tractors. Especially noticeable was the low rate of belt use in A-tractors, speeding (i.e. vehicle tuning) and the high number of passengers travelling in the vehicles. As the vehicles have increased significantly, new regulations are needed to find possible changes that can improve the driving education and increase traffic safety for drivers with A-tractors. Furthermore, driver training has an important preventive role and to be allowed to drive an A-tractor a certificate of competence obtained through driving practice should be required.

Keywords: A-tractor · AM driving license · young drivers · driving education · traffic safety

1 Introduction

In the new proposal for a driving license directive in the EU, a new driving license category B1 is being discussed, where member states can expand the driving rights of license holders to operate vehicles with a maximum speed of up to 45 km/h. Sweden has had experience with similar vehicles for many years, known as the "A-tractor", which are limited to a maximum speed of 30 km/h. An A-tractor is a modified car originally intended for agricultural use but has become increasingly popular among young people, not only in rural areas but also in cities. From 2019 to 2020, the number of A-tractors increased by over 30%, partly due to simplified technical requirements for converting a passenger car into an A-tractor in 2020. Since then, the number of registered A-tractors has grown significantly, reaching nearly 53,000 vehicles by the end of 2022 [4].

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For an A-tractor, it must be clear that it is no longer intended for the transportation of persons or goods. However, it may have one or two seats beside the driver's seat, but the back seat is not allowed to be used and should not be accessible. There was previously no requirement for seat belts, but in August 2023, new requirements were introduced, which mandate that drivers and passengers must wear seat belts, and only one passenger is allowed on a seat. All A-tractors must be equipped with a so-called "LGF" sign at the rear, indicating that it is a slow-moving vehicle. Furthermore, A-tractors can be driven on all roads except motorways.

In Sweden, A-tractors can be driven from the age of 15 with the requirement that the driver holds an AM driving license. However, the training for the AM license is designed for two-wheeled mopeds and only includes theoretical knowledge along with practical training on two-wheeled mopeds. There is no opportunity for practice with an A-tractor at a driving school, and practicing on-road with parents is also illegal, which means that young drivers have limited skills when they start driving the vehicle. The Swedish Transport Agency has initiated a review of the training curriculum due to the significant increase in the number of these vehicles.

As the number of these vehicles has increased, so have the number of accidents [5]. However, it is suspected that not all accidents are reported to the authorities, resulting in a significant underreporting of incidents involving these vehicles. In a compilation for the period 2016–2022, a substantial increase in the number of accidents was reported, from 109 accidents in 2016 to 348 accidents in 2022. In 2022, 78% involved individuals aged 0–17, and 44% were females. Previous reports have indicated that virtually all fatalities in A-tractors have been unbelted occupants [5].

There is a great interest in A-tractors, but research on driver and road user safety is lacking, and more knowledge is needed to improve training and ensure safer drivers. The purpose of this study was to gain better knowledge into the use of these vehicles and the drivers' perceptions of road safety.

2 Method

Data was obtained through interviews and a questionnaire from young drivers in Sweden who have experience of driving A-tractors.

2.1 Questionnaire

A random sample of 5,931 A-tractor owners was obtained from the Road Traffic Register administered by the Swedish Transport Agency. The vehicles and owners were located throughout Sweden and received a postcard with information about the study and a QR code to a questionnaire. The questionnaire included questions about the AM education they had undergone, how and where the vehicles were used, and questions about various aspects of road safety, risks, and responsibilities. In total, 921 young people, aged 15–17, who drove an A-tractor, responded to the questionnaire (48% were females).

2.2 Interviews

To gain knowledge and understanding of the aim of the study, six focus group interviews were conducted based on participants' own experiences and perceptions. An interview guide was used with questions about the vehicle, where and when they drive, road safety, and the AM education. Participants were recruited through a driving school, and a total of 20 young people aged 15–18 were interviewed, with the majority (n = 14) being 15 years old. The interviews were recorded with the participants' consent and transcribed. Both participants and their parents consented to participation. The interviews were analyzed using a method for Content Analysis [2].

3 Results

Sixty percent of the young people indicated that the theoretical part of the driver education was very or quite suitable, while 40% said they would have preferred more practical training with a four-wheeled vehicle instead of a two-wheeled moped. When they obtained their license, many initially found it challenging, including aspects like vehicle manoeuvring, positioning, and applying traffic rules. Some had practiced with their parents, while others had start driven on their own.

> *"I just drove by myself right away. Had to learn by myself. It was a bit difficult at first, but I got the hang of it after a few tries. The car had manual transmission, but I learned from my dad how to shift gears in a regular passenger car."* (Axel, 16 years old)

Through the A-tractors, a sense of community and belonging was established. Special meeting places emerged in parking lots where everyone gathered with their vehicles. Listening to music in their car was also important. The independence increased when their parents no longer needed to provide transportation, and it was more convenient since they didn't have to walk, cycle, or use public transport.

> *"It's much nicer, for example, going to school... I don't have any problems walking or anything, but it's much nicer now during winter to have a car."* (Nelly, 15 years old)

In total, 35% stated that they used the A-tractor several times every day, and an equal percentage used it 5–7 days a week. The A-tractor was primarily used to get to school (30%) or to drive around and be with their friends (30%). Somewhat fewer indicated it was used for leisure activities (21%) or to visit friends or family. The A-tractor rarely served as a complement to public transportation; 34% stated that it had completely replaced the bus or train to school. Reasons for needing the vehicle included the absence or inadequacy of public transportation, parents being relieved of driving duties, and the convenience of not having to walk or cycle.

An A-tractor can transport a maximum of two passengers, but 78% indicated that they sometimes transported three or more passengers in the vehicle. From the interviews, it emerged that it was common with more occupants in the vehicles. Some participants mentioned that they used to sit on each other's laps or on the center console. In some

cases, the reason was to be kind and give an extra friend a ride, even though there was no available seat.

"We once had seven people in an A-tractor, and the police drove past us, but they didn't say anything." (Olle, 15 years old)

In the questionnaire, only 41% stated that they always used seat belts, and only 25% of passengers always used seat belts in an A-tractor. During the interviews, it also emerged that it was common for young people or their passengers not to use seat belts.

"I think that, it's your own responsibility to use a seat belt when 30 is the speed limit. You use it if you want to." (Sara, 15 years old)

The questionnaire included questions about speeding and vehicle tuning, with 21% aware that the vehicle had been tuned to higher speeds at some point in the last two years. During the interviews, it became clear that vehicle tuning was common, and that it should be legal to drive faster in an A-tractor.

"...80 % of all A-tractors probably drive illegally... I think they don't care, if they want to go at 90, they'll do it." (Viktor, 15 years old)

According to the rules, the LGF sign indicating that the vehicles are slow-moving, and should be placed at the rear of the vehicle. In the questionnaire, 87% stated that the LGF sign was in good condition, and 11% said they had modified the LGF sign slightly. During the interviews, some participants mentioned that friends sometimes removed the LGF sign, replaced it with the license plate, and then drove on larger roads or motorways, thereby traveling at higher speeds.

"The LGF sign is centred at the back, where the license plate should be. You can snip it off and put on the license plate, and then you can drive on the motorway..." (Sara, 15 years old)

4 Discussion

In recent years A-tractors have become very popular among young people throughout Sweden and many obtain an AM driving license to drive these vehicles. The purpose of this study was to gain a better understanding of the use of A-tractors and the drivers' perspectives on road safety. During the interviews it became apparent that they had not reflected much on the driving education they had received. Perhaps they were not aware of what knowledge they have not received during the driving training. In the best case, they had practiced with their parents after obtaining their AM driving license, but there were also several people who had learned to drive their A-tractors entirely on their own.

Both questionnaire responses and interviews revealed that many people had replaced their entire bus or train commute to school with the A-tractor. Even those who had bus stops nearby stated that it was more convenient to drive their vehicles; aspects of freedom and independence carried significant weight. It is clear that there is a lack of awareness

regarding the environmental impact of A-tractors, and therefore, there is a need for requirements for exhaust emission control equipment (which currently does not exist).

According to the rules, the registration plate for an A-tractor should be mounted at the front and an LGF (slow-moving vehicle) sign should be placed at the rear of the vehicle. The young people highlighted that there is a safety risk on the roads because the LGF signs are poorly visible in the dark and only seen up close, which poses a risk of being rear-ended, especially on roads with higher speeds. During the interviews, participants also mentioned that some people occasionally removed the LGF sign on their A-tractor and replaced it with the license plate in order to be able to drive at higher speeds on larger roads or motorways. The LGF sign is a vital safety measure that alerts other motorists from a distance of a slow-moving vehicle. An A-tractor from a distance can resemble a regular passenger car.

Previous research has shown that there is a high level of acceptance for speeding among younger drivers [1], which was evident in various ways in this study. A common opinion among the participants was that it should be legal to drive faster in an A-tractor, preferably at least as fast as moped cars (45 km/h). However, there was also skepticism that a legal higher speed would reduce speeding, i.e., vehicle tuning. Moreover, it was common that their passengers did not use seat belts. During the interviews, it emerged that many passengers sat on each other's laps or on the center console, which poses a danger and obstructs the driver's visibility.

Lack of experience and young age are most often cited as reasons for the increased accident risk in traffic among young people [3]. It is well-recognized that a 15 year-old cannot handle complex traffic situations in the same way as an adult. However, the experience gained from driving A-tractors might facilitate the driver's education for passenger cars and contribute positively to their development as drivers, compared to drivers who do not have experience in driving those vehicles. However, further research is needed to investigate how young A-tractor drivers behave in traffic, evolve as road users, change their travel habits, perceive road safety over time, commit traffic violations, etc.

There is a need to develop new regulations for the education of AM license holders and the driving course curriculum. Lack of experience and young age are most often cited as reasons for the increased accident risk in traffic among young people. Driver education plays a crucial preventive role and young drivers should be encouraged to gain more driving experience. However, education should also focus more on risk awareness. Eligibility to drive an A-tractor should be a competence certificate obtained through training for this type of vehicle. Therefore, the training needs to be changed to prevent young people from developing attitudes and behaviors that are difficult to change and that can lead to traffic accidents and injuries.

5 Conclusion

If the trend continues of an increasing number of these vehicles, it is crucial to understand how road safety may be affected, especially as vehicle tuning and speeding is frequent among these drivers. Thus, there is a need for new regulations for A-tractors that can contribute to increase road safety for drivers and their passengers, as well as other road

users, including vulnerable road users. The study has also shown that the primary use of A-tractors is in regular traffic, which does not justify categorizing them as agricultural vehicles used and made for farmers. There is a need to determine the proper category for these vehicles, potentially requiring a different type of license, such as B1, with better education and a higher age limit.

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European Research and Innovation in Support of Transport Safety

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Abstract. Safety is a fundamental requirement for the mobility of people and the transport of goods across all transport modes. Transport safety is a key focus in the European Union's (EU) policy agenda, as outlined in the Sustainable and Smart Mobility Strategy (European Commission, 2021). The goal of "Vision Zero" in road transport is to achieve almost zero deaths and serious injuries in European road travel by 2050. Similar efforts are necessary to maintain excellent safety standards in air, sea, and rail travel. Research and innovation play a crucial role in achieving these objectives by developing safety technologies, safety management frameworks, suggesting regulations, and providing insights into human behaviour to promote better training and a safety culture. This study aims to analyse the EU's research and innovation efforts in transport safety, identify the main trends, and contextualise them within the overall policy objectives. The study utilises the open access Transport Research and Innovation Monitoring and Information System (TRIMIS) database (https://trimis.ec.europa.eu). Through this database, 143 EU-funded research and innovation projects related to transport safety were identified, with a particular focus on projects under the H2020 framework programme. By examining the scope, work, and outputs of these projects, this analysis provides an overview of the main trends in recently concluded and ongoing research.

Keywords: transport safety · road safety · research and innovation · knowledge management · transport policy

1 Introduction

1.1 Overall Context

Safety is essential for mobility, and Europe can be proud of being the safest region in the world. However, avoidable accidents still occur, especially in road transport, resulting in devastating consequences for victims, families, and communities, as well as financial costs for society.

Improving road safety and maintaining excellent safety records in aviation, rail, and waterborne transport is therefore a priority in the European Union's transport policy, as outlined in the Sustainable and Smart Mobility Strategy [1]. In the wider context

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of sustainability, improving road safety is a key lever for encouraging modal shift to active and micro-mobility in urban areas. This shift is crucial for improving quality of life and achieving climate neutrality in cities. Additionally, increasing rail traffic and replacing fossil fuels in the aviation and waterborne sectors also necessitate further safety improvements.

Research and innovation (R&I) play a crucial role in improving safety across all transport modes, developing vehicle and infrastructure technologies, safety management procedures, and complementing safety policy and legislation. The digital transition creates new opportunities for safer transport.

1.2 Policy Overview

Transport safety and security is one of the ten key action areas of the Sustainable and Smart Mobility Strategy's action plan. Furthermore, the New EU Urban Mobility Framework [2], emphasises the importance of the safety of micro-, active, shared mobility, and public transport as means of achieving a shift towards greener transport.

The objective of Vision Zero is to have near-zero fatalities or serious injuries in EU roads by 2050. The EU Road Safety Policy Framework 2021–2030 [3] outlines the action areas: infrastructure with a focus on safe roads and roadsides, safe vehicle technologies, driving behaviour, and response and rescue. It also sets up the monitoring of 8 Key Performance Indicators (KPI) to track progress towards Vision Zero.

Continuous effort is necessary to maintain excellent safety results in air, sea, and rail travel. The European safety agencies such as the European Union Aviation Safety Agency (EASA), the European Maritime Safety Agency (EMSA), and the European Union Agency for Railways (ERA), set certification and operational standards in line with international organisations, and oversee and monitor their implementation in the EU.

For aviation, Fly the Green Deal [4] outlines policy perspectives and R&I needs, including safety challenges related to sector competitiveness, automation, drones, airspace management, cybersecurity, and extreme weather. Further initiatives include the European Aviation High-Level Group on AI, for safe automation in air traffic management (ATM) operations, and Data4Safety, for secured identification of anomalies and potential incidents.

For rail, the policy focus [5] is on the promotion of safety culture, the rollout of new versions of the European railway signalling and train protection system (ERTMS), harmonising automatic train protection and communication systems and safety rules across the EU.

In the maritime sector, the European Commission (EC) will review existing legislation on flag state responsibilities, port state control, and accident investigation to enable safe, secure, and efficient maritime transport. EMSA guidelines address the human element in navigation accidents, which affects the safety of vessels and people on board.

Research policy includes safety-relevant calls in the European Framework Programmes. Furthermore, the European Public-Private Partnerships in the domain of transport establish roadmaps and R&I programmes, with safety always as a core requirement. These include the Connected, Cooperative, and Automated Mobility (CCAM)

partnership, the SESAR3 Joint Undertaking, Europe's Rail Joint Undertaking, and Zero Emission Waterborne Transport.

1.3 Method

This paper presents an overview of R&I in transport safety in Europe and recommendations for future orientations. It is based on the full report [6] by TRIMIS, the Transport Research and Innovation Monitoring and Information System [7]. The current analysis covers projects mostly funded under the Horizon 2020 (H2020) Framework Programme since 2014, with safety as a primary focus or core requirement for the project. The dataset of selected projects is available in [8].

2 Findings

2.1 Research Efforts and Trends

143 EU-funded projects were selected for the analysis of R&I in Transport Safety. For each mode, projects were grouped in thematic clusters which showcase the overall R&I trends. The majority come from the H2020 programme (130), yet FP7 projects were also considered for aviation safety. To facilitate interpretation of the charts for each transport mode, Table 1 provides a brief explanation for types of funding actions within H2020 and their approximate placement in the research and innovation cycle.

Table 1. Description of types of funding actions

R&I funding source	Description
Marie Skłodowska-Curie Actions (MSCA)	Actions that invest in the careers of excellent researchers and often focus on the development of methodologies.
Research and Innovation Actions (RIA)	RIAs address new R&I opportunities and aim their technical maturation. **Most projects in transport safety were funded by RIAs.**
Innovation Actions (IA)	Projects funded under IAs indicate solutions that are demonstrated in pilot deployments during the project.
Small and Medium-Size Enterprises (SME-2)	Projects funded under the SME-2 instrument aim market readiness and deployment for promising innovations
Coordination and Support Actions (CSA)	CSAs promote sector-wide collaboration and knowledge management.

For road safety, the 47 H2020 projects that were reviewed (Fig. 1), accounted for EUR 283 million of EU funding for a budget of ca. EUR 330 million. Projects primarily

address the safe vehicle technologies and driving behaviour action areas of [3]. Driver assistance systems, vulnerable road user detection and avoidance, driver fitness and distraction monitoring and alert, receive most attention. Virtual testing will lead to safer design and certification of vehicles and infrastructure. CCAM projects aim at future proofing road transport towards increased automation.

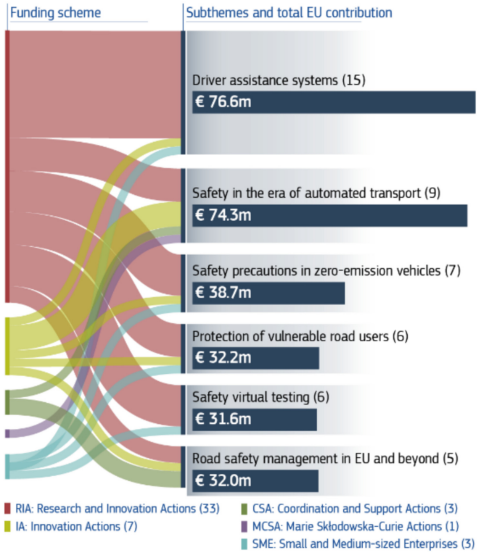

Fig. 1. H2020 road transport safety [6].

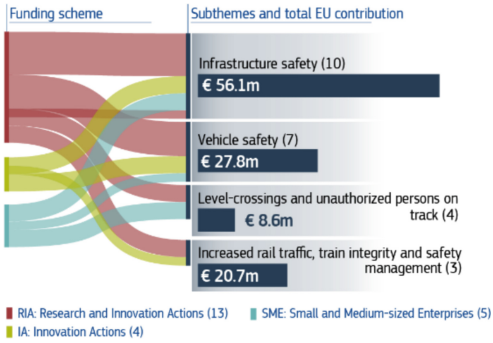

Fig. 2. H2020 rail safety [6].

In rail safety R&I, the 22 H2020 projects (Fig. 2) received EUR 94 million of EU funding for EUR 129 million of budget. Focus is put on infrastructure safety and security as most accidents occur due to unauthorized track crossings. EU Rail's projects advance towards high rail capacity and traffic concepts while maintaining safety.

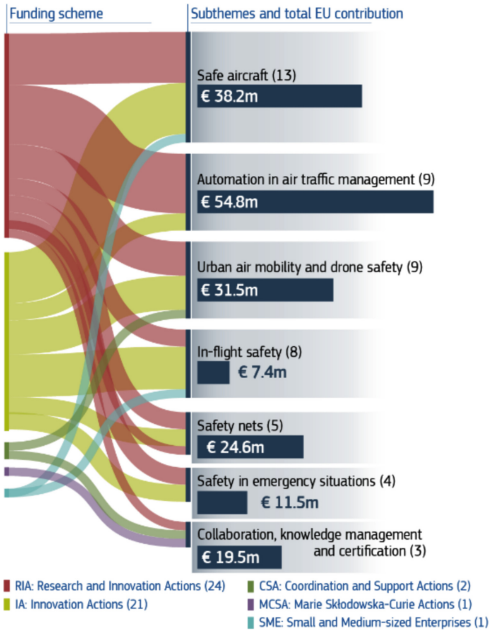

Fig. 3. H2020 aviation safety [6].

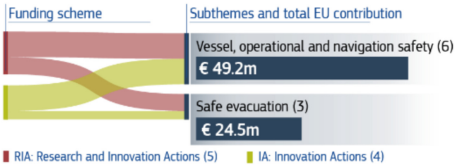

Fig. 4. H2020 waterborne safety [6].

In aviation safety (Fig. 3), 49 H2020 projects received EUR 180 million of EU funding for EUR 275 million of budget. Focus areas include improving aircraft safety, considering extreme weather but also preparing for alternative fuels and fuel cells. Increasing automation and the use of AI in Air Traffic Management is both an opportunity and a challenge. Finally, Urban Air Mobility and Drones create new safety requirements that require R&I, regulatory and industrial effort.

In waterborne safety R&I, the 9 H2020 projects (Fig. 4) account for EUR 74 million of EU funding for EUR 81 million of budget. Focus is put on detection and communication for safe navigation, human factors for safe navigation and safe evacuation during emergencies, and smart safety equipment.

2.2 Common R&I Patterns Across Modes

Several patterns emerge from the R&I activities across modes. These patterns are related to the opportunities that digitalisation provides, the challenges of increasing traffic for

certain modes, adverse weather and navigation hazards, and the study of human factors for the preservation of capacity, alertness and preparedness for every actor and in any situation.

Simulation and virtual testing allow to generate plausible traffic use cases and outcomes, with a great potential for safe design and certification of vehicles and infrastructure. **Safety data** collection and processing improve the understanding of causalities in incidents and accidents, and pinpoint the conditions that policy, R&I and industry need to focus on. **Performance indicators** extracted from safety data allow to benchmark progress. **Artificial Intelligence** (AI) trained on safety data allows to identify risk areas, predict the evolution of weather hazards, propose optimal navigation paths, and assist human operators both in the cockpit and control tower.

Concerning **human factors**, vehicle operator fitness monitoring and alert apply on all transport modes. The study of human behaviour under stress or distraction, has applications in innovative training for safe conduct under stressful conditions, to achieve positive outcomes in emergencies such as evacuation. Work on human machine interfaces, e.g., dashboards and mobile applications, contributes towards seamless and transparent interaction between human operators and automation.

3 Conclusions

R&I brings essential contributions to transport safety and is crucial to achieve the overarching objectives of the Sustainable and Smart Mobility Strategy. The analysed projects investigate automation, digitalisation and telecommunications as levers for improving operational safety for all modes. Human factors, for the preservation of operator fitness and alertness, and for the adequate response to emergencies, are appropriately investigated. Safe vehicle design is a consistent R&I theme, considering the challenges introduced by increasing levels of automation and the use of alternative fuels and energy sources in all transport modes. The reader is referred to the full report [6] for an overview of technological solutions and achievements and detailed analysis of projects.

3.1 Way Forward

On the way forward, transport safety R&I will continue to leverage the potential of digitalisation while contributing to overall objective of Sustainable and Smart Mobility. The ongoing research and innovation themes outlined in the paper will be further developed for practical implementation.

Sustainability objectives, such as increasing rail traffic will require continuous effort in safe high-capacity concepts that use precise geolocation and telecommunications. Similarly, decarbonisation of the aviation and waterborne sectors will need further developments to ensure the safe use of alternative fuels.

The benefits of automation and digitalisation as safety enablers have already been demonstrated, but their large-scale implementation requires considerable effort from all stakeholders. R&I can explore opportunities for synergies in cross-cutting topics, such as safety data management, human performance monitoring, and the use of AI for accident investigation and prediction of navigation, traffic and weather risks.

It is critical for R&I to investigate the cost effectiveness of safety measures, especially for modes that are prioritized for modal shift and transport decarbonisation, including rail, waterborne transport, and active, micro- and shared mobility in road transport. This presents a challenge for R&I at low and medium technology maturity levels, and efforts are needed to establish a harmonised methodology for estimating and reporting cost effectiveness in EU-funded projects.

Road transport safety can benefit from further showcasing the benefits of the safe system approach, which is a key policy priority. R&I can evaluate and demonstrate the combined benefits of technological innovation with non-technological measures such as speed reduction, infrastructure design, signage, and behavioural adaptations. R&I projects should also engage with the road safety KPIs as a policy initiative to measure progress towards Vision Zero, making the link between the solutions they develop and the indicators that they can improve. Safety data from on-board and infrastructure sensors, crowd-sensing and communication solutions can also be used for KPI monitoring. Further effort should be directed in improving infrastructure design, materials and signage, especially in rural areas.

R&I can help reduce regional differences in safety performance regarding rail and road transport by analysing the underlying causes and investigating relevant policy and technical solutions, including knowledge management and collaboration between member states.

Ensuring the safety of general aviation is particularly crucial as urban air mobility begins to become a reality. This can be achieved through enhanced cockpit and pilot aid solutions, remote piloting in emergencies, improved aircraft survivability, and effective distress tracking and localization systems.

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Secondary Roads in Europe – Challenges and Opportunities for Progressing Road Safety

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Abstract. Following the publication of Directives 2008/96/EC and 2019/1936/EC, European Union (EU) Member States (MS) developed a comprehensive set of road infrastructure safety management (RISM) procedures that are applied to all roads which are part of the Trans-European Road Network (TEN-T), all motorways and primary roads, and to EU funded interurban roads with full access control. These roads carry the bulk of traffic volumes in the EU.

This paper clarifies the notion of 'secondary roads', as those interurban roads falling outside the scope of RISM Directive. The main characteristics of both the crash occurrence phenomenon and traffic system operation on secondary roads from three EU MS are highlighted and consequences regarding safety management are extracted. Sources for viable good practice interventions for improving safety on these roads are presented, and the potential contribution from Connected and Intelligent Transport System (C-ITS) is discussed, taking in consideration the opportunities and limitations posed by this road category.

Keywords: Road Safety Management · Secondary roads · Road Design

1 Introduction

Road networks typically consist of a primary road network providing high-speed long-distance connections between regions or major cities supported by secondary interurban roads and roads providing connections between the interurban network and properties.

The primary network (motorways and primary roads) is generally well developed, financially well supported and relatively safe, also due to RISM application (in the EU).

Geometric and other design characteristics of primary interurban roads are standardized in each EU MS; nevertheless, these guidelines are slightly less strict than those for motorways. Other interurban roads are much more diverse, their characteristics depending on the role they have within each MS's network (e.g., regional or local collector, and access), and the level of administration supervising the operator – such as national authority, private concessionaires, and local authorities.

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At the macro scale the length of motorways and primary roads accounts for fewer kilometres than secondary and tertiary roads [1]. Overall, Europe has 87,728 km of motorways and 2,101,141 km of secondary roads [2]; the whole road network having 6,652,661 km. However, there is no general international agreement on interurban road categorization, as can be concluded when comparing international data bases, such as IRF [2] and Openstreetmaps [3]. For instance, for Portugal IRF includes only state operated roads whereas Openstreetmaps categorises some secondary roads as primary.

Roads are an important supporting mode for logistics and equitable accessibility. Roads account for the largest part of freight transport in the EU [4], with approximately 13700 million tons, out of a total of 32900 million tons moved by all modes – including seaports haulage, rail, inland waterways, and air (2021 annual data). Freight journeys of less than 50 km (6% of the annual ton-kilometres) accounted for almost half of the total moved freight. Short distance logistics is important, and so is the low-level road network used in the corresponding journeys; similar conclusions apply to short and medium range passenger accessibility, especially in non-urban areas.

The relevance of low-level road networks performance is recognized by the Conference of European Directors of Roads, which lists the following high priority safety actions: funding safety measures on secondary routes, implementing RISM procedures on all roads, and separating the most vulnerable road users (VRU) from modes that create greatest risk. These are recognized as challenges that need to be overcome [5].

It is difficult to assess the importance of the road safety burden on non-primary roads outside of urban areas. For instance, in the main source of harmonized accident data for international accident analysis at the European level – the CARE road accident data base – only three road classes are considered: motorways, urban roads and interurban roads. The last class includes all non-motorway roads outside urban boundary signs and does not distinguish the primary network from the secondary and lower-level networks [6]. The same type of classification is used in the IRTAD database.

Directive (Eu) 2019/1936 of the European Parliament and of the Council regulates the delivery of RISM on motorways and primary interurban roads at the European level, ensuring proper consideration of safety in these roads' life cycle.

Interurban public roads not in the scope of the RISM Directive and having a supra-local relevance can be grouped under the designation of "***secondary roads***". This categorization is relevant to road safety policy setting, due to the share of accidents and victims occurring there.

2 Secondary Road Characteristics

Both national and local entities are usually responsible for secondary roads' design, construction, and operation, meaning that design characteristics, operational features and maintenance programs may differ in the same MS, as national and regional/local authorities may apply their own guidelines to their networks. As a result, differences can be found in secondary road network elements, relating to several characteristics such as physical separation of travel directions, type of access control from adjacent properties, prevailing type of intersections (grade separated or not), design characteristics (e.g., design speed) and the allowed types of road users (in some cases bicycles or

agricultural vehicles are not allowed). Often, these roads have direct access from bordering properties, due to their mixed function; however, they are diverse in what refers to roadside characteristics (paved/non-paved shoulders and clear zone dimension), as well as regarding their motorized traffic volumes.

Similarly, operational conditions on secondary roads are diverse, as local and regional authorities have their own practices regarding important aspects, such as speed limit setting and traffic control devices. Road maintenance quality also differs considerably among secondary roads, due to, on the one side, their long extension and low traffic volumes; and on the other by the small dimension and the usually low technical sophistication of responsible local authorities. Figure 1 shows an example in Portugal of different levels of maintenance on two similar bridges, constructed at the same time.

Fig. 1. Example of maintenance conditions of contemporary bridges on a secondary (left) and primary (right) interurban road (source: Cardoso, J.L.).

Secondary roads also differ with respect to the environment they pass through. Roads operated by local and national road administrations may include short through-village stretches within urban boundary signs (small villages), that are not yet operated as urban roads. These through-village roads serve both local and through traffic – mainly because their traffic volumes and village population size do not justify constructing a bypass.

3 Current Road Safety Challenges

In general, motorways and primary roads carry most of the road traffic and share the bulk of road infrastructure investments. However, secondary roads correspond to a major proportion of the road length, requiring efficient priority allocation of maintenance and redesign activities, to provide enhanced safety operation. For instance, in Portugal (2015–2019), secondary roads (11919 km) accounted for 64% of the State Road network (NRN) length. Municipal interurban roads corresponded to 517% of the total NRN (eight times the length of NRN's secondary roads).

Accidents and related injuries on secondary roads account for a sizeable proportion of registered occurrences. Table 1 shows the total registered fatalities by road category in Czechia (2019–2022) and Portugal (2015–2019), and registered fatal accidents in the Netherlands (2019–2021). Overall, secondary roads account for no less than 20% of the fatalities. In these three countries crashes on secondary roads are more serious than the average, as the percentages of accidents (23% in Czechia, 12% in the Netherlands, and 22% in Portugal) on these roads are lower than those for fatalities.

Table 1. Distribution of registered fatal outcomes by road category

Country	Motorway	Main interurban	Secondary interurban	Urban	Other
Czechia	118	662	483	668	
Netherlands	136	404	330	607	57
Portugal	294	67	1172	758	119

Outside of urban areas, crashes on secondary roads and the resulting victims are an important share of the road safety burden, accounting for almost half of the occurrences in Czechia and the Netherlands and even more in Portugal.

The main conclusion is that improvements are needed on secondary roads, for EU road safety policy to be successful, and current targets to be reached.

Accident characteristics on secondary roads are quite different from those on RISM scoped roads, on both single and dual carriageway roads. See Fig. 2, where the percentages of fatal run-off-road crashes (ROR), collisions with pedestrians (Pedestrian hit), frontal collisions (Frontal col.), rear-end crashes (Rear-end), lateral collisions (Lateral col.), and other types of crashes (Other) are shown, for main (left) and secondary (right) interurban roads in Czechia (Cz), the Netherlands (NL) and Portugal (PT).

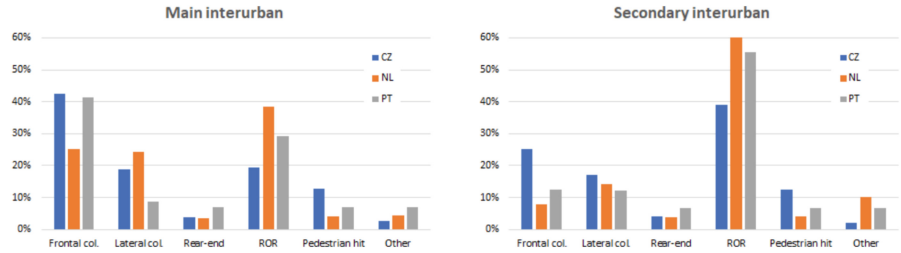

Fig. 2. Distribution of registered fatal outcomes by road category.

ROR accidents are the most common type of fatal accident on secondary roads, whilst both ROR accidents and frontal collisions are prevalent on main roads, especially in CZ and PT. There are differences between the share of crash type per country, and in each country the accident occurrence phenomenon is different on main and on secondary roads. For instance, frontal collisions are an important share of crashes on both Czech main and secondary roads; ROR crashes account for more than half of the Dutch and Portuguese fatal accidents. On the other hand, Dutch data shows higher shares of frontal and lateral collisions on main interurban roads.

ROR crashes (on links) and lateral collisions (at intersections) may be associated with inappropriate speeds; ROR crashes and collisions with obstacles relate to lack of protection from roadside dangerous obstacles. More detailed data analysis also reveals problems on road work zones (maintenance and reconstruction).

4 Emerging Safety Challenges and Effective Safety Interventions in the Road Life Cycle

Safe System principles are applicable to all roads, but their implementation needs to be specifically tailored to each category, more so to secondary roads due to their general non-conformity.

The configuration of the road environment (the geometric design and its roadside characteristics) should facilitate the correct driver perception of the appropriate speed, by means of the application of self-explaining and forgiving roads concepts, and the systematic application of consistent markings specific to each class of road, to foster an almost automatic recognition of the road category and the adoption of the appropriate driving behaviour to each road.

The concept of a safe speed [7] is an important principle of the Safe System approach and directly relates to the biomechanical tolerance of humans to prevalent injuries in typical crash scenarios on likely traffic interactions. Typical criteria for setting safe speeds correspond to the impact speed where the chance of death is less than 10% or to the point on fatality risk curves where they change from shallow to steep ([8] and [9]). This should be attended when integrating traffic modes and explains segregating vulnerable modes from motorised at speeds above 30 km/h. Dutch data show the benefits of progressive adoption of roundabout intersections, as regards lateral and frontal serious crashes. Due to the road length involved and the diversity of characteristics and followed guidelines, a long-term constant stepwise approach to improvement is needed.

In general, there are several useful sources for selecting effective engineering road safety interventions (e.g., [10–12] and [13]). However, due to the low traffic on secondary roads and the non-linear variation of crash frequencies with traffic, caution is advised when benefit-cost analysis supports prioritizing decisions [14]. Issues such as land use, public transport, area wide traffic calming, and transition zones are key aspects to consider in trough-village road stretches [15]. The benefits of correcting design inconsistencies have been demonstrated [16].

C-ITS technologies and decarbonizing road transport policy implementation are the main drivers of two emerging road safety challenges for secondary road administrators: increase of VRU traffic volumes, especially in spring/summer periods, when motorized traffic volumes are higher; and growing market penetration of advanced driver-assistance systems (ADAS) and intermediate levels of automation, in several cases dependent on key characteristics of the road infrastructure and environment.

Past and current planning, as well as space restriction challenge widespread bicycle segregation. Prioritising methods for segregating or mitigating (lower speeds) are to be adjusted to local conditions and traffic volumes. Motorcycles have special needs regarding skid resistance and safety barriers.

In the medium term, secondary road networks will remain mostly a conventional infrastructure, not reaching Infrastructure Support Levels for Automated Driving (ISAD) higher than level D (corresponding to digital mapping of static signs – see Inframix EU project) at the most. However, secondary roads administrations can benefit from advances in the integration of new-generation data sources for road condition and traffic operations assessments into their maintenance and safety management.

Conventional data updating will continue to rely on low frequency visual inspections and probe vehicles surveys. However, data from road users (i.e., from their vehicles and their smartphones) is available with high update frequency. Appropriate data analytics and visualization tools may support the development and standardization of novel system performance indicators. Sharing these indicators with local road administrations through the MS National Access Point (created under Directive 2010/40/EU on ITS), allows their combination with current conventional indicators in technical evaluation and roadwork procurement. Besides supporting evidence based and data driven road safety management by secondary road administrations, these crowdsourced data allow mapping the likelihood of ADAS availability and providing road users with suitable expectations concerning their availability in alternative routes, contributing for improved ADAS performance and use on secondary roads.

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Monitoring National Road Safety Strategies in the EU

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Abstract. The EC has released an ambitious Road Safety Policy Framework for the decade 2021–2030, setting new intermediate targets to halve the number of fatalities and the number of serious injuries on European roads by 2030. The need for monitoring the implementation of the road safety strategies and the road safety progress over the decade has been highlighted by almost all EU Member States, so that preventive measures can be taken in time in order to achieve the goals set at the end of decade. The objective of the current study is to provide an overview of the existing national road safety strategies of the EU Member States and current practices in monitoring the progress of the implementation of the national strategies and in assessing the effectiveness of strategy interventions in road safety. Additionally, the development of a tool for monitoring the implementation of the national road safety strategies/ action plans in the EU Member States for the decade 2021–2030 is presented. This monitoring tool aims to motivate and assist the EU, national authorities, industry, and the road users by supporting the implementation of policies, programmes and measures, exchanging best practices among the countries and benchmarking performances.

Keywords: road safety · road safety strategy · European Union

1 Introduction

Road safety constitutes a significant public health problem, with 1,35 million people being killed in road crashes every year worldwide [1]. In the European Union (EU), almost 20,000 people were killed in road crashes in 2021. While Europe is the safest continent in terms of road safety, progress in reducing EU-wide road fatality rates has stagnated in recent years [2]. The progress made so far is a 12% decrease in road fatalities for the 27 EU Member States between 2019 and 2021 and with lower fatalities numbers in almost all the countries.

Over the previous decade (2011–2020), the EC had set a target of halving road fatalities in 2020 compared to 2010. However, the European Union did not achieve its target, but instead a decrease of 36% in road fatalities was recorded. Out of the 27 EU Member States, only one country achieved its target of halving road fatalities in 2020.

Within this context, the European Commission released an ambitious Road Safety Policy Framework for the decade 2021–2030, setting new intermediate targets of reducing the number of road deaths by 50% between 2020 and 2030, as well as reducing

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the number of serious injuries by 50% over the same period. The Road Safety Policy Framework also suggests the monitoring of road safety progress through a set of Key Performance Indicators (KPIs), which are directly related to the prevention of road crash casualties [3]. Almost all EU countries have also developed and released their new national road safety strategies or action plans for the decade 2021–2030, setting quantitative targets for reducing road crash fatalities and injuries.

The objective of the current study is to provide an overview of the existing national road safety strategies of the EU Member States and current practices in monitoring the progress of the implementation of the national strategies and in assessing the effectiveness of strategy interventions in road safety. Additionally, the development of a tool for monitoring the implementation of the national road safety strategies/ action plans in the EU Member States for the decade 2021–2030 is presented. The results of this study are based on work carried out in the project "Support to the European Road Safety Observatory".

2 Methodology

For the purposes of the current study, a short survey was distributed to national road safety stakeholders involved in the implementation and monitoring of the road safety strategies in the EU countries. Through the survey, information was asked on the current national road safety strategies and the national practices implemented or foreseen for the current decade concerning the monitoring of the implementation of the road safety strategies and the evaluation of their impact on road safety progress.

13 Member States of the European Union responded to the survey, i.e., Belgium, Bulgaria, Denmark, Finland, Germany, Greece, Hungary, Italy, Luxembourg, Malta, Poland, Slovakia, and Spain. Also, the current road safety strategies/action plans of all EU Member States were reviewed, and an overview of their road safety targets is provided below.

3 Overview of EU National Road Safety Strategies

Most of the EU Member States have adopted and implemented strategic plans with specific targets for more than two decades as a key success tool to continuously improve safety in the European Union. All road safety strategies of the current period include quantified road safety targets, for road safety outcomes, i.e., road crash fatalities and serious injuries. Also, the monitoring of road safety progress is also foreseen in most strategies, most of them through a set of performance indicators. In order to better monitor the road safety evolution and take the appropriate measures in time, some of the Member States have also set quantified targets for these indicators.

3.1 Timeframe

Out of 27 European Union Member States, information was retrieved for the national road safety strategies for 26 (except Romania). For almost all Member States of the

European Union, the national strategies/action plans span the decade 2021–2030. It is noted, however, that the road safety strategy of Ireland is divided into three phases, i.e., 2021–2024, 2025–2027, and 2028–2030.

As shown in Table 1, the road safety strategies/action plans for six countries span different time periods.

Table 1. Timeframe of national road safety strategies/action plans in EU

Time Period	Member States
2021–2030	18 EU MS: Austria, Bulgaria, Czechia, Denmark, France, Germany, Ireland, Greece, Spain, Croatia, Italy, Cyprus, Lithuania, Netherlands, Poland, Portugal, Slovakia, Sweden
2021–2025	Belgium
2016–2025	Estonia
2022–2026	Finland
2020–2022 & 2023–2025	Hungary
2021–2027	Latvia
2019–2023	Luxembourg
2014–2024	Malta
2023–2030	Slovenia

3.2 Targets

Fatalities and Serious Injuries

Almost all EU Member States have adopted the safe system approach in their national strategies and vision zero for 2050, meaning zero fatalities in road crashes up to 2050. In order to achieve this, most EU countries have adopted intermediate targets for 2030. More specifically, the EU targets for the decade 2021–2030 of halving road deaths and serious injuries by 2030 have also been adopted by most Member States in their national policies.

Due to the covid pandemic in 2020 and the related traffic restrictions that led to a significant reduction of road crashes, this year is not considered as a typical year for road safety outcomes. Thus, the European Commission set 2019 as the baseline year for the target of reduction of fatalities and serious injuries by 2030. However, the baseline year for the EU Member States may differ from country to country (e.g., 2020, 2021, or average fatalities of 2017–2019, etc.).

It is also noted that some Member States have set either different targets or additional sub-targets for specific road users or crash types. An overview of these targets is provided in Table 2.

Table 2. Road safety targets per Member State

Country	Targets
Denmark	$<=$ 90 fatalities and 900 serious injuries in 2030
Germany	−40% in fatalities and a significant reduction in serious injuries
Greece	−50% in fatalities and serious injuries, sub-targets for specific road users or crash types (motorcyclists, fatalities on islands, in cities, on motorways, in single vehicle crashes). Intermediate targets for 2025 have also been set
Ireland	Target for the end of Phase 1: −15% in road fatalities and −10% in serious injuries in 2024
Poland	−50% for all fatalities, also max. 397 deaths of pedestrians, 129 cyclists, 191 moped users and motorcyclists, 133 victims in alcohol related crashes −50% for all serious injuries, also max. 1,237 pedestrians, 686 cyclists, 758 moped users and motorcyclists, 442 victims in alcohol related crashes
Spain	also, different targets in urban and non-urban areas per user type
Sweden	−25% in fatalities by 2030, max. 3,100 seriously injured in 2030, −25% in seriously injured pedestrians by 2030, −25% reduction in seriously injured cyclists by 2030

Key Performance Indicators

As already mentioned above, the EU Policy Framework for road safety for the decade 2021–2030 suggests monitoring the road safety progress through a set of 8 Key Performance Indicators (KPIs), which concern the safe road use (i.e., speeding, use of seat-belt and child restraint systems, use of helmet, driving under the influence of alcohol, driver distraction), vehicle safety, infrastructure, and post-crash care [3]. The European Commission in collaboration with road safety experts from the EU Member States defined these KPIs, while the first data collection under a common methodological protocol was carried out in 2021–2022 within the Baseline project [4].

Most EU countries have adopted these KPIs in order to monitor road safety progress over the current decade. However, only four countries (Austria, Belgium, Greece and Sweden) have set specific targets for these KPIs for the end of the decade. More specifically, Austria has set specific targets for KPIs related to safe road use, while targets on vehicle safety, post-crash care, infrastructure and attitudes towards risky behaviour will be defined in separate action plans. Belgium has set a 50% reduction for all behavioural KPIs by 2030. Greece has also set different targets per KPI to be achieved in 2030 and sub-targets for specific road types or road user types. Finally, Sweden has set targets for 18 indicators for the end of the decade.

3.3 Monitoring the Implementation of Road Safety Strategies

Based on the responses of the Member States in the survey, it is shown that practices concerning the monitoring of the implementation of road safety strategies/action plans vary among the countries. Monitoring is carried out on an annual or biennial basis, while

few countries have also performed ex-post evaluation of the impact of their national policies at the end of the implementation period of previous strategies.

As shown in Table 3, monitoring may include either the state of the implemented measures or actions, the work progress of the responsible authorities or the state of the road safety situation, mainly based on the road safety outcomes (crashes and casualties). It is worth noting that the most complete procedures regarding the monitoring of the implementation of a road safety strategy and the evaluation of its impact in road safety includes the following steps:

- evaluation of road safety outcomes achieved in relation to the target set,
- evaluation of KPIs achieved in relation to the target set,
- degree of completion of the actions/measures of the strategy/action plan,
- qualitative assessment, based on feedback from responsible authorities or related stakeholders.

Table 3. National monitoring practices

Country	Monitoring practices
Belgium	Monitoring of measures of RS plan. Ex-post evaluation based on road safety outcomes & KPIs
Bulgaria	On an annual basis, monitoring work progress for responsible authorities
Finland	The monitoring group meets at least twice a year, supervises the implementation and impacts of the measures
Germany	Biennial reports on implementation of road safety measures
Greece	It is envisaged in the RS strategy for 2021–2030 decade
Italy	It is envisaged - two intermediate evaluations in correspondence with the intermediate objectives and an ex-post evaluation
Malta	Currently carried out (at the end of the RS strategy)
Poland	On an annual basis - State of road safety and activities
Slovakia	On an annual basis - Implementation of the measures of the previous year
Spain	RS outcomes & KPIs on an annual basis, progress of implementation of measures every two years

4 A Monitoring Tool for National Authorities

A comprehensive tool for monitoring and assessing national road safety strategies and action plans is currently being developed within the project, which will be available in the European Road Safety Observatory (ERSO). The methodology components of this tool include close cooperation with national authorities, the development of a set of specially designed quantitative and qualitative indicators, a specially designed matrix with all indicators, and a specially designed dashboard with the performance and progress results.

The development of the tool is based on a three-step approach: road safety performance, monitoring strategy implementation and effectiveness evaluation. Specific indicators have been set for the two first steps, including related contextual framework (socio-economic indicators, road safety management, legislation), crash fatalities and injuries (characteristics and trends, comparison with targets), Safety Performance Indicators (characteristics and trends, comparison with baseline and targets), and the progress of implemented measures (budget spent, progress percentage in time). The strategy implementation effectiveness is evaluated by attempting to link the actions progress with the respective safety performance. A methodology guidance is developed for this purpose, with focus on before-after and time-series analyses.

5 Conclusions

To conclude, most of the EU Member States have adopted and implemented strategic plans for more than two decades. Setting ambitious but also realistic targets has been proved a key success tool to continuously improve safety in the European Union. For the decade 2021–2030, most EU countries have released their national road safety strategies aiming to halve road fatalities and serious injuries by 2030. The need for monitoring the implementation of the road safety strategies and the road safety progress over the decade has been highlighted by almost all countries, so that preventive measures can be taken in time in order to achieve the goals set at the end of decade.

Within this context, the monitoring tool of the implementation of the European national road safety strategies, that is currently developed for the European Road Safety Observatory, is considered as highly important as it will lead to higher transparency and accountability of national road safety authorities and consequently to improved efficiency of national road safety strategies. Also, such a monitoring tool will motivate and assist EU, national authorities, industry, and the road users by supporting policies, programmes and measures, exchanging best practices and benchmarking performances.

Acknowledgement. This paper is based on work carried out by the National Technical University of Athens (NTUA), SWOV Institute for Road Safety Research and Kuratorium für Verkehrssicherheit (KFV) for the European Commission DG Mobility and Transport, in the framework of the project Support to the European Road Safety Observatory (EC Service Contract MOVE/C2/SER/2022-55/SI2.888215).

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Model-Based Human System Integration to Optimize Railway Systems Safety Analysis

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Abstract. In the context of increasingly autonomous of railway operations, this paper presents a model-based and human in the loop simulation approach to optimize safety analysis. The first objective is to bridge the language gap between technical systems engineering and human factor engineering practices. The second objective is to increase safety assurance by analyzing both the safety-critical scenarios caused by technical component failures and human factors. The proposed methodology is evaluated through some design scenarios at grade of automation level 2 of automatic train operation.

Keywords: Model-Based · Systems Engineering · Safety Analysis · Human System Integration

1 Introduction

In traditional systems engineering approaches, human is considered as an actor who interacts with the technical system (machine) through human-machine interfaces. Today, with the emergence of autonomous systems and artificial intelligence, needs have evolved towards human and machine collaboration and cooperation to achieve a common goal. Therefore, the concept of Human-Machine Teaming (HMT) combines perspectives from systems engineering, artificial intelligence and human-centered design, to achieve Human Systems Integration (HSI) through the development of an integrative system that encapsulates human and machine attributes and properties [1].

A concrete example of HMT is the teaming between the train driver and semi-Automated Train Operation (ATO). The introduction of the European Rail Traffic Management System / European Train Control System (ERTMS/ETCS) and Automatic Train Operation (ATO) enables the transition from non-automated operation (Grade of Automation 1 - GOA1) to unattended operation (GOA4). At GoA2 (Semi-automated train operation), ATO On-Board equipment (ATO-OB) shall drive the train automatically while it is engaged by the driver. The ATO-OB shall drive the train so as to respect the journey profile (including departure and arrival time, ATO inhibition zone, etc.) provided by ATO Track-Side equipment (ATO-TS) without infringing the safe limits imposed by ETCS-OB. Figure 1 shows the reference architecture of ATO over ETCS.

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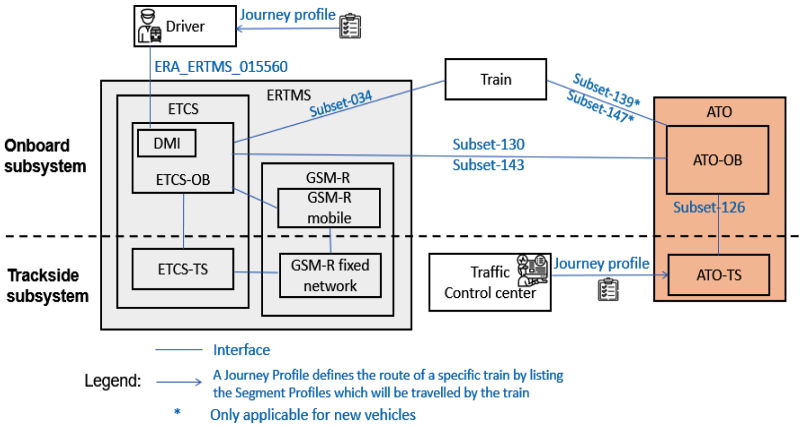

Fig. 1. ATO GoA2 over ETCS Reference Architecture (adapted from [2,3]).

While the subsystems and interfaces specification are still document-centric, some railway projects are moving towards the application of Model Based Systems Engineering (MBSE) in order to manage system complexity and ensure consistency between all system interfaces [4]. Recent researches try to extend the MBSE modelling languages to support modeling of human tasks [5] or human-machine teams [6]. But there are either theoretical or underspecified for specific domain such as railway domain [7]. This raised our first research question.

Research question 1: what is the suitable railway domain specific modelling language of MBSE that take account human factors at the early design phase? It should be the first step towards bridging the language gap between technical system architects and human factors specialists by relying on a same modeling language of system functions and human tasks. This modelling language should also help other engineering specialists to perform their work, such as safety engineers for safety assurance.

With the rapid advancement of MBSE, Model-based Safety Analysis (MBSA [8]) has been gaining more attention for its ability to verify whether the safety scenarios are properly addressed by a design solution. Many MBSA approaches have been developed over the past two decades and a systematic review can be found in this paper [8]. In general, the MBSA approaches start with a given design model, then faults are modeled to achieve a safety model and finally, verification is conducted to see whether the given properties (functional or safety, deterministic or probabilistic) are satisfied. However, there are still an open challenge. If certain safety scenarios are not considered in the given design model, or the properties do not correctly reflect the hazard, the results of MBSA cannot be fully trusted for safety assurance. In addition, a human activity (what is effectively performed) is often divergent of a human task (what is prescribed to be performed). This raises the second research question.

Research question 2: what is the appropriate model-based design methodology that can support the analysis of safety scenarios of automated driving systems? This methodology should help to identify the scenarios caused by both technical component failures and human factors.

The remainder of the paper is structured to address these two questions and discuss the proposed approach.

2 A Metamodel for Human Systems Integration

This section addresses the research question 1 by extending our previous domain specific languages for railway system architecture [9] to support modelling of human-centered and safety scenarios. Figure 2 presents the graphical view of the proposed meta-model. The terms used in the metamodel are applied in the systems engineering, human factors engineering, and safety engineering literature. Unfortunately, these terms are not used consistently across these disciplines and their related model-based best practices (MBSE: Model Based Systems Engineering, MBHSI: Model Based Human System Integration and MBSA: Model-Based Safety analysis).

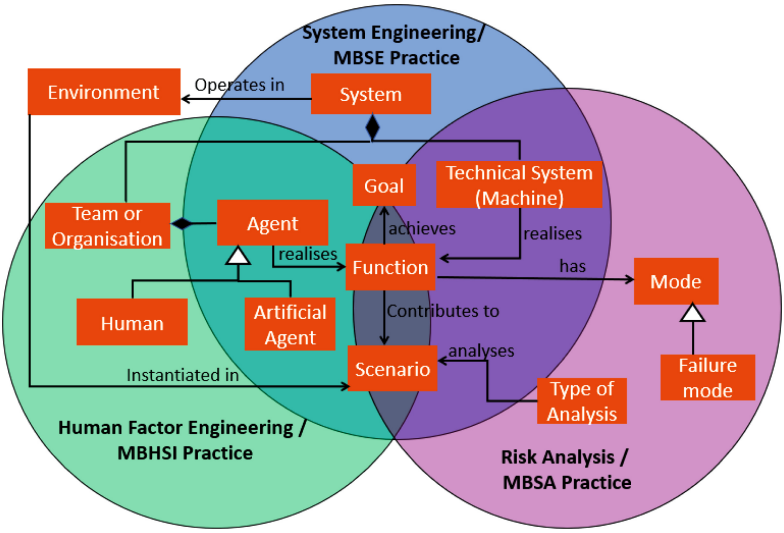

Fig. 2. The proposed human systems integration metamodel by using block definition diagram.

At the top of metamodel, a "System" is defined according to the railway standard EN 50126–1 as a set of interrelated elements considered in a defined context as a whole and separated from their environment. The system is comprised of a "Technical System (Machine)", such as a train or infrastructure, and an "Organisation or Team" which controls the technical system. The team is potentially comprised of other teams and multiple agents. An "Agent" is an entity capable of perceiving its environment, processing the perceived environment to determine a desired action, and performing the desired action in response to the environment. An agent can be "Human" or "Artificial Agent" functioning to interact with the machine. The agents cooperate in a structured way by adjusting their behaviors to achieve a common "Goal" within the goal hierarchy. Each goal is measured with the aid of different metrics [10]. With the purpose of achieving

one or more business goals, a "Function" represents either a technical function that can be performed by the technical system or a task performed by an agent or multi-agents (humans or artificial agents). The functions contribute in a given "Scenario", which represents envisioned applications of the systems within a specified "Environment". Our general approach is based on three phases: 1) the construction and selection of prescribed scenarios for specific perspectives, such as reliability, availability, safety, security, etc., 2) the human-in-the-loop simulations of selected scenarios on suitable simulators and 3) observation and analysis of activities effectively performed during simulation compared to functions prescribed in order to enables, early in the design phase, the elicitation of emergent properties of a human-machine teaming. The next section presents our approach for safety perspective.

3 Human-in-the Loop Simulation of Safety Scenarios

This section addresses the second research question by extending state of practice of MBSA and human-in-the-loop simulation to support safety performance assessment of design scenarios (Fig. 3).

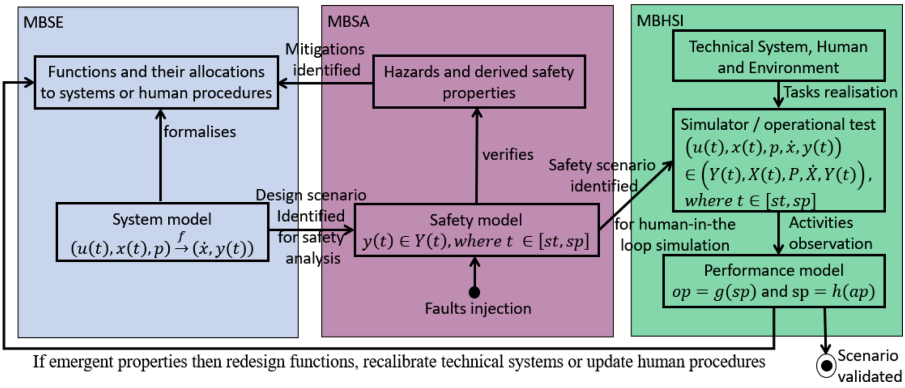

Fig. 3. Methodology for safety performance assessment of design scenarios

First, the system theory provides a generic formalism $(u(t),\ x(t),\ p) \xrightarrow{f} (\dot{x},\ y(t))$ to formalise the controlled systems, where u is the control, x is the system state, p is the set of parameters and y is the output. This generic construct needs to be properly constrained for system components which are within the design state (controlled systems, controllers) and those that are out of the design scope (i.e., environment or human behaviour that the designer has no control). Second, for specific scenarios within the design space, the prescriptive constraints are defined on the output behaviour, i.e., $y(t) \in Y(t)$, where $t \in [st,\ sp]$. If a design model is not properly constrained, it can lead to hazardous scenarios. Existing MBSA methods allow to constraint the output of functions considered in the given design solution (e.g., ETCS signalization display or ATO functions) with failure modes, such as loss, erroneous or untimely (erroneous of start time st, stop time sp or

evolution in time windows [st, sp]. However, for functions that designers have no full control (i.e., detect obstacle on the rail, bad weather and human effective activities such as engage or disengage ATO), we need one more step to validate the assumptions on the environment and human tasks.

Finally, each model constraint may have assumptions on the environment and the human to be validated during simulation or operational test. Indeed, a model is an abstraction of a real-world system, which is used to increase our understanding of it by evaluating various appropriate metrics. [10] proposed the common Metrics to benchmark human-machine teams. In our approach, we used 3 levels of metrics: operational performance (op), system performance (sp) and agent performance (ap). The high-level performance can be derived from low level performance: op = g(sp) and sp = h(ap).

Operational performance op is an high-level metric that analysis system performance in a specific context and measures the distance between an expected performance (i.e., prescribed task) and effective performance (i.e., activity). It is based on the analysis of sp data categorized according to three indicators: task completion (i.e., did the agent successfully complete the assigned mission?); resource availability (i.e., did the agent meet resource management guidelines, e.g., energy management, time management?); risk management (i.e., did the agent maintain an appropriate level of safety relative to the level of risk of the mission?).

For example, in our case study presented in the introduction (Fig. 1), one of expected performances of driver reaction during the ATO disengaging scenario is to react in 5s. Indeed, according to the ATO specification SS126: If the driver applies the brake using the Traction/Braking Lever or selects "ATO Disengage" before 5 s, the ATO-OB transitions from "disengaging" to "not available" state and the ETCS-OB leaves automatic driving Mode. The model and human-in-the-loop simulation (Fig. 4) shows that the driver may not react before this threshold regarding the driving context or external environment events.

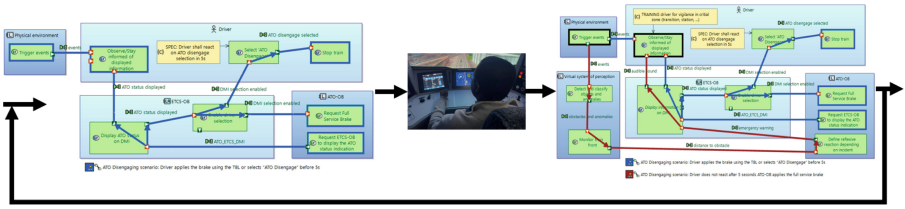

Fig. 4. Example of human-in-the-loop simulation based on [1] and [7]. The left side of the figure is the initial design model with ATO disengaging scenario in blue chain. The middle side is the simulation of this task scenario in an ATO simulator. The right side is the redesign of the scenario after the simulation results (identification of emergent scenario in red chain).

In case of distance between an expected performance (i.e., prescribed task) and effective performance (i.e., activity) as illustrated in Fig. 4, a discrepancy should be analyzed and understood. From this example, the identified emergent function "audible warning" needs to be appropriate designed to remind the driver for ATO disengaging.

4 Conclusion

This paper addresses 2 main questions that can help to progress in the implementation of human system integration. The first contribution is the proposal of human systems integration metamodel by bridging the language gap between technical systems engineering practice (MBSE) and human factor engineering practice (MBHSI). It relies on a same modeling language for system functions and human tasks analysis and then help to construct the design scenarios for expected performances. The second one is the methodology for safety performance assessment of design scenarios. It is based on 2 steps: identification of safety scenarios caused by technical system failures by using a MBSA practice and analysis of safety-critical scenarios by using human in the loop simulation. The first experimentation shows that MBHSI has become possible at the earliest stages of design by using scenario-based design and virtual simulation to understand human activities. Consequently, advanced visualization technique, data acquisition and cognitive low-level measures techniques, such as eye tracking and electrocardiograms are needed in future works to increase tangibility and elicitation of human teaming metrics, such as trust and collaboration.

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Influence of the Airflow Concept on the Aerosol Spreading in a Generic Train Compartment

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Abstract. In our recent studies, we have applied a measurement system for aerosol spreading in the generic train laboratory Göttingen (GZG) for different source locations and various ventilation concepts. The latter comprised, among others, different exhaust positions either in the lateral ceiling or in the legroom. The measurements were carried out until a quasi-stationary local aerosol particle concentration was reached. The evaluation was performed in terms of the mean aerosol concentration load in the compartment and with regard to the number of seats revealing aerosol concentrations above certain thresholds. First results highlight the influence of the airflow concept on the aerosol spreading within the passenger compartment. In this context, the exhaust position caused only a minor change in the local aerosol particle concentrations, whereas larger differences were found for alternative, hybrid air-supply positions.

Keywords: passenger train · compartment ventilation · airflow management · aerosol spreading · HVAC system · local air quality

1 Introduction

The ventilation of passenger train compartments has to meet several standards, e.g. DIN EN 13129 [1] for long-distance trains, to guarantee thermal comfort for the passengers. At the same time, the energy demand of the HVAC system – which is the second largest consumer during a train journey [2] – and the local air quality must be considered. Balancing these three main pillars (thermal comfort, energy demand and air quality) is a challenging task in terms of ventilating passenger trains. Additional boundaries are defined by the geometrical constraints, i.e. available installation areas for air channels and openings as well as by specific operational conditions of the train such as different climate zones or fast changing conditions such as tunnel passages.

In previous studies, alternative ventilation concepts were evaluated regarding thermal comfort and energy demand, see e.g. [3]. These studies were performed in a generic train compartment with well-defined boundary conditions to ensure a) a high repeatability and b) a more general knowledge compared to highly specific solutions for selected train series. Therefore, thermal manikins were used to experimentally simulate the obstruction and heat release of seated passengers (see Fig. 1, left).

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Although the air quality in terms of a sufficient fresh air supply is already defined and has been established in standards for a long time, the Sars-CoV-2 pandemic draw additional attention to this topic. The newly raised questions are: How do exhaled aerosol particles spread in the compartment and in specific how "contaminated" are the other passenger seats?

2 Setup and Methods

2.1 Generic Train Compartment (GZG)

Fig. 1 The generic train compartment equipped with thermal manikins during a smoke visualization (left); with the aerosol-exhalating face and aerosol particle sensors (right) ©DLR.

The study was conducted in a generic laboratory, representing the lower cabin of the DLR's next generation train (NGT), see Fig. 1. The inner dimensions of the compartment are 6.0 x 2.88 x 1.95 m^3 (length x width x height) and it is equipped with 24 seats. Thermal manikins are used to simulate the blockage and the heat release of real passengers. Fresh air is supplied by an external HVAC system, which controls both the volume flow rate and the inflow temperature. The HVAC system is operated at 100% fresh air to solely investigate the effects of the interior airflow on the aerosol spreading, avoiding background contaminations caused by recirculated air.

2.2 Experimental Analysis of Aerosol Spreading

The experimental analysis of the aerosol spreading comprises three main points: the generation of the aerosol particles, the detection of the aerosol particles and the evaluation of the measured local aerosol particle concentrations (for details see [4]).

Generation of the Aerosol Particles. The aerosol generator consists of an airbrush pistol used to disperse a constant mist of artificial saliva (mixed in accordance with NRF 7.5, receipt see [4]). After the initial generation, the particles are guided through a settling chamber. The setup is designed in such way that the particles already have an age of more than one minute before being released into the cabin, i.e., all evaporation

processes are expected to be finished, and pure dry particles are released. The particle size distribution of the generated particles shows that particles with diameters smaller than 2.5 µm are produced corresponding, e.g. to normal breathing.

Detection of the Aerosol Particles. For the spatially resolved acquisition of particle number densities within the cabin, 24 SPS30 low-cost particulate matter sensors are used and operated via the mobile measurement system of the DLR [6]. The sensors are mounted in the face area of all seated thermal manikins, and thus the local aerosol concentration can be recorded at a sample rate of approx. 0.9 Hz in our setup.

Evaluation of the Recorded Concentrations. To determine the amount of potentially 'inhaled' aerosols, the locally measured equilibrium-state particle concentrations [1/cm^3] are multiplied by the typical human tidal breathing volume and by the typical breathing frequency resulting in the number of measured 'inhaled' particles per minute ($\dot{N}_{seat}$). As our source produces more aerosol particles compared to a human, we calculate the 'inhalation fraction' $f_N = \dot{N}_{seat}/\dot{N}_{source}$, representing the amount of inhaled compared to the amount of exhaled aerosol particles.

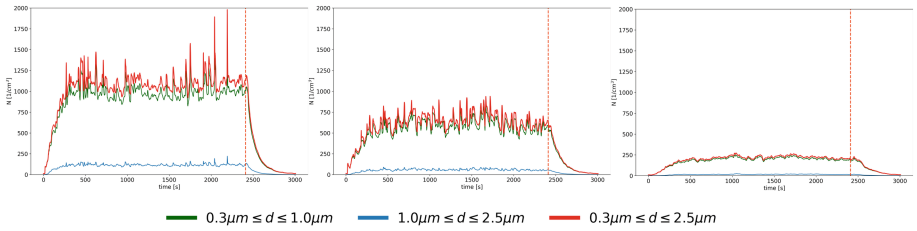

Fig. 2 Curve of the local aerosol concentrations over time; t = 0 s: start and t = 2400 s: stop of the aerosol exhalation. The source was positioned on an aisle seat. Concentrations recorded at the neighbouring window seat (left), the window seats one row behind (middle) and two rows behind the source (right). The data belongs to the MJV-CE case shown in Fig. 3. (left).

The measurements are performed until a quasi-stationary local aerosol particle concentration is reached. The average values for this quasi-stationary period, i.e. the 300 s before switching-off the aerosol source (see dashed lines in Fig. 2), are calculated for all seats. The evaluation is performed in terms of the mean aerosol concentration load in the compartment and with regard to the number of seats with aerosol concentrations above certain thresholds.

2.3 Investigated Ventilation Concepts and Boundary Conditions

In the present paper, the results of the aerosol spreading are compared for three different ventilation concepts, see Fig. 3. Microjet ventilation (MJV) with ceiling exhaust (CE) is characterized by an air supply via a trickle ceiling above the aisle and the air exhaust being installed in the lateral parts of the ceiling (Fig. 3., left). MJV with floor exhaust (FE) is operated with the same air supply system but the exhaust is realized at floor level in the lower side walls (Fig. 3. middle). The hybrid system also uses the ceiling

exhaust openings. However, the fresh air is supplied by a combination of MJV and cabin displacement ventilation (CDV). The latter is installed using dense membranes which generate a low-momentum air supply below all seats. This hybrid MJV-CDV concept, shown in Fig. 3. (right), is investigated for three volume flow rate splits between MJV and CDV air supply.

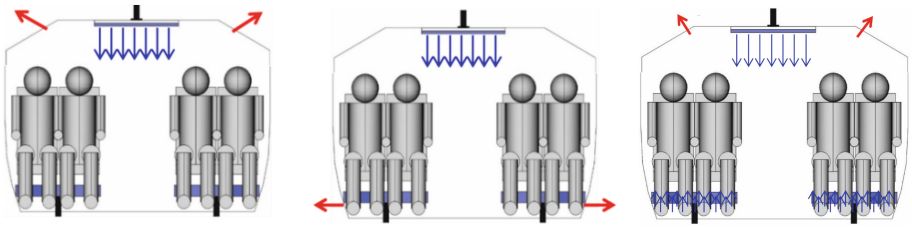

Fig. 3 Sketch of the investigated ventilation concepts. MJV-CE (left), MJV-FE (middle) and MJV + CDV (right). The latter was investigated for a 50%-50%, a 70%-30% and a 30%-70% volume flow rate split between MJV and CDV supply openings. ©DLR

3 Results

Figure 2 presents the curves of the concentration over time for three different seat locations (left: A02, middle: A03 and right A04), that is, with increasing distance from the aerosol source for the MJV-CE case. Furthermore, both the total number concentration (0.3 - 2.5 μm) and the curves of the individual particle size bins are shown. There are three main points to note: Firstly, the aerosol particle concentration decreases with increasing distance from the source. Secondly, the flow in the train compartment shows strong turbulent behavior, represented by the strong fluctuations of the local aerosol concentrations, especially in the vicinity of the source. The magnitude of the concentration fluctuations decreases with increasing distance from the source, as mixing with the cabin air dilutes the exhaled aerosol particle steam. Thirdly, the majority of the particles are smaller than 1.0 μm. Particles in the range of 1.0 - 2.5 μm have only a negligible impact on the local number concentrations. However, it should be noted that the impact on the transported fluid volume is different, since the volume of the larger particles increases with the third power of their diameter.

Figure 4 presents the time-averaged steady-state aerosol load in the compartment for the four configurations with the inhalation fraction indicated in different colors for the individual seats. The source remained on seat B02, marked as 'S'. In general, we find the highest contamination in the vicinity of the source. Increasing distance from the source leads to a decreasing inhalation fraction. The comparison of the different exhaust positions for MJV – (a) and (b) – reveals only a minor impact, e.g. on the seat directly behind the source. The hybrid configurations (c) and (d) result in an increased spreading of the aerosol particles on the other side of the aisle, while slightly decreasing the forward and backward spreading. The hybrid configuration with a volume flow rate split of 30%-70% (MJV-CDV), see (e), stands out with significantly lower inhalation

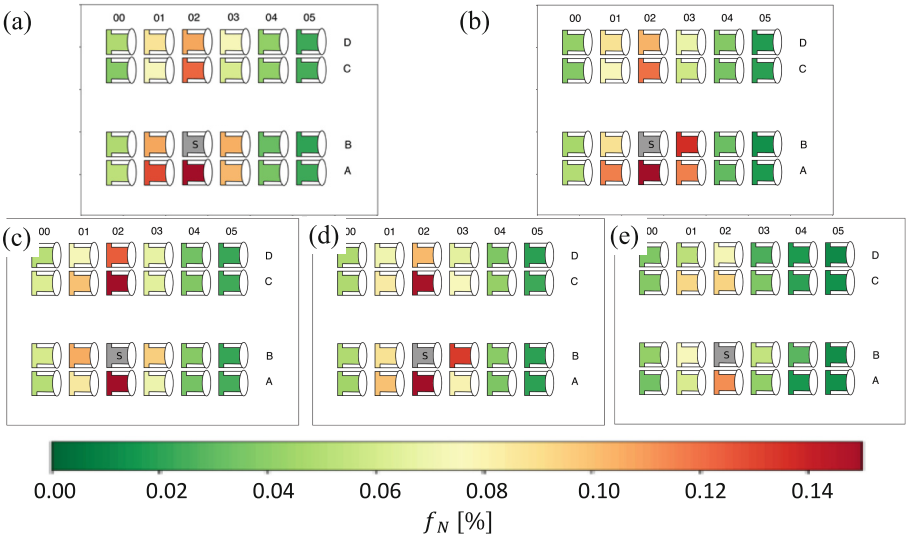

Fig. 4 Results of the aerosol spreading as heat map representation of the fraction of potentially inhaled aerosol particles within the compartment: MJV-CE (a), MJV-FE (b), MJV + CDV 50–50 (c), MJV + CDV 70–30 (d) and MJV + CDV 30–70 (e).

fractions. The increased fraction of floor-based air supply has clear advantages over the other concepts regarding the local inhalation fraction, as a more efficient removal of the exhaled particles towards the outlet is provided by the airflow.

Table 1. Summary of the average inhalation fraction on all seats as well as number of seats with a concentration above a certain threshold for all ventilation concepts. The volume flow rate amounted to $230 l/s$ for all cases.

Ventilation concept	$\langle f_N \rangle$ $\left[10^{-3}\%\right]$	Number of seats with $f_N > 0.05\%$	Number of seats with $f_N > 0.10\%$
MJV CE	68.5	12	7
MJV FE	64.8	12	6
MJV + CDV 50–50	68.7	15	4
MJV + CDV 70–30	66.4	11	4
MJV + CDV 30–70	43.3	8	1

Finally, the results of the local aerosol particle distributions are summarized in Table 1. for the comparison of the four analyzed configurations. In addition to the averaged local inhalation fraction $\langle f_N \rangle$, we evaluated the number of number of seats with a concentration above. The selected thresholds are arbitrary and not based on specific infection risk assumptions. The first thing to note is that in case of pure MJV supply,

there is only a negligible effect of the exhaust position on both average particle load and number of seats with concentrations above the thresholds. That means that the change of the exhaust system, only changes the local distribution (Fig. 4) with a rather weak impact on the global values. In contrast, the combination of MJV with CDV reduces the number of highly contaminated seats and the volume flow rate split between ceiling and floor supply has a major impact. The 50%-50% and the 70%-30% configuration both result in a slightly reduced number of highly contaminated seats, while not changing the average load in the compartment. The 30%-70% configuration, i.e. most of the air is supplied at floor level, however, reveals significantly better values. For this configuration only one highly contaminated and only 8 intermediate contaminated seats were found and the mean load in the compartment was reduced by 36% compared to the MJV CE case.

Finally, it should be noted that all presented results are recorded for the source positioned on an aisle seat. The spreading behavior will be different for other source locations. Thus, a general evaluation of the concepts purely based on the given data is not recommended.

4 Summary and Conclusions

We presented results of an experimental investigation of the aerosol particle spreading originating from one selected source location in a generic train compartment for different airflow configurations. The results proved that the sole change of the exhaust air position from ceiling-based exhaust to floor-based exhaust has only a minor influence on the mean particle load in the breathing zone of the seated passengers.

In contrast, the integration of an additional floor-based air supply and thus a hybrid ceiling and floor-based air supply at a 30%-70% split ratio, with maintained total supply airflow rate, strongly reduces the local particle concentrations. The averaged particle load, evaluated in terms of inhalation fraction, was reduced by 36%, while the number of ‘highly contaminated seats’ was also minimized from seven to one.

It can be concluded that the airflow concept in the passenger zone of a train has a significant impact on the spreading behavior of locally induced aerosol particles, e.g. exhaled by a sick passenger.

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EGNSS MATE: Towards Accurate and Reliable GNSS and Map-Supported Train Localisation

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Abstract. The paper presents the EGNSS MATE project on map-supported train localisation with onboard sensors and GNSS (Global Navigation Satellite Systems) for ERTMS (European Rail Traffic Management System). Details for the overall project and its work packages (state of the art, architecture, advanced GNSS and interference, map data and map-supported multi-sensor fusion, measurement campaigns) are given. The project is conducted within the ESA NAVISP programme by the partners SBB, IABG and DLR.

Keywords: GNSS · train localisation · map data · Galileo · ERTMS ETCS

1 Introduction

EGNSS MATE (European Global Navigation Satellite System based Map Assisted Train localisation for ERTMS) is a project that contributes towards climate-friendly, cost-efficient, digital, interoperable, and safe European railways by researching and analysing advanced GNSS onboard train localisation. The project partners comprise the Swiss Federal Railways (SBB) as railway operator, Industrieanlagen-Betriebsgesellschaft mbH (IABG) as GNSS and testing expert company, and the German Aerospace Center (DLR) as research institute with a transportation focus. EGNSS MATE has started in January 2023 and has a planned duration of 2 years.

The focus of EGNSS MATE is onboard train localisation within the European Train Control System (ETCS) of the European Rail Traffic Management System (ERTMS). GNSS technology and map-supported multi-sensor fusion algorithms on all vehicles will facilitate moving block operation and thereby increase line capacities. Track-side infrastructure for localisation can be reduced, which translates to lower costs and more flexibility for operators. A prerequisite for this is

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a safe and accurate localisation of trains. Improved accuracy can be achieved by exploiting the track-constrained vehicle motion. Suitable map data need to be provided and tightly integrated into localisation algorithms. GNSS signals are transmitted over the air and received by onboard antennas. Although GNSS provides advantages in terms of flexibility and ETCS interoperability, there are potential risks of signal interference that must not be ignored. A thorough understanding of railway-targeted GNSS jamming and spoofing (J/S) is needed to find safe and secure localisation solutions. Furthermore, advanced GNSS services (Galileo HAS, Galileo OSNMA) have good potential in aiding onboard localisation. The above aspects are researched on actual measurement data from an SBB vehicle that traverses the entire SBB rail network.

The following sections reflect the EGNSS MATE work package structure and provide insights into the project work.

2 State of the Art and Requirements

In order to provide a firm basis for the project a dedicated state of the art work package has been included in the first three months of the project. The main goals have been to understand the complex stakeholder landscape (focus on Europe), to survey existing literature and project results that are relevant to the work packages, and to define requirements in different contexts.

The stakeholder landscape for EGNSS MATE comprises railway and infrastructure operators, railway technology providers, political institutions and funding agencies, and research institutes. Their interests can be in conflict. For example, the reduction of track-side solutions in favor of onboard GNSS localisation reduces the costs for railway operators, but also reduces the track-side business. Large research and development activities are performed in different partner constellations, often funded by the European Commission (see the CORDIS portal [3]) and often managed by railway or space agencies (EUSPA [7], ESA [4]). The network is becoming denser in the sense that stakeholders are in conversation in conferences and working groups (ERTMS Users Group, EUG [5]).

The relevant literature is as diverse and spread over different communities (GNSS, railway, sensor fusion). Review articles such as [8] provide good starting points for both GNSS and algorithm details, as well as the railway context. A rich GNSS background is available in [13]. More focused scientific papers have been surveyed for the advanced GNSS and localisation algorithm development work packages. Parts of this literature review are being prepared for publication in the spirit of [8].

Requirements for the project work and beyond have been defined based on available results. Environmental conditions for the onboard localisation are considered, including modes of vehicle operation (e.g., low and high density lines). Functional requirements on the data sources (map data, GNSS and multi-sensor data) and the localisation output (continuous at 10 Hz, restricted to tracks or track hypotheses, with confidence intervals) have been formulated.

3 Architecture

EGNSS MATE contributes to a wider solution for onboard localisation for future implementations within ERTMS. Architecture aspects from the Open CCS Onboard Reference Architecture (OCORA, CCS—Command, Control and Signalling) [11] are considered. Specifically, contributions to an onboard localisation unit (LOC-OB, [6]) are developed. With OCORA under development and certain research aspects in mind, the following architecture decisions have been made for EGNSS MATE.

The onboard data acquisition is conducted with a number of sensors and systems that record time-stamped data. The onboard hardware utilised for the sensor fusion algorithm comprises GNSS, IMU and velocity sensors (wheel odometer, optical speed sensor). The devices used for ground truth computation also include GNSS, IMU and a wheel odometer with the difference that the employed devices are of higher quality and therefore provide high precision position data. Moreover, the output of the sensor-internal data fusion and an Eurobalise reader are available as additional data sources. Messages for each onboard device have been agreed. The data are stored for offline access in a relational database.

For the algorithm development and testing, a simulation environment is set up in the back-office. Simulation is here understood as replay of onboard data streams so that localisation and integrity monitoring algorithms can be executed as if they were on the actual vehicle. Robot Operating System (ROS) [12] is considered for the implementation of the simulation environment. ROS provides convenient replay functionalities and facilitates the integration of the EGNSS localisation algorithms (written in Python) as ROS modules.

4 Advanced GNSS and Interference

EGNSS MATE investigates the radio-frequency interferences (RFI) affecting the GNSS signals in onboard train localisation and the potential added value of the Galileo High Accuracy Service (HAS) and the Galileo Open Service Navigation Message Authentication (OSNMA). For a while, RFI had mainly concerned armed forces. Nowadays, so-called Personal Protection Devices (PPD), which disturb or prevent GNSS receivers of receiving GNSS signals by inducing interference [2] are available on the market, constituting a potential threat. Therefore, GNSS interference is now a significant problem for civilian applications. In-band interferences, for example, intentional jamming and spoofing of GNSS receivers show a source of potential threats to the safe, secure, and robust operation of a dense railway system utilising GNSS as the main positioning method. The impact and importance of addressing the RFI threats were demonstrated by RFI cases affecting aeronautical users in [1]. In the railway context, efforts have equally been made in terms of detecting GNSS interferences in [14]. EGNSS MATE focuses on two interference types: jamming and spoofing. Jamming describes a threat case or single event in which an entity intentionally tries to prevent a GNSS processing device from receiving satellite signals by transmitting an

interfering higher power signal in the same radio frequency bands as used by the GNSS receiver. Spoofing is understood as a method that intentionally emits an imitated satellite signal towards the receiver forcing it to calculate erroneous position, velocity, or time (PVT) solutions. Jamming activities target degrading the GNSS availability, spoofing targets degrading the GNSS integrity. To our knowledge, no large-scale statistical analysis utilising ground-based infrastructure for detecting GNSS interferences in the railway domain is available.

First, a preliminary analysis of a one-year long data set of GNSS receiver recordings collected on an SBB wagon traveling across Switzerland has been performed. It has revealed multiple RFI occurrences, made salient their signal profiles, and allowed to infer correlations between RFI events and anomalies in the GNSS data.

The project analyses the use of the new Galileo Services HAS and OSNMA for rail applications. HAS provides an improved PVT solution, OSNMA a robust solution against spoofing attacks. Both will be available to public users from 2024. HAS is likely to meet rail requirements in terms of accuracy [10]. As for OSNMA, current performance looks promising as the authentication of OSNMA data has already reached a 99.9% success rate. Data analysis using the MuSNAT software receiver [9] will bring novel insights by conducting a test campaign specific to the rail domain.

5 Map Data and Map-Supported Sensor Fusion

Localisation in the rail domain is challenging for many regulatory and technical reasons. For instance, there is no single onboard sensor or system (e.g., standalone GNSS or odometry) that can provide safe and accurate location and velocity estimates at the required availability. Hence, a combination of onboard sources must be used. This is addressed in EGNSS MATE by developing multi-sensor fusion algorithms.

The employed onboard sensors and systems have individual error characteristics. GNSS requires signal reception that is often compromised (tunnels, urban areas). With enough satellites in view, however, accurate global positions and velocities can be derived. Inertial measurement units (IMU) provide acceleration and turn rate measurements in the sensor coordinate frame. IMU exhibit typical offset or bias errors that slowly drift over time. Calibration is required. Integration of IMU accelerations can yield velocities and positions. The bias errors, however, cause quick error growth (linear in the velocity and quadratic in the position). Hence, compensation (error reset) with complementary measurements is required to maintain accuracy. Velocity sensors based on wheel rotation are affected by slip and slide phenomena. Optical or radar velocity sensors can exhibit errors that depend on the weather conditions.

Rail vehicle motion is constrained to paths in the railway network. Transitions from track to track can occur only at switches. There is much potential in exploiting this information by using appropriate map data. Therefore, SBB map data is available for tight integration into the localisation algorithms.

The systematic combination of onboard sensor and system data is achieved with tools from the field of statistical sensor fusion. Specifically, Kalman filters (KF) are developed as theoretically sound, flexible, yet simple class of algorithms. Selected KF advantages include the modularity with respect to available sensor set-ups, the separate modeling of the state evolution (how positions and velocities change over time) and the individual measurements (one measurement equation per sensor), as well as the capability to embrace uncertainties (process and measurement noise, localisation output with state estimates and covariance matrices).

The nature of the vehicle motion along discrete paths in the network cannot be achieved with one KF alone. However, banks of KF can be employed. These continuously maintain a list of current path hypotheses. Each hypothesis has a KF in path coordinates in which the position is represented as a scalar on-path distance. The performance of a hypothesis can be assessed using the measurement data (analysis of the KF measurement residuals). Developing the methodology for the KF bank with all its subtasks (path extension, hypothesis merging and pruning, output computation) is at the core of EGNSS MATE.

EGNSS MATE follows a timely and collaborative approach in the algorithm research by developing open-source software. A localisation toolbox for expert users will be published within the project.

6 Measurement Campaigns

Measurement campaigns are performed using an SBB vehicle on the entire network. The vehicle is equipped with the two sensor setups, one as input source for the algorithm testing, and one for the Ground Truth dataset. The test vehicle is in continuous operation on the whole Swiss normal gauge network. It covers the entire network at least once a year. During these runs we will perform a continuous recording and collection of measurement data. The data are used to perform large scale testing of the developed algorithms in a big data environment.

Two dedicated GNSS test campaigns are planned. The first test activity will perform an analysis of the OSNMA availability, as well as identification of RFI along the selected paths. During the second activity J/S attacks will be conducted. Particularly critical cases are investigated, e.g., start of mission or shunting.

Any testing needs a reliable reference dataset to compare against (Ground Truth). A methodology for validating high-precision INS measurements, aided by RTK-GNSS and a wheel tachometer, again Eurobalise information, map data and route information recorded in SBB databases will be developed. Only where these independent data sources match, the Ground Truth is assumed to be valid and can be used for testing. In this way we can clearly attribute deviations between Ground Truth and test data to the measurement or algorithm errors.

7 Concluding Remarks

The activities in EGNSS MATE foster the use of GNSS- and map-supported onboard localisation algorithms within ERTMS/ETCS. The paper has provided information about the project context and the individual work packages. The insights and results of the project will aid in the implementation, GNSS testing, and certification ambitions in the railway stakeholder landscape.

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Sensor Fusion and GNSS Augmentation Services for Safe Train Positioning - Accuracy and Integrity Performance Evaluations

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Abstract. European rail actors are exploring innovative solutions for ETCS to improve the competitiveness of railway transportation services. One potential technology being studied is GNSS (Global Navigation Satellite System) and SBAS (Satellite Base Augmentation System), which can enhance safe train positioning and make it profitable for railways. However, the main challenge lies in providing safety demonstration to certify these new systems. Airbus D&S works on designing new EGNOS features for Rail aligned with rail safety-of-life application needs. The proposed solution, developed in CLUG's projects [3], involves using sensor fusion and integrity algorithms with GNSS and EGNOS based on extended Kalman filter called LOC-OB (LOCalisation On-Board unit). This combination allows real-time position and velocity determination with a high level of integrity required for rail Safety-of-Life operations. The focus of this study is evaluating how these new services impact LOC-OB's integrity performance by determining achievable safe Confidence Intervals (CIs). The paper presents performance predictions considering features offered by future EGNOS add-ons such as time correlations, satellite velocity corrections, clock drift corrections, and integrity indicators. Improved models and algorithms are implemented in Airbus' SALSA-for-Rail performance prediction tool. It demonstrates that time correlation significantly inflates estimated CIs and emphasizes the importance of accounting for this inflation in CI computation algorithm to ensure safety compliance.

Keywords: EGNSS (Galileo · EGNOS) · Train localization · Sensor fusion · Integrity performance · Railway safety · Time correlation

1 Sensor Fusion Localization for Trains

As previously stated in [1–3] and shown in Fig. 1, the proposed solution is based on multi-sensor fusion using measurements from a GNSS receiver producing safe and filtered GNSS raw measurement (no PVT), an inertial measurement unit (IMU) and a speed sensor (e.g. tachometer) with the support of a digital map of the rail multi-tracks.

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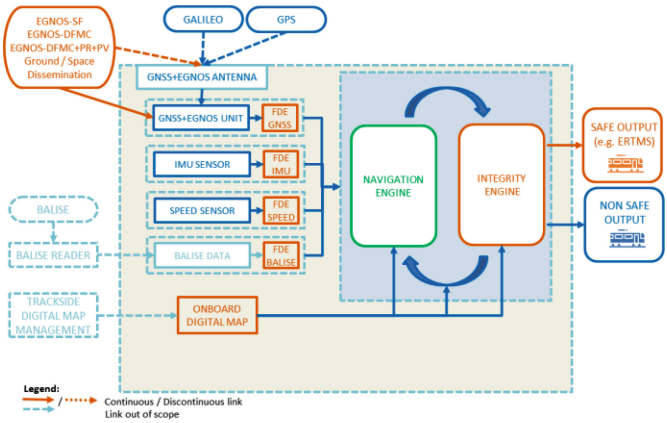

Fig. 1. Train Localization On-Board Unit functional diagram

The different sensors implement Fault Detection and Exclusion algorithms to remove faulty measurements, in particular the GNSS+EGNOS module, focusing on local environment impacts.

The multi-sensor fusion algorithm processes the safe and filtered measured data together with supporting information from the Digital Map to compute train localization: 1D along track position, speed, acceleration, direction and other 3D parameters not expected as safe; also, variances on position, velocity and acceleration are computed for internal integrity data computation.

The integrity function computes and guarantees the integrity of the LOC-OB 1D motion parameters, benefiting from the data FDE barriers at sensor and at system levels to compute the safe Confidence Intervals (CI) with respect to the required safety integrity levels (THR).

2 EGNSS Augmentation Services for Rail

Two new EGNOS services are foreseen for fulfilling railway needs: E4R-DFMC+PR[1] service based on EGNOS-DFMC flux in short-term [2026+], and E4R-DFMC+PR+PV[2] service for Rail based on a new EGNOS-DFMC+PR+PV flux in mid-term [2030+]. These rail-services are defined differently from aviation services, providing complementary integrity parameters at pseudo-range and range-rate levels.

In their current versions, SBAS SF and DFMC fluxes provide users with corrections on GNSS satellites orbits and clock with associated error covariance matrices, allowing the aviation users to compute safe position from corrected GNSS pseudo-range measurements and applying SBAS specified algorithms, and this assuming no RF harsh environment.

[1] Service for rail users based on EGNOS-DFMC flux + Pseudo Range commitments.

[2] Service for rail users based on EGNOS-DFMC flux + Pseudo Range and Pseudo Velocity commitments.

Safe GNSS-based velocity navigation solutions must be computed from pseudo-range measurements variation to ensure integrity. This results in wide confidence intervals as using pseudo-range variation instead of Doppler measurements to compute velocity is sub-optimal. The proposed enhanced evolution consists in, at SBAS system level, computing corrections and residual error covariances of GNSS Doppler measurements, i.e. velocity and clock drift, collected by the SBAS reference stations.

Velocity and clock drift corrections (i.e. range rate corrections) for each GNSS satellite with associated covariance matrices are then disseminated to users thanks to dedicated new SBAS message types in the EGNOS-DFMC+PR+PV flux, allowing optimal computation of the safe confidence interval of velocity.

Table 1 provides specific information about impacted parameter estimations for each GALILEO and GPS satellite at EKF level.

Table 1. Suggested integrity parameters of the upcoming rail EGNOS services

Safe estimations at user level (EKF outputs)	Integrity parameters
Position & CI	SBAS range error time correlation over-bounding model (correlation time, magnitude)
	Integrity Alerts on residual range Alert Limit
Speed & CI (only for EGNOS-DFMC + PR + PV)	SBAS Range Rate corrections (GNSS satellite velocity and clock drift corrections)
	Parameters of SBAS range rate error time correlation over-bounding model (correlation time, magnitude)
	Integrity Alerts on range rate Alert Limit

2.1 EGNOS Dual Frequency Multiple Constellation at Pseudo Range Level for Rail Safety-of-Life Service (E4R-DFMC + PR)

The proposed service, named E4R-DFMC+PR, is based on EGNOS-DFMC V3.2, and provides integrity parameter commitments only pseudo-range level, but not at range rate level. These parameters, defined as static values, are related to time correlation on SBAS range error and alerts on residual range (i.e. range after applying SBAS pseudo-range corrections). The E4R-DFMC+PR implementation doesn't require updates or modifications to the existing EGNOS system; however, official static values for these parameters would need to be defined and committed.

2.2 EGNOS DFMC at Pseudo Range and Pseudo Velocity Levels for Rail Safety-of-Life Service (E4R-DFMC + PR + PV)

The enhanced EGNOS for rail E4R-DFMC+PR+PV would be based on an additional EGNOS DFMC+PR+PV flux producing safe augmentation data, complementing the

EGNOS DFMC data. This DFMC+PR+PV flux would provide SBAS range-rate correction on top of the pseudorange corrections, with real-time values of the integrity parameters of Table 1, instead of the static and conservative values proposed in the E4R-DFMC+PR service.

To achieve this, new EGNOS algorithms would dynamically calculate these parameters, allowing for smaller CIs in position and speed estimates for any LOC-OB EGNSS-based solutions within any GNSS constellation geometry and environmental context. This algorithmic development is limited to the EGNOS Central Processing Facility (CPF) and can therefore be implemented in the mid-term future.

The transition from one EGNOS flux to another is facilitated by remote software up-grades within the EGNSS-based LOC-OB system, as it is expected that the on-board hardware equipment remains compatible with all services throughout its lifespan.

3 Temporal Correlation Impact on Confidence Interval

The approach adopted in this work to take account of time correlation in measurement error and confidence interval computed from EKF covariance predictions is derived from the method proposed in [4]. It consists in modeling the measurement errors with first-order Gauss-Markov processes (1GMP), to derive analytically the impact of such error into the EKF equations framework. Algebraic developments performed by the authors, involving 1GMP measurement error model into the EKF algorithm framework led to a modified analytical formulation of the EKF state error covariance posterior prediction that is used to compute the Confidence Interval. Such modified formulation is given by:

$$\begin{aligned}\widehat{\boldsymbol{P}}_{\boldsymbol{k}}^{+} = \boldsymbol{A_k}\widehat{\boldsymbol{P}}_{\boldsymbol{k}}^{-}\boldsymbol{A}_k^T + \boldsymbol{K_k}\boldsymbol{E}\left[\boldsymbol{w}_{m,k}\boldsymbol{w}_{m,k}^T\right]\boldsymbol{K}_k^T - \boldsymbol{A_k}\boldsymbol{\Phi_{k,k-1}}\boldsymbol{B_k}\boldsymbol{C}_{corr,k}^T\boldsymbol{K}_k^T \\ - \left[\boldsymbol{A_k}\boldsymbol{\Phi_{k,k-1}}\boldsymbol{B_k}\boldsymbol{C}_{corr,k}^T\boldsymbol{K}_k^T\right]^T\end{aligned} \tag{1}$$

where $\widehat{\boldsymbol{P}}_{\boldsymbol{k}}^{-}\Phi_{\boldsymbol{k},\boldsymbol{k}-1}\widehat{\boldsymbol{P}}_{\boldsymbol{k-1}}^{+}\Phi_{k,k-1}^{\mathrm{T}} + \boldsymbol{Q_k}$ is the prior predicted covariance, $\boldsymbol{A_k} = (1 - \boldsymbol{K_k}\boldsymbol{H}), \boldsymbol{Q_k} = \boldsymbol{E}\left[\boldsymbol{w}_{s,k}\boldsymbol{w}_{s,k}^T\right]$ is the system noise covariance, $\boldsymbol{\Phi_{k,k-1}}$ is the transition matrix, $\boldsymbol{K_k}$ is the Kalman gain, $\boldsymbol{w}_{m,k}$ is the measurement error at epoch k, modeled as a 1GMP $\boldsymbol{B_k} = \boldsymbol{E}[(\boldsymbol{x_{k-1}} - \boldsymbol{E}[\boldsymbol{x_{k-1}}])\boldsymbol{w^T}_{\boldsymbol{m,k-1}}]$ is an additional term derived from the correlation from previous estimates. The computation of this additional term is made recursively as

$$\boldsymbol{B_{k+1}} = \boldsymbol{A_k}\Phi_{\boldsymbol{k},\boldsymbol{k}-1}\boldsymbol{B_k}\boldsymbol{C}_k^T - \boldsymbol{K_k}\boldsymbol{E}\left[\boldsymbol{w}_{m,k-1}\boldsymbol{w}_{m,k-1}^T\right] \tag{2}$$

where $E[\boldsymbol{w}_{m,k}\boldsymbol{w}_{m,k}\boldsymbol{^T}] = \boldsymbol{C}_{\boldsymbol{corr,k}}^{E}[\boldsymbol{w}_{m,k-1}\mathbf{w}^{\mathbf{T}}{}_{m,k-1}]\boldsymbol{C}_{\boldsymbol{corr,k}}^{T} + \boldsymbol{S_k}\boldsymbol{R_k}\boldsymbol{S_k}^T$, $E[\boldsymbol{w}_{m,1}\boldsymbol{w}_{m,1}\boldsymbol{^T}] = \boldsymbol{R}_1, \boldsymbol{B}_1 = 0_{\boldsymbol{nx,nk}}$, where n_x is the size of the state vector and n_k is the number of observed measurements at epoch k.

From standard EKF equations, the Kalman gain is computed as

$$\boldsymbol{K_k} = \boldsymbol{P}_k^{-}\boldsymbol{H}_k^T\left(\boldsymbol{H}_k\boldsymbol{P}_k^{-}\boldsymbol{H}_k^T + \boldsymbol{R}_k\right)^{-1} \tag{3}$$

where $\boldsymbol{H}_k$ is the geometry matrix, and $\boldsymbol{R}_k$ is the measurement covariance matrix.

In the corrected state covariance Eq. (1), the two first terms correspond to the standard expression of the EKF. The two additional terms represent the time correlation impacts on the state covariance.

4 Performance Evaluations

4.1 SALSA-for-Rail (S4R) Prediction Tool for Performance Assessments

Performance predictions of the GNSS-based sensor fusion solution proposed for safe Rail navigation are assessed using S4R prediction tool. S4R is a software tool developed by Airbus to evaluate performance of safe train solutions, providing estimates of the achievable confidence interval values for a large representative set of user locations, dates, and environmental conditions (Fig. 2).

4.2 Safe Doppler Corrections Impact on Along Track Speed CI Predictions

For this study, only the GNSS was modeled (not the whole LOB-OB solution developed in CLUG projects), to better visualize the effect of the doppler corrections. Assessments have been performed using S4R tool integrating representative models regarding the addition of GNSS satellites orbito velocity and clock drift corrections and integrity parameters to the EGNOS DFMC data provided to the LOC-OB. To focus on the impact on CI resulting from the proposed orbito velocity and clock drift evolution, only augmented GNSS pseudorange and Doppler measurements are considered in the EKF navigation filter modeled in S4R. Figure 3 shows the maximum achievable half-CI as a function of the availability required by the mission. Curves labelled with "DFMC" provide results in the case of EGNOS DFMC system model (using delta-pseudo-range for train speed computation) while curves labelled with "ENHANCED" provide results in the case of the proposed enhanced model that includes orbito-velocity and clock drift corrections and supplementary integrity parameters offered in EGNOS DFMC+PR+PV flux. As expected, performances are significantly improved.

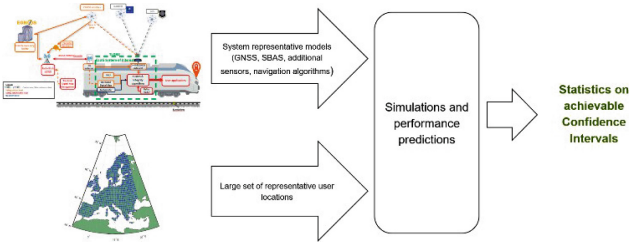

Fig. 2. SALSA-for-Rail prediction tool

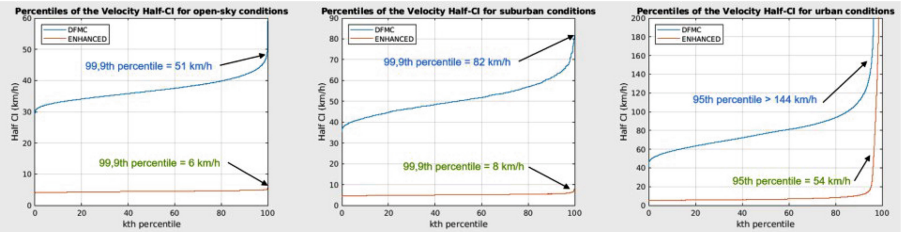

Fig. 3. Maximum achievable along track velocity half confidence interval as a function of the availability required by the mission, using GNSS augmented measurements only, with an integrity risk lower than 2.10^{-9}, for open sky, suburban, and urban modeled environments

4.3 Correlation Time Impact on Along Track Position CI's

Assessments have been performed using S4R tool with and without accounting for time correlation into the EGNOS-corrected pseudo-range residual errors. Results presented here are focused on Confidence Interval of the along-track position. The full model of the GNSS-based sensor fusion solution proposed for safe rail navigation is considered in the simulations, including representative models of measurement error for IMU and tachometer. As shown in the Fig. 4, impact of time correlation in the confidence interval computation appears clearly to be significant in all environment cases (open sky, sub-urban and urban), meaning that modeling such characteristics is mandatory to compute safe confidence intervals.

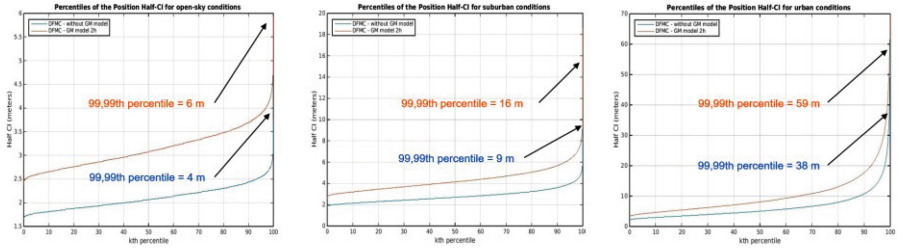

Fig. 4. Maximum achievable along track position half confidence interval as a function of the availability required by the mission with an integrity risk lower than 2.10^{-9}.

5 Conclusions

Results reported in this work confirm that the time correlation of SBAS-augmented GNSS pseudo-range residual error has a significant impact on integrity Confidence Intervals, meaning that time correlation modeling and enhanced confidence interval computation algorithms are mandatory for the future SBAS system to ensure safety. Moreover, the addition of orbito-velocity and clock drift corrections with integrity parameters into SBAS augmentation data should significantly improve performances of GNSS Doppler-based safe velocity/acceleration estimators.

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The RailHOF Platform: Supporting the Worldwide Rail Community in Developing Awareness and Competence in Human and Organizational Factors

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Abstract. The importance of human and organizational factors (HOF) is increasingly recognised in legislation such as the European Commission's 4th railway package which requires HOF to be integrated into railway company safety management systems using recognised expertise and methods from the human factors/ergonomics discipline. Apart from legislative requirements, applying HOF to the design, operation and maintenance of a transport system makes good business sense. A HOF-focused approach to design centres the design of systems around human capabilities and limitations, and this has benefits not only for safety, but also for efficiency, effectiveness, system reliability and quality of service.

However, despite these drivers, there is currently a relatively low application of HOF in practice, partly driven by a lack of available expertise and awareness. The RailHOF platform aims to address this by creating forums and content to engage with different target groups and improve the accessibility of HOF concepts and approaches. The platform has three primary elements: a LinkedIn group; a forum hosted by the International Union of Railways (UIC); and a website. This paper describes the HOF platform and how it aims to support the necessary growth in awareness and application of HOF in the rail and other transport sectors, with the aim of increasing the application of HOF so as to improve outcomes for safety, performance, and the reliability of the rail system.

Keywords: Rail safety · human performance · human and organisational factors · human-centred design

1 Human and Organizational Factors

Human and organizational factors (HOF) refer to all the influences on human performance within a system. The core discipline is ergonomics (or human factors (HF)) which is defined as 'the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applied theory,

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principles, data, and methods to design in order to optimize human well-being and overall system performance' [1]. The term 'human and organizational factors' has started to gain currency as the application of the ergonomics discipline with a particular focus on how the design and management of the organization influences human performance.

The benefits of applying an ergonomics/human factors approach are laid out in a report by the UK Chartered Institute of Ergonomics and Human Factors (CIEHF) and can be summarized as 'Applying ergonomics and human factors ensures that systems, products and services are designed to make them easier, safer and more effective for people to use' [2]. In the transport sector, there is a particular focus on safety and investigations into major transport accidents across all modes have consistently found that the ability of human operators to consistently and reliably carry out their allocated tasks can be a weak point in the system. While traditionally these may have been dismissed as 'human error', the human factors discipline is increasingly successful in reframing such incidents as a failure of the system design to adequately account for the human operators it relies upon. HOF takes a human-centered viewpoint to examine the interactions between humans and other elements of a system and how these elements can influence the way people behave. It focusses on the 'fit' between the people, equipment and environment.

2 HOF in Rail

HOF or HF have been applied for many decades in the aviation transport sector, but is a less well established discipline in rail. However, in recent years there has been a marked increase in research in the rail sector [3], covering topics from the introduction of automation to driving cabs [4], to fatigue risk management [5], or safety culture assessment [6] along with many others.

The inclusion of HOF in operational railway systems is firstly for safety reasons, and the requirements for the integration of HOF into rail operations is mandated in legislation in many countries. For example: the EU's Railway Safety Directive [7] states 'Through its processes, the safety management system should ensure that human capabilities and limitations and the influences on human performance are addressed by applying human factors knowledge and using recognized methods'. In Australia, the requirement for the integration of HOF principles "during the development, operation and maintenance of the safety management system… and into all relevant aspects of operational and business systems" is established within the Rail Safety National Law National Regulations [8]. Additional requirements on integrating HOF are contained in EU railway common safety methods that are mandatory in EU railways.

However, despite these promoters, there is currently a relatively low application of HOF in practice, partly driven by a lack of available expertise and awareness. The benefits that HOF can bring to optimizing the relationship between people and the rail system were potentially remaining unrealized as a result. The human factors groups at both the International Union of Railways (UIC) and the European Union Agency for Rail (ERA) recognized this gap and created the RailHOF platform to address this by creating forums and content to engage with different target groups and improve the accessibility of HOF concepts and approaches.

3 The RailHOF Platform

The platform has three primary elements:

- a LinkedIn group to spread general awareness and generate debate;
- a website to host content and provide direction on how to address different HOF topics.
- a forum hosted by the International Union of Railways (UIC) for experts to discuss and share information;

All three aspects are overseen and developed by a group of HOF Specialists drawn from the worldwide rail HOF community. The group are all HOF leaders within their organisations spanning regulators, research and standards organisations, and industry.

3.1 LinkedIn Group

The RailHOF presence on LinkedIn is aimed at raising the profile of HOF within a rail context, and encouraging discussion and debate on HOF topics across the industry. The group is moderated by the RailHOF editorial team. To date, the LinkedIn group has a membership of 785 and regularly posts on HOF topics generating comments and discussions in the HOF and rail community, and directing people towards the website for more detailed information on specific topics. https://www.linkedin.com/showcase/rail-hof/

3.2 RailHOF Website

The RailHOF website (www.railhof.org) creates a community environment for learning and sharing on HOF within a rail context. The website content provides general information on HOF and HOF news, as well as a series of detailed articles on different HOF topics. Each article aims to give a brief overview of the topic, explain its relevance to rail, describe approaches and models used in relation to that topic, and provide links to examples from different railways and relevant research papers. The topics cover four main areas:

1. how to apply HOF to enhance safety management, including topics on safety culture, HOF in change management, HOF in design, etc.
2. available HOF standards and tools, including topics on safety regulations, standards, human centred design, etc.
3. key topics in human performance, including non-technical skills, fatigue management, human error, workload, fitness for duty, etc. and
4. examples of applying HOF techniques in practice, including HOF in Signals Passed at Danger (SPAD), cab design, alarm design, etc.

The website (see Fig. 1) was launched in October 2022 at the International Railway Safety Council in Seville and has had a growing audience of visitors in the first 6 months of operation from across the globe. It also includes the ability for members to ‘share their experiences’ on how they apply HOF in practice, allowing other members to learn from best practices.

3.3 RailHOF Forum

A forum has been established through the UIC extranet site to facilitate discussion and knowledge-sharing by rail practitioners in a protected environment. The online forum enables registered members to ask questions related to HOF and start discussions across rail organisations. This element is expected to generate new topics and content related to member experiences which can be made more widely available through the website.

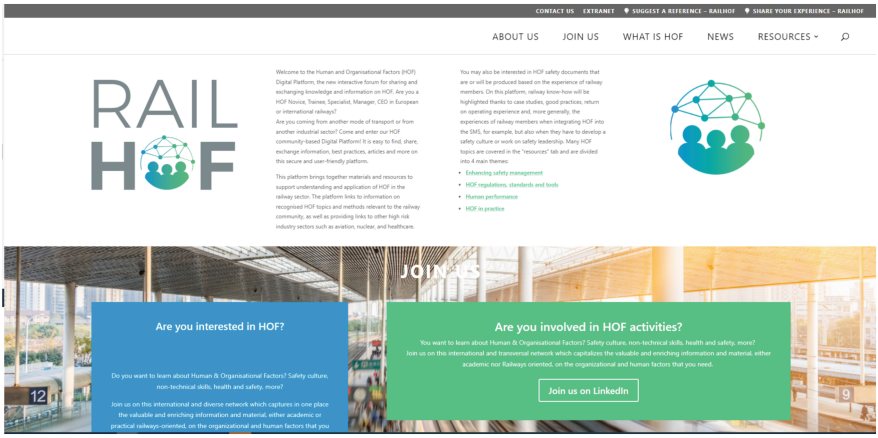

Fig. 1. RailHOF webpage

4 Conclusions

The RailHOF digital platform was developed to support the uptake and applications of HOF in the worldwide rail transport sector. A HOF-focused approach to design centers the design of systems around human capabilities and limitations, and this has benefits not only for safety, but also for efficiency, effectiveness, system reliability, and quality of service. By providing access to information, applied examples and an active community of HOF practitioners, the RailHOF digital platform aims to support the necessary growth in awareness and application of HOF in the rail and other transport sectors, with the aim of increasing the application of HOF so as to improve outcomes for safety, performance, and the reliability of the rail system. Early indications suggest it's track to achieving that as increasing numbers engage with the platform.

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Train Identification Using Distributed Acoustic Sensing

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Abstract. Over the past three decades, Distributed Acoustic Sensing (DAS) has garnered considerable attention, primarily due to its potential across a wide range of applications, especially in the railway industry. In particular, DAS has proven to be an effective tool for train tracking and the detection of anomalies in railway platforms and track structures.

In the present work, we explain how to use the DAS system in order to perform train classification. Our approach is based on the estimation of the bogie displacement frequency of the operating train which allows to estimate its car count which is an efficient parameter to identify the train's class.

To obtain such estimation, we employ a frequency analysis of the temporal signals collected by the DAS interrogator at various positions during a train's passage using Continuous Wavelet Transform (CWT). The performance of the proposed algorithm was tested using real data from measurements taken on the french rail network. These tests resulted in a great classification accuracy of around 96%, demonstrating the effectiveness of our approach.

Keywords: Distributed Acoustic Sensing (DAS) · Train classification · Optical fiber sensors · Track monitoring

1 Introduction

With the recent growth of the railway industry, new challenges have emerged, including the need to develop new real-time and cost-effective train tracking and monitoring systems. To address these challenges, several technologies and techniques have been proposed, including the Distributed Acoustic Sensing (DAS) system, which can be considered as one of the most attractive and promising solutions.

Distributed Acoustic Sensing (DAS) is a technology based on the Rayleigh backscattering effect that light undergoes as it propagates through optical fibers. As a laser pulse propagates through the fiber, it interacts with the microscopic

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imperfections and undergoes Rayleigh backscattering. The backscattered light is detected at the end of the fiber using a photodiode, which converts it into an electrical signal. When a vibration occurs near the fiber, the amplitude and phase of the backscattered light are affected. This information can then be analyzed to determine the location, frequency and magnitude of the vibration. This transforms the fiber into a virtual array of sensors that allows to characterize the properties of fiber's vicinity.

In the railway industry, DAS is usually performed using a long optic fiber cable that can be buried underground or installed overhead in cable channels parallel to the railway tracks. This makes it a low-cost and eco-friendly technology. In this context, the French National Railway Company (SNCF) aims to take advantage of the 25,000 km of fiber optic cable that run along its rail lines.

DAS has gained significant attention due to its potential for a wide range of applications, including pipeline monitoring, perimeter security, and railway monitoring. For the railway industry, many interesting applications have been achieved, including moving train tracking [7], train speed estimation [6], rail defect detection [1,4], and wheelset anomaly detection [5]. In this article, we want to go one step further by explaining how the DAS system can be used to achieve train classification. By this, we mean identifying the type of train moving on the track among a set of types known a priori. This task is of great importance because it allows a better understanding of traffic patterns on the track and more informed scheduling, maintenance, and traffic management decisions.

The structure of this paper is as follows. In Sect. 2, we start by detailing the data acquisition process. Next, in Sect. 3, we present the classification algorithm in detail. The performances of the algorithm are evaluated in Sect. 4. Finally, in Sect. 5, we highlight our main contributions and discuss some possible extensions of our work.

2 Data Acquisition

The signals acquired by the DAS system are spatio-temporal matrices. These signals correspond to the phase and amplitude of the backscattered light recorded at different positions of the fiber [3]. As we shall see later, to perform our classification approach, we will exclusively work with the amplitude signal (see Fig. 1).

In our study, data were collected between two SNCF train stations located in Paris, separated by a tunnel. The acquisition was performed at 3125 positions that were equally distributed along the tunnel (2.5 km), which corresponds to a spatial sampling period of 81 cm. For each recording position, the temporal sampling frequency is 1 kHz.

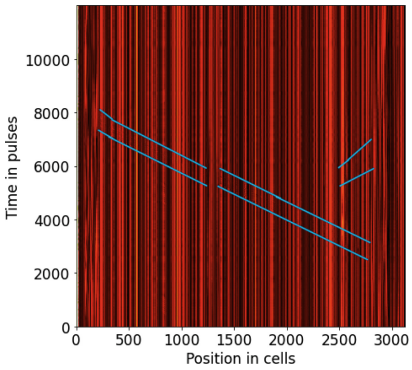

Fig. 1. An example of raw amplitude. The train's position is bordered by the blues lines.

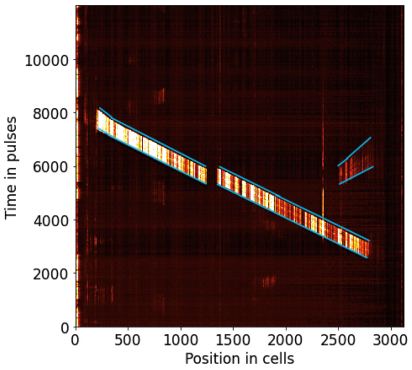

Fig. 2. Denoised amplitude signal.

3 Our Classification Approach

This section is devoted to describe our approach for performing train classification. The main idea is to estimate the number of bogies in the moving train using CWT analysis of recorded signals at different positions along the optical fiber. Naturally, we need to have access to the train's passage zone in the spatio-temporal matrix. This task has already been addressed in [2]. Therefore, we will assume that the passage zone is known for each train that we want to classify.

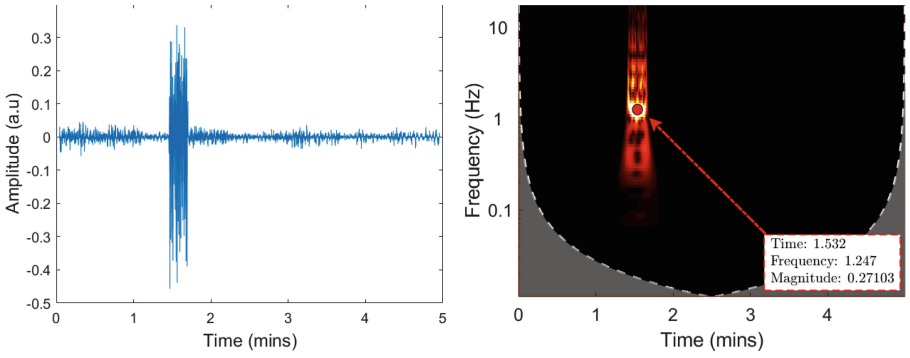

Fig. 3. Recorded temporal signal (left) and corresponding scalogram (right).

Our approach can be divided into four main steps. The first step consists in improving the signal quality using suitable filters. The second step is the standardization step, which is performed to normalize the noise level across different

positions. Next, in the third step, for each recording position, we perform CWT analysis on the temporal signal associated with that position to extract relevant parameters, such as the signal's frequency components and energy distribution. In Fig. 3, we display an illustrative example of a scalogram associated with the temporal signal recorded at a particular channel (i.e. reconding position). In particular, we can see that the CWT has a peak at 1.24 Hz, which corresponds to the frequency of displacement of two adjacent bogies.

Finally, for each recording position, we use the parameters determined in the previous step as input to a peak detection algorithm to estimate the number of cars of train. It may happen that the estimated number of peaks varies from one recording position to another. To address this, we perform a simple clustering algorithm to identify the most likely number of peaks which allows to identify the train.

4 Results

To evaluate the performance and reliability of our classification approach, we used it to classify the trains in a dataset of 35 real recordings (each recording is associated with one moving train on the rail), as detailed in Sect. 2. Each recording is 6 min long, and the trains in the dataset are either type NAT (9 bogies/train unit) or type Mi2N (10 bogies/train unit) , as shown in Fig. 4, which is known in advance. A NAT train unit has 8 cars, while a Mi2N train unit has 5 cars.

Fig. 4. Cross-sectional views of two types of trains MI2N (above) and the NAT (below).Source: http://www.mlgtraffic.net/SNCF_F_IdF_A.xml

Figure 5 shows the results of peak detection on five consecutive channels. The number of detected peaks is correlated with the number of cars in the rolling train. In this example, we considered two trains, one NAT and one Mi2N, each consisting of two units. The peaks at the edges of the signals, correspond to prepossessing artifacts. These outliers are considered in the clustering step.

The accuracy of our algorithm can be defined as the ratio of the number of correctly identified trains to the total number of trains considered. Using our classification approach, we obtained an accuracy of 96% using only the signal at a single recording position. When we combine the results obtained at multiple recording positions, the accuracy of our algorithm becomes 100%.

The results of this study are encouraging for the development of a train type identification system. In addition to the fact that this information is useful for

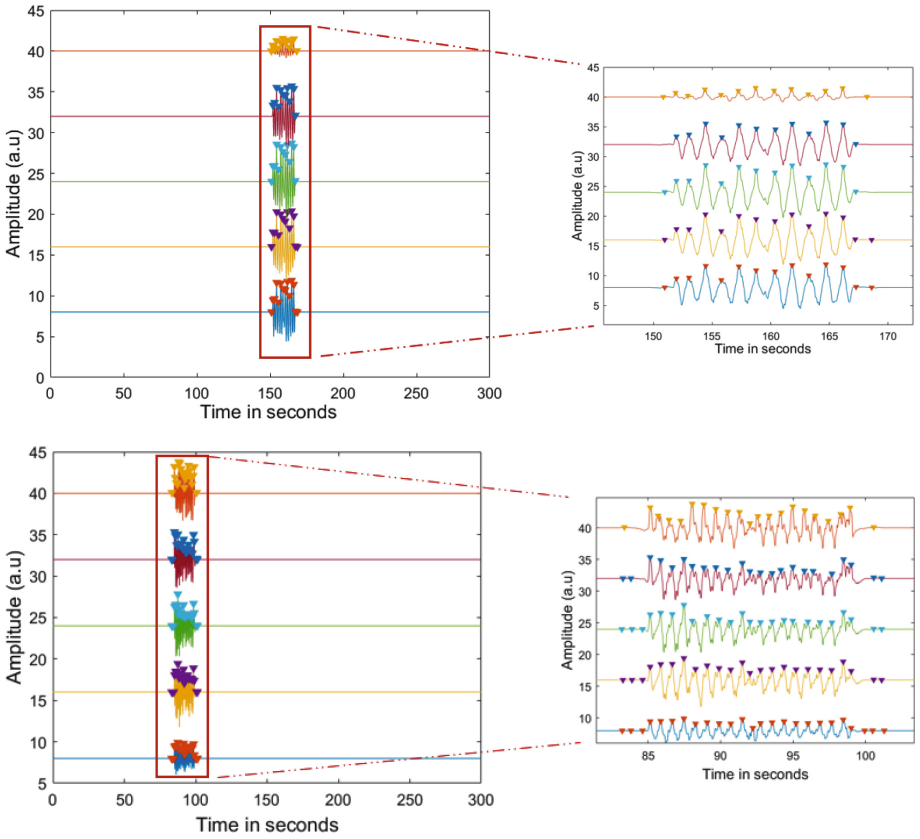

Fig. 5. Result of peak detection algorithm for a MI2N train (top) and a NAT train (bottom) applied to five successive positions (depicted on the left) of 300-second signals, with a focus on the train passage interval shown on (right).

traffic management systems, it can also be used to improve speed calculation and reduce tracking error. However, there are still some challenges to overcome before the system can be deployed in a real-world environment. For example, the system was tested in a tunnel, where the signal quality is relatively good. In a more noisy environment, such as an open track, the system may not be as efficient.

Additionally, the system was only tested on a limited number of train types. To improve the performance of the system, it is important to test it on a wider range of train types. Although the current work focuses on the amplitude signal, the state of the art shows that the differential phase signal [3] is also related to the vibrating target. In some positions, such as when a train passes over a rail defect, the differential phase signal can even be used to distinguish between train axles. However, the main challenge is fading noise, which completely degrades the signal in random positions. Therefore, it is necessary to use techniques to reduce

this noise before using the differential phase signal for train type identification. Another option is to combine the amplitude and phase signals, which could help to reduce the effects of noise and improve the accuracy of the algorithm.

5 Conclusion

In this article, we have shown a way of using DAS system to perform train classification. The efficiency and reliability of our algorithm have been confirmed using a real-world dataset. Several interesting extensions of this work are possible, including explaining how the DAS system can be used to estimate more relevant characteristics about the moving trains. This will likely require working with the phase signal instead of the amplitude signal.

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Irish Rail's Level Crossing Safety Programme: Our 25 Year Journey

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Abstract. Iarnród Éireann (IÉ) / Irish Rail's network is largely rural in nature and is characterised by a large quantity of level crossings. These assets do range in type but can be broadly characterised into two main groups; Attended and Unattended level crossings.

IÉ have a responsibility and legal duty to assess the risks at all level crossings. This aids with determining whether risk control measures are appropriate for a particular location. In this respect and in demonstrating how our transport systems are becoming increasingly digitalised, we will discuss the introduction of our Level Crossing Risk Model. This paper will outline how me manage our unique risks at each level crossing via our network wide level crossing risk model and how it facilitates calculation of our overall level crossing risk across the entire network. Linked to this, we will present data of how key metrices have continual declined at level crossing since the inception of our programme.

Thereafter, placing the user at the centre of our programme and proposed solutions, we conclude with an overview of our new Level Crossing Decision Support System (DSS) at User Worked Level Crossings. This remotely monitored and automated system was unique to Ireland at the time of its introduction. We will demonstrate how we are providing a system that automatically detects a train approaching a level crossing, informing the level crossing user of an approaching train, thus empowering the user to then take this information into account when deciding if it is safe to use the crossing.

Keywords: Level crossings · safety · risk · human interface

1 Introduction

The Irish Rail network is broadly radial in nature with main inter-city routes emanating from Dublin and, apart from double-track main routes to Cork, Belfast and within sub-urban areas, the network is extensively single line track. In 1999, an Irish Rail project team was established with a mandate to enhance safety through the upgrade or removal of level crossings across the network. At the outset of the Railway Safety Programme there were more than 2,500No. Level crossings across the network. These level crossings ranged in types but were generally broken down into two main groups – Attended and

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Unattended. At the time of authoring this paper, Irish Rail hold responsibility for the management and safety of 868No. Level crossings on the Irish railway network.

This paper presents the works that has been undertaken by the Company to help improve safety and reduce risks at these types of level crossings. Each level crossing type has its own unique protection arrangements and safety enhancements, but they all fundamentally rely on good user behaviour and compliance.

A breakdown of the four main types are as follows:

- **Type F:** User worked unattended field level crossing used primarily for agricultural purposes;
- **Type P:** User worked unattended pedestrian level crossing - for pedestrian use only;
- **Type O:** User worked unattended occupational level crossing primarily on a private road providing access to a private dwelling(s) or in a limited number of cases, a business premises;
- **Type OP:** User worked unattended occupational level crossing on a public road.

2 Irish Rails Approach

2.1 Background to Approach

In response to the on-going risk posed by this high-risk asset category, Irish Rail initially developed a level crossing asset strategy. This strategy had a key objective, of improving safety and reducing risk through an approach of a level crossing upgrade programme that included, elimination's, introduction of technologies, standardisation, education and enforcement [1, 2].

2.2 Stage 1: Key Principles

Principle 1 – Eliminations
The policy of Irish Rail is always to seek to close level crossings where possible and practicable. Thereafter, we seek to resist the introduction of new level crossings that cross our network. Once it becomes known that the land on both sides of a level crossing is no longer in common ownership, Irish Rail consult with Córas Iompair Éireann (CIÉ) Group Property Management and if their searches reveal split ownership, the level crossing should be closed. Where it is possible to reach an agreement with the level crossing User to close a level crossing, again, Irish Rail seek to close a level crossing.

Other alternatives to remove a user worked level crossing are upgrade to existing provisions. These upgrades include, replacement of the level crossing with an overbridge or underbridge and/or upgrading of the safety provisions via the automation and/or installation of CCTV type technology.

Principle 2 – Application of Developments in Technology and Safe Systems
One of the key drivers for change was that user-worked level crossings operate in a modern environment for which they were not. The first of these level crossings were constructed in or around the 1840's and were designed to prevent horses and livestock inadvertently escaping/entering onto the railway. Modern, faster and more frequent trains

are operating over live roadways, where the expectation is for the road user to operate the level crossing gates and where the only means currently, of alerting the user as to the presence of trains is their own visual check. Today these same level crossings are more commonly traversed by mechanically propelled vehicles, emergency services personnel, cyclists, pedestrians and animals.

Warning system technology has been advancing continuously over the last number of years and such solutions are being progressed at user-worked crossings in a number of railway administrations. Irish Rail is looking to build on the technological advances in this area through utilisation of such systems, adapted to the specific characteristics of our rail network. These technologies represent a cost-effective approach to of achieving significant risk reduction at a greater number of level crossings. This would otherwise only be achievable through costly capital investments required for level crossing closures or upgrades.

Principle 3 – Risk Based Prioritisation

Central to the overall strategy is ensuring that there is a clear understanding of the risks at each level crossing. Irish Rail operates a National Level Crossing Risk Model (LCRM) which, is a live tool evaluating the collective and individual risk at all level crossings on an on-going basis.

The LCRM is a tool used for the calculated ranking of collective and individual risk at level crossings. While the risk profile is constantly changing, the LCRM is a key tool in allowing the identification of any intolerable risks as well as any evolving negative trends. If an individual risk at a User Worked Unattended Level Crossing is presented as intolerable, then this requires an immediate intervention. For example, a temporary speed restriction may be introduced until the risk has been removed.

Principle 4 – Engagement and Enforcement

Communication on an on-going basis with the level crossing user is an important adopted principle. A selection of the engagement and enforcement programmes that we run, include:

Level Crossing Awareness

- Key actions and responsibilities now included in the new Government Road Safety Strategy 2022 -2030.
- An Garda Síochána appointment of dedicated community engagement Garda for each high-risk road/rail interface to co-ordinate public awareness.
- Irish Rail presentations to key stakeholders in the investigation and enforcement of level crossing incidents
- Continued communication with media streams to highlight road/rail safety.
- Development of a suite of documentation as shown in Fig. 1, that are distributed to users via a dedicated booklet drop approach [3–8].

Level Crossing Enforcement

- High level road/rail interface working group to discuss and develop interface issues and opportunities.
- Facilitate development of strategic actions

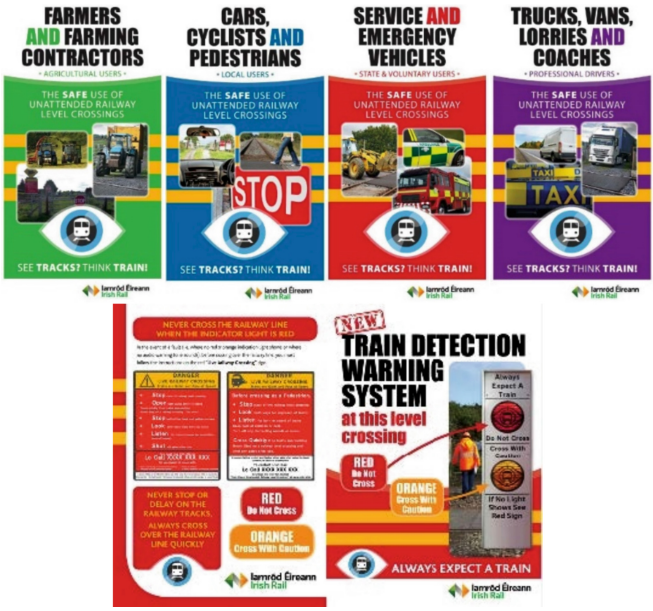

Fig. 1. Examples of user worked level crossing booklets on the correct use of the level crossing [3–8].

- Review trends on emerging issues
- Propose actions and implementation of such actions.
- Garda safety camera programme to conduct speed monitoring at a number of bad actor locations.
- Commissioning of a number of our Engineering Road fleet vehicles to have a special custom wrap applied.

Principle 5 - Standardisation

The complexity of the level crossing infrastructure along with diversity of current traffic demands such as heavily traffic roads and agricultural road users are factors are contributors to the high risk associated with level crossings. The principle of standardisation of our level crossing infrastructure is therefore important to develop and improve the overall interface for the level crossing user and to ensure this interface is fit for purpose and appropriate for the usage requirements [9, 10].

2.3 Stage 2: Five Key Strategic Areas

These principles gave rise to the following five key strategic areas, designed to provide a complete framework for the management of user-worked level crossings:

- To develop and implement technological solutions at user-worked level crossings.
- To implement targeted closures of level crossings on a cost-effective basis.
- To reduce the risk of collisions and near misses at level crossings.

- To improve the safety culture and awareness both of internal and external stakeholders.
- To implement standardised approaches to level crossing types.

Strategic Area 1 - Technological Solutions at User-Worked Level Crossings
A fundamental component of the strategy was the development of a warning system for user-worked level crossings on the network. These systems were to provide the level crossing user with an appropriate alert as to the approach of trains. This system must have fail-safe modes to further alert users that it is in degraded mode and advise the user on a safe course of action to take.

The overall principle of the project is the introduction of a low-cost technological solution. Irish Rail are currently working with Schweizer Electronic in the rollout of these low-cost solutions through their proprietary 'Vamos' Decision Support System (DSS). In conjunction with an audible warning the system operates a two-aspect colour light warning to level crossing users; orange to indicate that a train has not been detected and red to indicate that an approaching train has been detected. Thereafter, Irish Rail are installing two versions of this system, they include:

- Always On: In this configuration the indicator lights normally remain on.
- On Demand: In this configuration the indicator lights remain unlit until activated by the user, using an 'on demand' button.

Strategic Area 2 - Level Crossings Closures
Ultimately, the elimination of level crossings is always going to provide the highest return on safety and to the reduction of risk. As financial and engineering constraints often curtail major capital investments in the elimination of level crossings, through provision of new bridges, a comprehensive and detailed network review was undertaken with a view to identifying opportunities for low-cost level crossing elimination.

This can typically be through searches for split ownership of land entitling Irish Rail to close a level crossing, where low value property acquisitions can be made or where apparently disused level crossings can be formally closed. This is a potentially high value for a low-cost programme of work. The project involves the close liaison between the Infrastructure Manager entity of Irish Rail with the supporting Property and Legal services.

Since the commencement of the strategy, significant progress has been made in this initiative. In particular, with respect to field level crossings where low value closures have been achieved throughout the network. However, while this initiative will continue, it is anticipated that the rate of success will naturally decrease as all realistically achievable closures under this programme are achieved.

Strategic Area 3 - Risk Reduction Collisions and Near Misses
A number of serious collisions and near miss incidents have occurred on the network over the last number of years. These continue to occur, despite safety improvements made over the last number of years as well as continued level crossing closures resulting in a 59% reduction in this prime risk category since 2010.

Our Level Crossing Risk Model (LCRM) determined that train collision with vehicles at level crossings remains one of the single highest incident types on the network.

Consequently, they have been identified as those that contribute most to the overall risk on the Irish Rail network.

To counteract these serious incidents, a key component of the strategy is a risk reduction programme for collisions and near misses. A specific programme for this element focuses on the highest risk areas with the development of a bespoke risk management plan on a crossing-by-crossing basis.

The output of this then leads to a series of relevant actions and interventions determined as necessary on a specific crossing-by-crossing basis. These can typically include, road improvements, traffic calming measures, additional signage as well as targeting of specific users involved in any incidents with educational material.

Strategic Area 4 - Improvement of Safety Culture

A two strand approach is adopted under the strategy for the improvement of the safety culture at level crossings made up of engagement and enforcement. Engagement focuses on positive communication efforts with level crossing users and stakeholders.

Enforcement focuses on safety culture improvement through application of legal means. A targeted and proactive surveillance campaign, with a view to successfully obtaining prosecutions for abusers of level crossings, is carried out at those crossings where the level of abuse warrants this. The programme is carried out in line with all legal requirements such as data protection laws.

Strategic Area 5 - Standardisation of Level Crossings

Standardisation of level crossing types provides a more consistent interface for the level crossing user. Currently, that interface can be varied and so improvements in basic level crossing infrastructure at user-worked level crossings can greatly enhance the interface. Furthermore, these improvements can be achieved at relatively low-cost.

The typical works involved include:

Installation of standardised warning signage.

Provision of an adequate road surface to and from the level crossing as well as over the level crossing,

Phe provision of adequate road markings.

Vegetation clearance to afford the user an adequate view of oncoming trains and general enhancements to the interface for the road user.

3 Conclusions

Key to the achievement of the strategic objectives is to have meaningful work programmes associated with each objective with appropriate success 'measurable'. These have been established and are monitored on an on-going basis.

The overall day-to-day implementation of the strategy is carried out within the framework of the level crossings asset plan which is an annual programme identifying the detailed work programmes in a given year. The purpose of the asset plan is to identify the safety, reliability, availability and maintainability issues that currently or will have a future impact on level crossing safety, and to develop strategies for each issue identified, with an accompanying programme of actions to ensure asset performance levels are

maintained or exceeded including in line with the objectives and works associated with the level crossing asset strategy.

The overall measure of success of the strategy will continue to be the cumulative reduction of level crossing risk on the network.

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A Methodology of Elicitation of Safety Requirements of Artificial Intelligence Based Functions in Railways

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Abstract. In the recent progress towards autonomous trains, the Automated Driving System (ADS) provides the so-called perception units. These components implement Artificial Intelligence (AI) modules for the assessment of events and their relevance around the system to ensure the situational awareness. This raises many challenges concerning the level of safety (globally at least equivalent to the level of the existing system with a human operator) and the means to achieve it for safety-critical transportation. Our work aims to clear the pathway of AI systems performances meeting the safety-related requirements of autonomous train. In this paper, we propose a methodology of elicitation of safety requirements from system level to AI model level taking into consideration a use case related to the perception function: monitoring of Level Crossing (LX) failure.

Keywords: Railways · Autonomous trains · Safety · Artificial Intelligence · perception

1 Introduction

The deployment of autonomous trains, in open environment, raises many questions and challenges, particularly those concerning the level of safety and the means to be implemented to achieve it. Autonomous driving is mainly based on perception functions referring to the ability to collect data from the environment, extract contextual knowledge and classify it by their semantic meanings to understand a situation such as the presence of an obstacle in front of the train. Perception systems are crucial because they hold the responsibility of providing reliable information to the train control system for the Grade of Automation 4 (GoA4) operation. Based on data collected from one or a combination of sensors, AI and particularly Machine Learning (ML) includes powerful methods and models to analyze the environment and act in perception systems to predict useful information for the driving. We have seen numerous contributions from motion tracking, failure or intrusion and obstacle detection that could have a

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great impact on safety of train operations. Challenges to tackle for the environment monitoring are various: weather conditions, long range vision, real-time analysis, unexpected disruptions, or perturbations that are well known weaknesses of AI models.

These add more uncertainties to the system safety assurance process with the introduction of ML in the development of safety-critical systems [4]: Uncertainties in the specification, technical uncertainties due to robustness and generalization issues, uncertainties in the safety assurance. For these reasons, a new methodology for safety assurance shall be proposed to deal with the new challenges by defining what is required for the ML based components in the railways to be safe.

This paper aims to clear the way from system level to the ML model level requirements of a perception system. Based on newly state-of-the-art papers of safety requirements in the field of autonomous cars, we expose the ML function requirements to build up an ML model that answers the specific use-case of detecting open barriers of level crossings.

2 Safety Requirements of Perception Functions

The consequence of a crash at a LX is often death or a serious injury. Among all the reasons that made an accident possible, many can concern the lack of signaling or the barrier failure to close properly as the train passes. In this study, we choose to only work on an onboard system of perception that detects LX with open barriers and hence prevents from future accidents. A ML-based algorithm is developed to detect open and close barriers in front of autonomous train and evaluated regarding the safety requirements in Sect. 2. If a LX is detected as open, actions to be taken are an emergency braking and upstream information to the supervisory system.

The performed safety analysis objective consists in eliciting the safety requirements from system level to ML level. Following the Guidance on the assurance of machine learning in autonomous systems (AMLAS) process [3], the ML safety requirements are then refined in this present into performance requirements and robustness requirements which shall be then refined into data management, model learning, model verification and model deployment requirements.

2.1 System Safety Requirements

The preliminary risk analysis resulted in safety requirements as mitigations to cover the identified hazards at system level. We have identified the requirements, including quantitative safety target in terms of tolerable hazard rate related to the environment monitoring function that includes the LX monitoring.

– **SYS_REQ_1**: In GoA3 and GoA4 mode, the ADS-OB must detect the following anomalies when crossing protected LX: failure to close, absence of barriers, damaged barrier, and apply driver regulations.
Where ADS-OB is the onboard automated driving system.

– **SYS_REQ_2**: The tolerable hazard rate (THR) corresponding to the undesirable event in GoA3 and GoA4 mode: the ADS-OB does not detect failure to close or absence of barrier or damaged barrier when crossing protected LX is estimated to 10^{-6} per hour.

2.2 Safety Requirements Allocated to ML Components

Based on the Failure Mode and Effect Critical Analysis (FMECA), the hazard that has been identified and shall be mitigated is related to misdetection or late detection of LX anomalies: failure to close, absence of barrier, and damaged barrier. To mitigate the hazard of LX failure misdetection, a list of mitigations is specified as ML based component safety requirements as examples:

– **SYS_ML_REQ1**: The environment monitoring module shall safely activate the detection, identification and classification of the state of the LX by approaching each LX.
– **SYS_ML_REQ2**: The ML algorithm shall perform the classification with a sufficient level of performance.
– **SYS_ML_REQ3**: The Tolerable Functional Failure Rate (TFFR) of LX monitoring function is estimated to 10^{-6} per hour.

2.3 AI/ML Safety Requirements

The requirements derived from the FMECA are refined at ML level corresponding to requirements for the process of developing a ML algorithm and performance indicators according to the AMLAS methodology.

Performance requirements

From the requirements $SYS_ML_REQ1...3$, the performance requirements are specified in terms of quantitative targets for the LX monitoring component:

– **SYS_PER_REQ1**: The LX monitoring system shall detect the status of LX with confidence level of $x\%$ at least when the LX is 120 m maximum away from the camera on the train, which corresponds to 450 pixels. This level of confidence $x\%$ shall be chosen according to the targeted false positive and false negative rate. The tested system of LX monitoring performed a classification of open/closed LX with a confidence level of 80% with a train velocity of maximum 90km/h corresponding to processing more images, and a confidence level of 60% between 90 and 140 km/h.
– **SYS_PER_REQ2**: The false negative rate shall not exceed 12 images per 1.08×10^{11} within a distance not exceeding 120 m or 450 pixels at 140 km/h.
– **SYS_PER_REQ3**: In a sequence of 12 consecutive processed frames, a LX at distance of max 120 m is classified as open if it is detected as open in at least one frame, otherwise it is classified as closed.

– **SYS_PER_REQ4**: The LX monitoring component shall allow an inference speed of 30 FPS (frame per second) corresponding to 33 ms maximum of inference time.

Note that the false positive rate shall also be specified. This can be derived from operational availability rate and translate it into false positive rate. In fact, a false positive means that the LX monitoring system detect a failed LX when it is not i.e., LX open instead of closed or no LX. This will result in slowing down the railway traffic and longer travel time. It is also strongly related to the choice of Out Of Distribution or negative examples data and their quantity, and the Intersection Over Union IoU value.

Robustness requirements

ML robustness represents the models ability to perform well when the inputs encountered are different but similar to those present in the training data, covering both environmental uncertainties, e.g. flooded tracks, and system-level variability, e.g. sensor failure. Therefore, the system shall automatically detect when it is not working properly according the Operational Design Domain defined as follows:

Environmental conditions: time (day, night), climate (snow, rain, fog, sun)

Operational constraints: speed variations (30, 60, 90, 120, 140 km/h)

Objects: LX open, LX closed

The following requirements represent what is required for the ML model to be robust:

– **SYS_ROB_REQ1**: The ML component shall handle environmental factors (rain, fog, snow, day, night) affecting the vision of the camera and convey error codes if the vision is impaired or obstructed.
– **SYS_ROB_REQ2**: The operation of the system shall not be critically affected by time of day even during night hours. The ML model shall perform within specified parameters regardless of time of day and lighting conditions.
– **SYS_ROB_REQ3**: The ML component shall detect and identify the status of the LX (open/close) irrespective of the length, type, angle around the vertical axis, angle with respect to the track.
– **SYS_ROB_REQ4**: The LX monitoring component shall perform as required in all situations under system variability e.g., sensors failure: the ML component must detect if the camera is malfunctioning and convey an error code.
– **SYS_ROB_REQ5**: The ML shall detect an obstruction of more than 40% of the concerned object when the image consists of the same or similar pixel values (or black).

3 Implementation of the ML Function

We use a state-of-the-art deep neural network to process input RGB images to predict presence, localization and state of barriers as a testing model to test

the safety requirements related to performance and robustness. We built up a database from real-world acquisitions from a prototype of a regional train by collecting and annotating data of a wide range of situations, see Fig. 2.

3.1 Neural Network Implementation

Among all the available literature of object detectors, we implement a method based on Fully Connected Neural Network (FCNN) named YOLO version PaddlePaddle (PP-YOLO) because it has the advantage of improving the accuracy of the detector compared to 2022 state-of-the-art object detectors while ensuring that the processing speed is almost unchanged.

The presentation of the neural network and its different layers is shown in [2]. We implemented this neural network architecture with hyperparameters tuned for the dataset of LX barriers.

		Event-level performance	
		Prediction	
		Positive	Negative
Ground-truth	Positive	True Positive	False Negative
		7	1
	Negative	False Positive	True Negative
		11	189

Sensitivity (recall)	0,875
Specificity	0,945
Precision	0,389
Negative prediction	0,005
Accuracy	0,942
F1-score	0,538

		Frame-level performance	
		Prediction	
		Positive	Negative
Ground-truth	Positive	True Positive	False Negative
		75	47
	Negative	False Positive	True Negative
		321	2835

Sensitivity (recall)	0,615
Specificity	0,898
Precision	0,189
Negative prediction	0,016
Accuracy	0,888
F1-score	0,290

Fig. 1. Quantitative performances of LX barriers detection in open positions.

3.2 Experimental Results

We experimentally tested the algorithm on edge servers composed of graphic processors implemented on the prototype of autonomous train by blocking and guarding LX with open and closed barriers. Then we analyse test results and deployment performances using usual metrics of object detection algorithms [1].

The analysis of the performance of an algorithm using the confusion matrix in Fig. 1 focuses in 2 parts: **Event-level** (overall performance on a sequence) or **Frame-level** (performance calculated per image analysed). Event-level answers the question "When an object is present, is it detected at least once in order to correctly execute the expected train reaction?". Frame-level performance answers the question "Out of a number of images containing a LX barrier, how many were used to detect the barrier?". On-site performances of ML should also be considered in database and model development requirements.

The following metrics were used to describe the deployment of the perception system:

- The rate of continuous detection for each class is 0.71% of detections on successive frames until the state of misdetection.
- The computation speed needed for the analysis of 1 frame is 38 ms with a standard deviation of 0.05 ms, and the total average time elapsed between taking the image and sending the detection to other subsystems of the autonomous train: 38.6 ms with a standard deviation of 0.06 ms.
- Of the 8 analyses of LX with at least one barrier open, the average distance of first detection of the barrier is 115.7 m in longitudinal distance and its standard deviation is 6.59 m.

Prediction visualisations on input images are represented by bounding boxes and labels names in Fig. 2.

Fig. 2. Predictions examples from images, owned by Railenium. **Left** Example of true positive detection of open barrier under heavy rain conditions. **Right** Example of true positive detections of 2 close barriers of LX.

4 Conclusion

We conducted experimental tests of a state-of-the-art ML algorithm applied for the detection of open and close barriers of LX. Results implemented on the prototype could comply with many safety requirements that we propose in this paper to ensure safety level by setting performance and robustness requirements upon the ML algorithm. These safety requirements give some hints on how to design a neural network based ML algorithm and how to evaluate the ML system in the context of autonomous trains.

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Analysis of the Effects of Cascading Events Due to Safety and Security in Port Areas

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Abstract. Ports, intended as critical infrastructures, are ever more exposed to safety and security issues due to several reasons, including also international situation, globalization, and climate change. The purpose of the paper is to underline the importance of considering disruptions that safety and security events can introduce in ports, analyzing the "cascade effect" that a single event could introduce in the logistic network. The objective of the paper is to carry out a theoretical analysis of the benefits induced by the sharing of risk management plans towards the resilience of ports to adverse events in terms of safety and security, and consequently identify new best practices in the port security assessment methods.

Keywords: Logistics · safety · security · cascade effect · risk · sharing

1 Introduction

In the last decades, the importance of ports as logistics hubs has become increasingly higher; ports are not intended only as infrastructural assets but also as central logistics platforms in which efficiency and optimization of operations play a key role.

The world seaborne trade continues to grow, mainly because of the global economic interdependency that the world has faced after globalisation. In this scenario, all port's stakeholders are considered part of a holistic system in which everyone has its own scope. Seaport's stakeholders interact in different risk scenarios, with each seaport having a unique network's structure. These networks reflect the complex operations that are carried out at seaports and play an important role in the knowledge transfer among organizations and entities.

In the last thirty years, and foremostly after the terrorist attacks of September 11, 2001, International Maritime Organization (IMO) started to reimagine the concept of maritime security in a wider way, including port facilities and physical logistic platforms in the vulnerable critical assets. In response to the security threats, IMO has set up new guidelines entered in force under SOLAS (Safety of Life at Sea) chapter XI-2, on 1 July

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2004, known as International Ship and Port Facility Security Code (ISPS Code); this new regulation immediately became the basis for a comprehensive and mandatory security regime for international shipping and for the security management of port's facilities. ISPS Code has been designed with a risk-based approach; this means that companies and competent authorities identify the potential risks to which they are exposed, and consequently they develop strategies to mitigate them, in accordance with the level of risk.

This paper aims to focus on the process of port's facility security risk assessment methods, in order to highline the importance of the cascade effect and the role of complex interactions among port's stakeholders in the vulnerability assessment. This document is part of a wider work conducted in the Ports of Genoa, and it's intended to be a theoretical modelling to define the priorities in the security processes' re-engineering and in the establishing of mitigation actions to put in practice to reduce the effects of bad events in ports. In the first part, notions related to risk management are outlined, with a focus of port safety and security risk assessment; the second part is dedicated to the definition of a dependency risk scenario in which all port's stakeholders collaborate to reduce the impact of risks they have in common; finally, the last part gives a brief overview on the centrality measures of graphs in order to define a new collaborative common damage - based risk management method.

2 Background

2.1 Notions Related to Risk Management in Port Areas

Definition of "risk" depends on the field application, but in port operations case study, risk is an indicator of the possibility that a natural or anthropic phenomenon could cause damage to port's infrastructure and road network, environment and individuals. Depending on the type of activity, situation, and consequence, risk groups can further be distributed in different categories, including operational, technical, organizational, and environmental; networks-of-networks are inherently more fragile than isolated ones, so that identifying and understanding interdependencies is one of the biggest challenges in analyzing the complex infrastructures on which traditional systems rely. Related to the purpose of this work, the following formula for risk calculation has been used [1]:

$$R = PxM \tag{1}$$

where R is the risk, P is the probability of occurrence of a hazard in port area, and M is the magnitude value that measures the severity of its consequences.

The "risk management" is the process of handling the risk and to mitigate the consequences of the events that could occur in ports, acting on the lowering of the probability of occurrence or minimizing the effects of those events on port assets, as defined.

A step of risk management is the "risk assessment," as a crucial activity of the process aimed at providing a set of data and information of potential hazard, estimating the vulnerability of the system and developing a proper countermeasure to reduce at minimum the risk that those hazards involve.

2.2 Literary Review of Risk-Based Ports Risk Assessment

Seaports are often located in densely populated areas, with operational activities i.e., loading and unloading of dangerous goods conducted in close vicinity to vulnerable and city areas. There are over 2,5 million TEUs containers passing through in the Port of Genoa [2], the site in which this research activity is conducted, and among them also dangerous goods. The outcome of the assessment is the final result of a qualitative and quantitative analysis that could be done following several methodologies, but the main principles are [1]: identifying the assets and the critical infrastructure that could be potentially object of hazards or threats, estimating the likelihood that these hazards or threats can cause bad events (in order to establish prioritization of actions), evaluating the possible consequences and designing a mitigation strategy to reduce the risk that the hazard or threat could happen again in the future. This approach is named "risk-based decision-making model," and it is the one that was used in the designing of International Ship and Port Facility Security (ISPS) Code (Chapter XI-2 of SOLAS).

3 Methodology

3.1 Beyond the Risk-Based Port Risk Assessment: The Common Damage Risk-Based Approach

As seen in the previous paragraph, the port risk assessments are commonly based on a risk-based approach, following the principle that each port facility or stakeholder has its own exposure to risk. This concept implies that each stakeholder must design a specific Port Facility Risk Assessment (or Port Facility Security Assessment) based on its exposure to risk, without considering the indirect exposure that a port's facility could have in regard to another risk that it's not peculiar.

Considering a list of port's actors, such as: terminal operators, ship repair companies, passenger terminal, etc. it's possible to combine all risks associated to them, for example based on security issues, safety hazards, terroristic attacks, natural disasters, economic losses, etc. The results of the association could be filled in a matrix as the following, considering a generic list of n stakeholders and s risks associated to them:

where R_{X,St_n} stands for the risk that a hazard "X" ($X = \{A, B, C, \ldots, s\}$) could impact on the generic stakeholder n, , calculated on the basis of the guidelines provided by CISM (Comitato Interministeriale per la Sicurezza dei Trasporti Marittimi e dei Porti) [3]. R_{X,St_n} is an important quantitative measure for each stakeholder to identify mitigation actions to reduce its own exposure to risk, but traditionally it's not correlated to other stakeholders. The principle of "common damage risk-based approach" implies the inversion of the described matrix, defining risk as a primary key, and consequently to associate a list of port's stakeholders that share the risk they have in common. In this scenario, it's necessary to read vertically the matrix finding the correlations between R_{s,St_y}, being $y = \{1, 2, 3, \ldots, n\}$ the set of stakeholders that share the exposure to a determined hazard s.

	Hazard A	Hazard B	Hazard C	...	Hazard s
Stake-holder 1	$R_{A,St1}$	$R_{B,St1}$	$R_{C,St1}$	...	$R_{s,St1}$
Stake-holder 2	$R_{A,St2}$	$R_{B,St2}$	$R_{C,St2}$	...	$R_{s,St2}$
Stake-holder 3	$R_{A,St3}$	$R_{B,St3}$	$R_{C,St3}$	...	$R_{s,St3}$
...	...	...	...	...	...
Stake-holder n	$R_{A,Stn}$	$R_{B,Stn}$	$R_{C,Stn}$	...	$R_{s,Stn}$

Fig. 1. Basic stakeholder – hazard risk matrix

3.2 Impacts of Cascade Effects on Logistic Chains

"Cascade effect", or "domino effect", has not a unique definition, but for the purpose of this work it can be defined as the propagation phenomenon of a hazard to a port asset, that could become the enabling event of a sequence of damages to other port assets [4, 6]. The paper aims at establishing the importance of the analysis of the cascade effect in port's risk assessment, since the literature review of risk assessment methods typically lacks in a quantitative algorithm in this fields. However, the field experience shows how important is to establish connections between different port's actors, in order to create new synergies aimed at providing an innovative risk management model.

Considering the system discussed before and taking into account a qualitative analysis based on the infrastructure manager experience, it is possible to identify the dependency risk chain among different stakeholders, due to a specific hazard. These links could be transformed into a dependency risk graph $G = (St, D)$ where St is the set of interested stakeholders and D the number of dependencies between them. In the adjacence matrix of the graph, called *dependency risk matrix*, $R_{St_{i,j}}$ is not zero if there is a correlation between Stakeholder i and Stakeholder j for a determined hazard, so $R_{St_{i,j}} = \{0,1\}$.

For the purpose of this paper, it's assumed that P_{Y,St_i}, $i = \{1, \ldots, n\}$, is the probability of occurrence of an hazard "Y" on stakeholder i, being $i = \{1, \ldots, n\}$ a set of n interconnected stakeholders, and it's one of the element of Eq. (1); the magnitude of the hazard, for our purpose, it's considered to be invariant if an hazard is due to a generating or cascading event. In this scenario, a domino effect relationship between two consecutive stakeholders in a dependency risk chain implies that:

$$P_{Y,St_{i+1}} = f(P_{Y,St_i}) \tag{3}$$

The frequency that a secondary event is generated from an enabling event could be assessed as follows [4]:

$$P_{Y,St_{i+1}} = P_{Y,St_i} * P_{de,Y_{St_i \to St_{i+1}}} \tag{4}$$

So, the probability that a secondary event is generated is expressed as the probability that the originating event occurs multiplied per the probability that the domino

	Stake-holder 1	**Stake-holder 2**	**Stake-holder 3**	**…**	**Stake-holder n**
Stake-holder 1	0	$R_{St_{1,2}}$	$R_{St_{1,3}}$	…	$R_{St_{1,n}}$
Stake-holder 2	$R_{St_{2,1}}$	0	$R_{St_{2,3}}$	…	$R_{St_{2,n}}$
Stake-holder 3	$R_{St_{3,1}}$	$R_{St_{3,2}}$	0	…	$R_{St_{3,n}}$
…	…	…	…	…	…
Stake-holder n	$R_{St_{n,1}}$	$R_{St_{n,2}}$	$R_{St_{n,3}}$	…	0

Fig. 2. Dependency risk matrix

effect happens ($P_{de,Y_{St_i \to St_{i+1}}}$). So, taking into account n interconnected set of stakeholders $St_1, St_2, St_3, \ldots, St_n$, the following formula calculates the probability of n-order cascading effect [5]:

$$P_{Y,St_n} = \prod_{i=0}^{n-1} P_{Y,St_i}, P_{Y,St_{i+1}} \tag{5}$$

In detail, this equation calculates the probability that, in a dependency risk chain, a Stakeholder St_n is affected by a domino effect from an originating event due to hazard Y that affects the previous actors in the risk chain: $St_1, St_2, St_3, \ldots, St_{n-1}$.

The probability found through Eq. (5) depends on the specific risk assessment techniques calibrated on the specific system object of analysis, and it's based on the background experience of the infrastructure manager; the relationships among stakeholders could be found on the basis of a dependency risk matrix, as defined in Fig. 2.

In order to understand the most relevant node of the graph, meaning the most important stakeholder on which concentrate the mitigation strategy, and consequently to reduce the impacts of a domino effect in a risk dependency chain, centrality measures techniques related to network analysis could be used. For the purpose of port risk mitigation, closeness centrality indicator, defined as the average shortest path between the examined node and any other node in the graph, appears to be the optimal technique to determine the most relevant node in the graph [5]. In the case of a dependency risk graph, nodes with high closeness tend to be part of many dependencies chain and, in many cases, they could even initiate dependency chains. The closeness could be computed not for all nodes but for the subset of the most important initiator nodes; for example, the ones with high outbound degree centrality are likely to participate in multiple dependency risk chains [5]. In addition, it is recommended to first identify the subset of the most relevant nodes for cascading failures and then calculate the closeness of all other nodes relative to this subset as a secondary criterion for mitigation actions.

4 Conclusion

The methodology presented in this document have demonstrated the need of a paradigm shift in the risk management policies of port actors, concentrated in the individual mitigation strategies to lower the consequences of a hazard inside a port's facility.

From the Port Authority point of view, this work aimed at outlining the lack of the actual risk assessment processes in the field of mitigation strategies to reduce the risk of occurring of a secondary event generated by a primary event. To do that, creating new synergies between stakeholders is necessary to collaborate on a new risk assessment process, based on a specific hazard, and considering all the relationships between port's actors in terms of domino effect. As anticipated in the introduction, this work has to be considered as a theoretical explanation of the benefit of considering cascading effects in port security management processes, and it has the purpose to give a framework to this concept. Further analysis will be conducted in the Ports of Genoa, where this methodology is object of development from the theoretical and practical point of view. As discussed in the second part of the paper, the inverted reading of the risk matrix (Fig. 1) could be used as a useful tool to evaluate if there are any probability relationships of events between stakeholders that share the same exposure to risk. An additional way to determine dependency risk chains among stakeholders is to fill the dependency risk matrix for a specific hazard, as the dependency risk matrix allows (Fig. 2). After this, the probability that, in a dependency risk chain, a stakeholder is affected by a domino effect from an originating event due to a hazard that affects the previous stakeholders in the dependency risk chain is calculated (Eq. 5).

The proposed work shows that the discussion is open for what concern the measuring techniques to evaluate the importance of a stakeholder in a network, and consequently how to determine prioritization in mitigation actions to be put in practice. This study focuses on the closeness centrality theory to establish the most important nodes of the network, but many other studies can be carried out in order to improve the scientific capability to individuate the most effective risk mitigation strategies in a complex interconnected port network system.

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Maintenance and Safety of the Road Infrastructure by a New Robotised System for Pothole Repair

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Abstract. The essential needs to maintain the integrity, performance, and safety of road infrastructures have been tackled in InfraROB, a research project funded by the EU research programme Horizon 2020 that aims to reach that objective through autonomous robotised solutions. A specific task of the project is the development of a 3D printer able to extrude a mixture for filling in small potholes. The printer is integrated into a small carrier that can autonomously reach the pothole while the operator remains in a safe roadside area. The study about the mixture was focused on material that, immediately after the laying, can be compacted by the wheels of the maintenance vehicle itself and later by the traffic vehicles. The development of the novel system, and its integration into an autonomous carrier was divided into four different phases: i) definition of the constraints due to the autonomous carrier; ii) definition of the parameters of the 3D printer system and repairing mixture; iii) design and construction of the 3D printer, and iv) system integration with the autonomous carrier. The final choice led to a mixture composed of 100% Reclaimed Asphalt Pavement and rejuvenator to be extruded through a head complying with the requested dimensions and weight. This paper also describes the printer's design consistent with the robot dimension and the preliminary phase of its integration with the autonomous carrier.

Keywords: Road pavement · Potholes repair · Safety at work · Autonomous robot · 3D printer · Mixture design

1 Introduction

InfraROB is a Horizon 2020 research project funded by European Commission (Grant Agreement N. 955337) and aims to maintain the integrity, performance, and safety of the road infrastructure through autonomous robotic solutions. In this framework, the prompt repair of small potholes helps to control further deterioration, reduces maintenance costs and extends road pavement life. Indeed, patching potholes prevents water from entering the subgrade and causing more pavement damage.

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A specific project task addresses the development of a 3D printer able to extrude an innovative asphalt mixture for filling in small potholes. The prototype is integrated into an existing small robot, to obtain an autonomous system. It can repair quickly potholes while reducing worker exposure to live traffic and increasing the road users' safety.

The printer dimensions are limited by the maximum payload of the robot and the available construction space for the integration. Due to these limitations, this research started with a preliminary definition of the printer based on the dimensions of the robot and the desired mixture characteristics.

This document describes the activities that led to the construction of the printer prototype and those ones needed to create the pothole 3D model as input to the printer.

2 Methodology

The development of a 3D printer system for filling in small potholes is divided into four steps: i) definition of the constraints due to the autonomous carrier; ii) definition of the repairing mixture; iii) design and construction of the 3D printer; iv) system integration with the autonomous carrier.

2.1 Definition of the Constraints

The 3D printer should be installed on an existing autonomous carrier provided by an InfraROB project partner [1]. Therefore, the maximum dimension, the weight of the 3D printer, and the amount of the transported repairing mixture were conditioned by the dimensions of the small robot (Fig. 1). The maximum weight that can be added to the carrier is about 25 kg; the 3D printer is about 20 kg heavy, so the maximum weight of the mixture is 5 kg, which is enough to fill in 3/4 small potholes (20 cm as diameter and 2 cm depth) per mission. The repairing mixture should be a cold material. Indeed, a small amount of a hot mix asphalt (HMA) would have cooled in a very short time and it would have required a heavy heater on the robot.

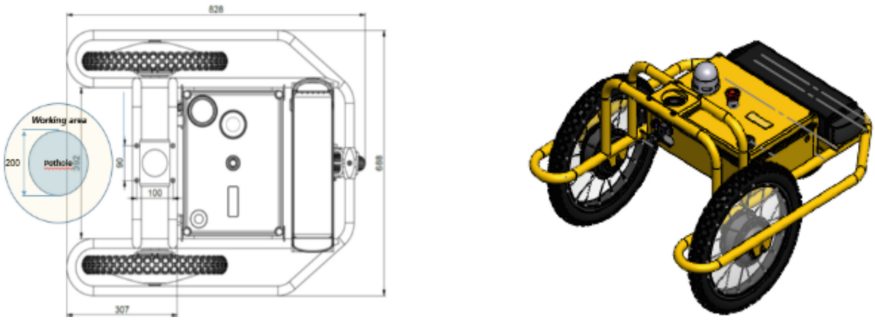

Fig. 1. Dimension of the autonomous carrier (courtesy of TinyMobileRobots)

2.2 Definition of the Repairing Mixture

Due to the problems described in the previous paragraph, only cold bituminous mixtures have been studied, namely:

1. Cold Mix Asphalt containing natural aggregate (30% basalt 0/3, 24% basalt 3/5, 45% basalt 5/10 and 1% cement) and emulsion.
2. Cold Mix Asphalt containing natural aggregate (69% basalt 3/5) and 30% Reclaimed Asphalt Pavement (RAP), 1% cement, waterproofing bituminous membranes, and vegetal flux oil.
3. 100% RAP and a Multifunctional Chemical Compound (MCC) consisting of antioxidants, plasticisers, vegetal rejuvenators, diluents, and dispersants. Cement and water are added to the mixture.

Grain size, Marshall Stability, void content, indirect tensile strength and material loss were studied in the laboratory. The expected targets, shown in the last column of Table 1, have been defined as the experiences made on busy urban streets.

Table 1. Tested cold asphalt mixtures.

	Emulsion	Flux oil		MCC	Target*
		Type 1	Type 2		
Additive [%]	8% (by weight of the mix)	30% (by weight of the bitumen)	30% (by weight of the bitumen)	3.0% (by weight of the mix)	
Water				4.0%	
Bulk density [g/cm^3]	2.12	2.08	2.02	2.11	
Maximum density [g/cm^3]	2.54	2.47	2.47	2.47	
Air voids [%]	16.5	15.4	13.2	14.6	
Indirect tensile strength 7dd [N/mm^2]	0.02	0.04	0.03	0.12	0.05
Marshall Stability 7dd [daN]	250	335	299	612	400
Particle loss 28dd [%] (Cantabro test)	90	80	72	3	10

* Specification of Milan Municipality

The laboratory tests of the first 2 mixtures gave results not compliant with the targets (Table 1). Instead, the test results of the third mix were very satisfactory. These

characteristics were evaluated by varying the additive and water content in the range of 1.5–3.5% and 3.1–5%, respectively. So, the study was deepened on the third mixture, by performing on-site tests loading some filled potholes with simulated traffic; the results have been presented in [2, 3]. In-situ tests showed substantial and good thickening, with no material disintegration or loss of cohesion, even immediately after laid or after six months of monitoring.

2.3 Design and Construction of the 3D Printer

The printer consists of (Fig. 2a): the tank containing the material to be extruded; the movement axis X and Y to control the movements of the print head along the horizontal transversal and longitudinal axis; the screw extruder that pushes the material; the electronics component to control the operation of the machine and the power cord to connect the 3D printer to the autonomous carrier.

The movement of the X and Y axes and the material extrusion is managed through the printer operating software, whose mail screen is shown in Fig. 2b.

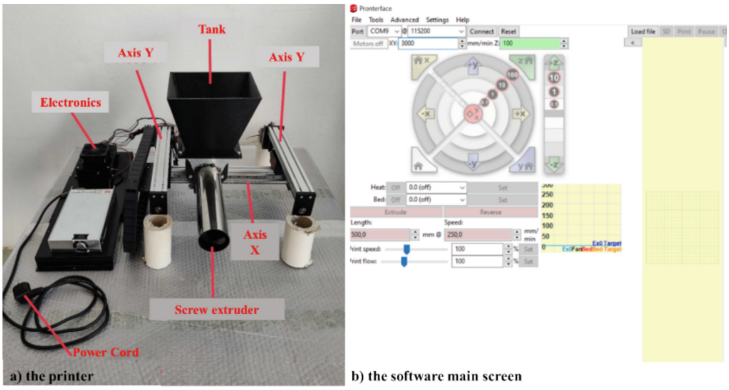

Fig. 2. The 3D printer (image by the authors)

A series of tests were carried out in the "Road Materials Laboratory" of the Sapienza University of Rome to test the printer's operation and define its optimal parameters. The tests were made with simple geometric shapes (e.g., cube and cylinder) by filling the printer tank with the material necessary for 3 or 4 potholes 20 cm wide and 2 cm depth. The printer worked adequately with the mixture that flows easily from the screw. In this phase, the goodness of the mixture was reaffirmed. Other mixtures showed packing problems inside the screw and extrusion difficulties.

2.4 System Integration with the Autonomous Carrier

At the moment the printer is not integrated with the robot yet. This step has just started, and only the hardware to capture images of the pothole has been developed to create the pothole 3D model in an STL file format as input to the printer management software.

The adopted methodology is based on a novel Raspberry-based system [4] that automatically captures a series of 2D images, from which it reproduces the pothole 3D model, and measures its properties using a digital photogrammetry processing software. The proposed monitoring system can survey potholes up to 75 cm in diameter.

The hardware platform assembled consists of consumer-grade components integrated around a Raspberry Pi 4 Model B 8 GB RAM (RPI 4B) [5] (Fig. 3a). The compact size of this computer (88 × 58 × 19.5 mm) makes portable the device.

The prototype is integrated into the rear part of the robot to capture photos using a low-cost camera sensor [6] along a circular path around potholes (Fig. 3b) and ensuring that each photo overlaps with the previous one. A GPS module [7] connected to the Raspberry Pi acquires location data that, combined with GIS technologies, allows displaying each pothole on a map, with details about the centre location, volume, amount of filling material, and a photo.

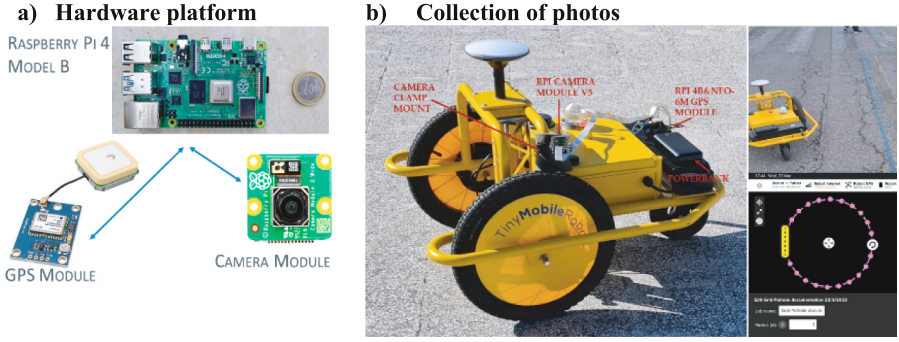

Fig. 3. Integration with the robot (image by the authors)

Considering the pothole centre as the circle centre, the robot follows circles with different radii in the range of 1.0–1.4 m around the pothole, and it shoots enough photos (4608 × 2592 pixels) to reproduce a detailed 3D pothole model. Each circle is discretised in 30 points at an equal distance, where the robot stops for 6 s allowing the camera to capture at least one picture of the pothole in static conditions. Indeed, a Python script has been implemented to enable the camera to shoot a photo every 5 s and save it in a JPEG file format.

The robot velocity driving to waypoints in automatic mode was set to 0.4 m/s. Upon start-up, RPI 4B was automatically connected to the Internet to perform remote access and launch the command routine without being in situ. Furthermore, at the end of the survey phase, storage was automatically arranged in a cloud accessible from a designated PC for post-processing data analysis.

The 3D pothole model using the collected photos is created with Bentley Context Capture [7], which uses aerotriangulation techniques. The resulting mesh can be exported in STL format, as required by the 3D printer as input. Tools are also available to perform measurements such as area and volume.

The procedure was tested on a 37 × 32 × 8 cm asphalt tile in which a bowl shape has been opened to simulate a real pothole. A scale constraint during aerotriangulation

was entered by selecting 2 user tie points in at least 2 photos and then specifying the real distance between them. The processing time to reproduce the 3D pothole model and to calculate the pothole volume was about 25 min. The average ground resolution was equal to 0.40267 mm/pixel. The actual volume was then measured in the laboratory by filling the pothole with water. The water volume measured was 485 ml and that calculated was 480.314 cm^3: only a relative error of 1% was detected.

3 Conclusion

This study presents the development of a 3D printer to extrude a specific mixture for filling in potholes. The printer is integrated into an existing small robot that can autonomously reach the pothole to be repaired. The operator remains parked in a safe roadside area, thus reducing workers' exposure to live traffic. The research about the suitable mixture was focused on materials that, immediately after the laying, can be compacted by traffic. A cold asphalt mixture was chosen to avoid the further weight addition of a heater for the material. The use of the rejuvenator improved the mixture's plasticity and adhesion, ensuring a long-lasting maintenance solution. The resulting mixture is composed of 100% RAP, 3% rejuvenator, 1% cement, and 4% water.

The printer consists of an extrusion horizontal screw that pushes the material, a tank containing the material to be extruded, and a coordinates reference system that controls the movements of the print head. The printer worked adequately with a designed cold asphalt mixture, that flows easily from the screw, while other mixtures had packing and extrusion problems.

The 3D printer needs a pothole model supplied by an STL file format saved with a novel Raspberry-based system integrated into the robot. The system has a camera managed by a mini-computer RPI 4B to collect overlapped 2D images of each pothole. The collected images are then processed through photogrammetric techniques to create the pothole 3D model and calculate the volume to fill.

The integration of the printer on the robot is still running.

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Recent Research on Passive Safety of Road Equipment in Germany

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Abstract. In Germany the guidelines for the use of vehicle restraint systems (VRS) indicate that always the best possible safety level should be found depending on the specific situation. As every situation is different it is necessary to investigate various approaches to reach a high safety level in road equipment. This paper introduces four recent BASt projects on passive safety of road equipment in Germany. The first research project deals with frequently used support structures for traffic signs in Germany. Real crash tests and numerical simulations were used to identify passive safe constructions for car occupants. The other projects focus on the safety of motorcyclist. While in the second project crash tests according to standard CEN/TS 17342 are used to improve motorcyclist protection systems (MPS) for VRS, an expert survey and crash test with a specific dummy are the basis for the definition of sharp-edged components of VRS in the third project. The fourth project gives an outlook on the development of a new test procedure for passive safe road equipment for motorcyclists, like signs for the indication of bends which are made of plastic material.

Keywords: passive safety · road equipment · forgiving roadside · support structures · vehicle restraint systems

1 Introduction

In Germany the "Guidelines for passive protection on roads by vehicle restraint systems" [1] give advice for securing hazardous areas at roads. The guidelines point out that the best possible safety level should be found depending on the certain situation. This means that vehicle restraint systems (VRS) are not always the best possible solution from a safety perspective. In some situations, the impact against a certain object next to the road could be even a lower risk for persons involved in this accident than a VRS that would originally be installed to create traffic safety. If a VRS is installed or not, to reach the highest level of safety it is important that everything that is placed in the road side is safe for all types of road users that might be involved in an accident. Therefore, several research projects of the German Federal Highway Research Institute (BASt) over the past years were focusing on the topic of passive safety of road equipment, as one part of a forgiving roadside. In this paper four projects will be introduced which were focussing on different road user types, in particular occupants of cars and motorcyclists.

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2 BASt Project FE 03.0555 - Passive Safe Road Equipment

This project [2] deals with frequently used support structures for traffic signs in Germany. Support structures for traffic signs are frequently used in the road sides. Depending on the specific construction they can be dangerous for car occupants in case of a run off accident and it could be necessary to place them behind a VRS. The guidelines [1] state that it has to be checked if a higher level of safety can be achieved by removing the obstacle or using objects that are constructed passive safe, i.e. must not pose a danger to the road user in case of an impact, before installing a VRS. According to that a solution can be to use passive safe objects in the road sides when it is not possible to remove an object and a VRS should be avoided.

Therefore, the aim of this project was to determine if some of the most frequently used support structures for traffic signs in Germany fulfil the requirements of the European standard EN 12767 [3] and can be characterized as passive safe based on the results. If it is not possible to fulfil the standard the objects should be modified and their performance has to be improved. The research methods used were real crash tests according to European standard EN 12767 and numerical simulations.

Two different types of license-free support structures for traffic signs, the "Gabelständer" and the "Trimast", were selected as research objects (Fig. 1). The size of the constructions and the corresponding signs were chosen according to occurrence, expected risk potential and expert assessment. The first step were real crash tests according to EN 12767. Each test according to the standard consists of two crash tests. One with a high velocity (50 km/h, 70km/h or 100 km/h) and a second mandatory test with a low velocity of 35 km/h. Both research objects were crash tested with 35 km/h and 100 km/h. The result was that both objects passed the 100 km/h test but failed the 35 km/h test. The reason was that the energy in the 35 km/h test was too low for the structures to yield. This led to vehicle occupant impact severity assessment indices beyond the thresholds.

Fig. 1. Left picture: The support structure "Gabelständer"; right picture: The support structure "Trimast". [pictures by author]

In the second step the results of the real crash test were used to build and validate computer models for numerical simulation. The simulation was used to analyse different

approaches to modify the constructions to be more yielding and to reach a positive result in a real 35 km/h crash test. It was determined that it is especially important for the result that the support structure detaches from its foundation as result of the impact. Only in these scenarios the measured vehicle occupant impact severity assessment indices complied with the thresholds. Approaches were the fixing of the ground plates or the weakening of the main poles of the support structures through defined notches. For the "Trimast" the only way to reach a result within the limits of the standard was to reduce the diameter of the main poles.

After a promising modification for each support structure was found, additional real crash tests were conducted. The objects were crash tested with 35 km/h, which was expected to be more critical for passing requirements of the standard. Both modified support structures passed the 35 km/h test. Finally, all results of the real tests and the simulations were evaluated and recommendations for the passive safety of "Gabelständer" and "Trimast" were derived.

Based on the results of these project new guidelines for passive safe support structures for traffic signs were developed and published in Germany [4]. The guidelines contain advises for the passive safe construction of support structures and is designed to be updated whenever new knowledge is achieved in the future.

3 BASt Project FE 03.0516 - Eligibility of Passive Safety Roadside Equipment to Protect Motorcyclists According to the Current European Standards

In recent years more and more vehicle restraint systems with motorcyclist protections systems (MPS) were installed in Germany on roads with a high traffic volume of motorcyclists. These MPSs are usually underride protection systems made of steel. They are attached to an existing steel barrier to prevent sliding motorcyclists from hitting the posts of a vehicle restraint system. The first license-free MPS were developed in Germany during a time, when there was no European standard covering this product. Therefore, these systems were mostly tested in research projects. Nowadays there are still some license-free VRS systems installed in Germany with no MPS classified according to the current standard (CEN/TS 17342 [5] respectively CEN/TS 1317-8 [6]) available.

The aim of the presented project [7] was to classify the MPS available for the VRS "Einfache Schutzplanke 4.0" [8] according to the current standard for MPSs. If it is not be possible to pass the test described in the standard CEN/TS 17342 the MPS should be improved.

As a first step all crash tests that were conducted during the development of the first MPS in Germany were analysed according to the measured safety parameters. The measured values were compared to the thresholds and requirements of the current standard. At the same time an investigation on other available MPSs on the market was conducted. As a result of these both steps it was identified, that it is helpful for the classification according to CEN/TS 17342 if the system is modified. Therefore, a new deformation element was developed that is installed to the post of the VRS and shall soften the impact of a dummy on the MPS (Fig. 2 right).

Fig. 2. The deformation element installed on the post of the VRS (marked with "9H"). [picture by author]

The MPS with installed deformation element was then tested according to CEN/TS 17342. Unfortunately, the test failed and further modifications were necessary. Especially the neck compression force was identified as a critical parameter for the failure. The threshold for this parameter was excided even before the new deformation elements had the chance to soften the impact. To reduce this value a new rail was used for the MPS with a thickness of only 3.5 mm. Also the deformation element was modified. In a second test according to the standard the modified MPS failed again. Additionally, a new problem occurred. During the impact the dummy got stuck with one arm beneath the MPS, which is another reason for failing the test.

As a whole it was not possible to find a solution for a MPS that can be attached to already installed VRS ESP 4.0 and which fulfils the current standard CEN/TS 17342. Nevertheless, some helpful findings were gained in this project that can be used to further improve systems to protect motorcyclists.

4 BASt Project FE 03.0514 - Criteria for the Assessment of the Hazard Potential to Motorcyclists from Sharp-Edged Components of Road Restraint Systems

Tenders for VRS in Germany often ask for systems with components that are not sharp-edged. The reason is to prevent motorcyclists from additional serious injuries when they come into contact with these systems in case of an accident. Although there is a common understanding about sharpness, the definition of a component or an entire VRS to be described as sharp-edged is not clearly regulated in German standards so far. Room for extensive interpretations was existing and has given the motivation for the above named BASt project [9]. The aim was to identify a definition for the sharpness of components or entire VRS. As suitable methods, expert surveys and crash tests with a specific crash test dummy were chosen.

The first step was to identify components of VRSs that are considered to be sharp-edged according to the existing common understanding. Therefore, pictures of different components were shown to experts in the field of planning and construction of VRS. The experts had to decide whether a certain component or system has to be considered as sharp-edged. They had to use a scale to rate the components on the pictures according to their expected sharpness.

Based on the results of the survey, several test scenarios were defined to investigate the risk for injuries in case of an accident of certain components or construction designs. The scenarios included different types of posts, heads of screws or gaps of different sizes between rails. Then tests were conducted according to these scenarios using specific dummies that allow the investigation of injuries.

As a result, different criteria were identified that can be used to assess whether a component of a VRS has to be considered as sharp-edged in the future in Germany. These criteria were also converted into a flow chart to examine VRS for sharpness.

5 BASt Project FE 03.0601 - Passive Safe Road Equipment for Motorcyclists

The main topic of this project is also the protection of motorcyclists. But in this case, the project is not focusing on the collision with a VRS but with other objects in the roadside, for example support structures for traffic signs. These objects can also be designed to be crash friendly for motorcyclist.

Over the past years, signs for the indication of bends which are made of plastic material were newly used at certain roads to test their suitability for general usage in Germany. (Fig. 3). Up to now it is unclear which requirements must be fulfilled by these objects and how they should be tested. Especially the question of safety during an impact was open and therefore, this should be addressed in a research project.

The aim of this project is to develop a new test procedure. This procedure should be able to deliver robust results for safety and use a simple and cost effectively approach to make rapid product development possible.

As a method, real accidents and already existing test procedures (for example for VRS) are to be evaluated in order to derive a possible test procedure. The procedure also has to be checked with regard to its practical suitability.

After completion of the project the developed test procedure shall be adopted to the national guidelines and if reasonable introduced into international standards. Results are expected in 2024.

Fig. 3. Example of a sign for the indication of bends which is made of plastic material. [picture by author]

6 Conclusion

All presented research projects addressed specific problems in improving road safety. For some already good improvements were identified and the results of the projects led to new guidelines. Other problems are not fully solved yet and need to be addressed by further research or are the topic of ongoing research. Overall, all presented research projects on passive safety of road equipment in Germany make their contribution to achieve a higher safety level for various situations.

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Geofenced Heavy Trucks to Protect Bridges: Experiences and Findings from Research Project

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Abstract. The paper discusses the advantages of utilizing winter conditions to increase the weight tolerance of frozen roads while safeguarding vulnerable bridges. It introduces the concept of geofencing as a tool to ensure that heavy trucks reduce their speed when crossing these bridges. A tool that can be useful for all bridges.

Geofencing technology was tested in a research project during winter 22/23 involving trucks from Volvo and Scania. The project was financed by the Swedish Transport Administration. Two geofencing technologies were evaluated: Scania's "active" geofencing, which allowed the truck to automatically maintain the designated speed limit over the bridge, and Volvo's "passive" geofencing, where the driver received warnings and had to manually slow down if necessary. The results indicated that active geofencing effectively ensured trucks adhered to speed limits and drivers generally had positive experiences with geofencing.

Regarding policy and regulation, the paper explores the feasibility of implementing geofencing technology and suggests that current legislation can accommodate it. Recommendations are made for regulations based on functional requirements and self-monitoring systems to ensure compliance.

In conclusion, the paper demonstrates that geofencing technology can effectively protect bridges and offer substantial societal benefits. It also outlines potential policy and regulatory frameworks for the widespread adoption of this technology to safeguard bridges and optimize transportation.

Keywords: intelligent access · geofencing · timber transports · policy lab

1 Introduction

1.1 Background

Winter is our friend. In northern Sweden, frost has been used to allow heavier transports for centuries as a frozen road body can carry large loads.

Bearing capacity class (BCC) is the classification used to grade the bearing capacity of roads. The regulation is needed to protect roads from, for example, premature degradation or to prevent accidents. Public roads are divided into four bearing capacity classes

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in Sweden with different weight restrictions. The four BC classes are BCC1 (maximum 64 tons), BCC2 (maximum 51,4 tons), BCC3 (maximum 37,5 tons) and BCC4 (maximum 74 tons). The maximum permissible weights for the road depend on the BCC of the road and the distance between the axles of the vehicle.

Certain public BCC2 and BCC3 roads in northern Sweden may be driven with gross weight equivalent to BCC1 during the period 16th November to 31st March. This makes it possible in winter (when the roads are frozen) to carry out heavy transport on roads that otherwise cannot withstand higher loads with divisible goods, e.g. timber. It is the Swedish Transport Administration that decides that a road should have a higher BCC during the winter.

BCC4 is not included in today's regulation for winter roads. If BCC4 is included, it would bring certain advantages. If the same truck is allowed to load more, it would mean reduced environmental impact and increased road safety. It would also mean reduced transport costs for the timber industry, as fewer vehicles are required to transport the same amount of goods.

Why BCC4 is not included has to do with bridges. Bridges do not have a better bearing capacity during winter. Bridges and compliance (driving so that the bridge is not damaged) is thus the challenge that needs to be solved to be able to classify more public roads to BCC4 during winter. Otherwise, there is a risk that the life of the bridge will be shortened and that the need for maintenance work will increase, which in turn will lead to increased costs.

1.2 Purpose

Our research project aims to investigate and test whether it is possible, through changes in the regulations, to allow transport with a gross weight equivalent to BCC4 (74 tons) on certain winter roads. Our starting point is that it is possible to generally allow heavier traffic in winter if the vehicle's speed is reduced to a low speed crossing the bridge. With the help of new technology and intelligent access, it is now possible to control and follow up the speed and weight of a vehicle crossing a bridge, e.g. through geofencing, which in turn means that the road operator can dare to take the step and extend the scope of winter roads to BCC4.

New technology and a changed regulatory framework can solve many of the challenges we face today in society. In the project, we mainly focus on the following research questions to build knowledge and understanding of:

- How can new technology (geofencing) be used to control a vehicle's access and speed crossing a bridge?
- How can we safely allow BCC4 vehicles on frozen roads from the perspectives of follow-up, control, and responsibility?
- How great is the potential, in terms of SEK and emissions, of a changed regulatory framework for frozen roads?

1.3 Method

To answer the research questions presented in the paragraph above, we have mainly used the following methods. They are normally included in a policy lab/a regulatory sandbox.

We have conducted literature studies to collect information about today's regulations and legal conditions based on this. The literature review has included sources of law (legislation, preparatory work, practice, and doctrine, etc.), but also reports and other publications.

We have during the winter of 22/23 carried out a pilot where we have geofenced four heavy trucks when they crossed twelve bridges in northern Sweden. With the help of a transport exemption for trials, the trucks were allowed to weigh up to 74 tons, provided that geofencing were used. We tested two different variants of the technology: Scania's system with "active" geofence technology where the truck was programmed to maintain a certain speed over the bridge and calculated and implemented this itself (the driver could, however, override the technology by pressing the accelerator pedal at the bottom), partly Volvo's system with "passive" geofence technology where the driver received a warning when approaching the zone (bridge) and then the driver slowed down the vehicle if necessary. In parallel, we collected data on how the drivers drove in a certain zone during the pilot, both from the vehicles' Fleet Management System (FMS) and from our own equipment. Examples of data collected were the position and speed of the vehicles.

In connection with the pilot, we have conducted interviews with the truck drivers to capture their experiences of using the technology. That the technology works in everyday life is an important prerequisite for achieving the acceptance needed for future scale-up. We interviewed the drivers both before and after the pilot. We have also interviewed people who work at the Swedish Transport Administration, the Swedish Transport Agency and Sveaskog (a large buyer of timber transport).

We have worked on the basis of an agile and iterative process where we in a number of workshops have checked results and different solution proposals.

For calculations of the societal benefits, data from a larger data base of vehicle follow-up has been used.

2 What is Geofencing?

Geofencing is a technology that has been used for quite some time in the transport industry. After the terrorist attack in Stockholm in 2017 (where the terrorist used a truck), and the gas bus accident at the Klara tunnel (Stockholm) in 2019, society's interest in using geofencing as a tool for societal protection but also as a tool to promote climate and transport policy goals increased. During 2020–2021, the Ministry of Infrastructure analysed geofencing from a legal perspective and prepared certain legislative proposals [1]. In conclusion there are currently no regulations that explicitly support geofencing in, for example, the traffic ordinance, but there is also no regulation that prohibits it. This means that different actors in society can use geofencing. However certain restrictions follow from international regulations.

There is no unambiguous definition of geofencing. The term is given different meanings in different contexts [2]. Typically, it refers to a geographically defined area that is "fenced" virtually using digital technology. The areas of application are many. The technology can be used, for example, to inform or assign specific conditions to vehicles in an area. Geofencing technology can be used, among other things, to control vehicle speed, powertrain (electric/hybrid drive) or access in time and space. To date, there are no common standards and rules for type-approval of geofencing technology in vehicles.

3 Data from the Pilot

The logging of the pilot's four vehicles began at the end of December 2022 and continued until February 2023. In total, just over 77,000 km and 203 passages of the designated bridges were logged. The trucks speed limit were 30 or 50 km/h crossing bridges. Of the twelve bridges, half were operated at least once.

In essence, both the passive and the active system of geofencing proved to work well. The vehicles reduced speed before the bridges and stayed below the stipulated speed limit throughout the bridge crossings.

4 Interviews with Drivers

In connection with the pilot, we conducted interviews before and after the pilot with the truck drivers (5 male, 1 female) to capture their experiences. During the pilot, half of the drivers drove a truck from Scania and the other half drove a truck from Volvo.

Before the pilot there was a spread among the drivers from negative to positive about the project's idea, but most were positive. All said that it is good to be able to load more to get the timber out of the forest faster. Two drivers said that they do not need the technology or that they want to be able to determine the speed themselves, not that the technology should decide for them. Four drivers said that it could be good to get help from technology. Two expressed concern about whether the technology would work as intended and about not having complete control over the truck (Scania's solution).

After the pilot the drivers were more positive about the project's idea and had different opinions on utility and upscaling. However, two drivers argued that the technology needs to be improved before proceeding with the idea. All the drivers stated that it was quick to get used to the technology and that they could trust the technology.

5 Transport Efficiency

We have quantified the societal benefits of using geofencing. More efficient planning, control and follow-up can lower costs, reduce environmental impact, and increase traffic safety. Calculations in the project show suggest that 1/3 of timber transports in northern Sweden use frozen roads and that they approx. Transport 1 million tonnes of timber during winter. They can benefit from the technology and if the technology is introduced, the industry would make savings of the equivalent of SEK 15 million / year and reduced energy use equivalent to 280 cubic meter diesel. At national level, this corresponds to an energy efficiency potential of 0.12 percent. The calculation is based on a comparison between a vehicle that can load 42 tonnes and 47 tonnes respectively and with a transport cost of SEK 1.30 per tonne-kilometre and SEK 1.17 per tonne-kilometre. In terms of energy efficiency, a BCC4 vehicle consumes 23.7 ml of fuel per tonne-kilometre and a BCC1 vehicle 26.0 ml per tonne-kilometre.

6 Regulation

In the project we investigated the legal space for geofencing heavy trucks when they cross bridges. In conclusion, the Road Traffic Ordinance [3], gives the Swedish Transport Administration the right to prescribe conditions in connection with BCC4 transports. Based on the wording of the provision, there are no restrictions or limitations on what conditions the Swedish Transport Administration may prescribe regarding BCC4.

The two most important parameters for follow-up and control in our project are the speed and weight of the vehicle at the bridge passage. The speed of a vehicle can vary greatly in a short period of time. The weight of the vehicle changes more slowly while driving. For example, a vehicle can accumulate snow during the journey and thus increase weight. Compliance and on-road control are the responsibility of the police. We learned from the pilot that at the moment the FMS do not have good enough data about speed and weight to use for control by the police. Instead, functional requirements and control by self-monitoring may be the best way forward to regulate.

We have investigated two different alternatives. Option 1 is more intrusive self-monitoring and option 2 is less intrusive self-monitoring. If the regulatory authority wants more control over the transport, it can introduce regulations that promote this. An example of this is trials with autonomous vehicles where a permit is required. In the case of trials with autonomous vehicles, self-checks in the form of factory acceptance tests (FAT) and site acceptance tests (SAT) are common. Based on the lessons learned from the pilot, FAT and SAT would be a way for an authority to gain control. We know from the pilot that if the technology is verified and active geofence technology is used, the vehicle will comply with the regulations. The disadvantage of such a process is that it is more expensive as administration costs are higher, both for authorities and for companies. It is also more time consuming. This in turn means that this type of self-inspection does not work for individual transports, but the alternative assumes that the same truck often returns to the same bridge. This is the case for timber transport.

If the regulatory authority can accept to have less control over the implementation of the transport and relies on the Police Authority's work with control and follow-up on the road, it can introduce a regulatory framework that promotes this. In short, such regulations would stipulate that geofencing should be used and that the drivers should verify and document that the technology works the first time they drive over the bridge. The carrier is then tasked with archiving the documentation and, upon request, presenting it to an authority. The advantage of such a regulatory framework is that administration costs are low, and it is possible to get started quickly with geo-fenced transports. The administrative costs of companies can be covered by the fact that they are allowed to transport more load.

7 Conclusion

The purpose of our proposal towards new regulation is to increase transport efficiency by enabling geofenced BCC4 vehicles when crossing bridges in winter. This requires regulation. The purpose can be achieved through regulations by the Swedish Transport Administration. Our suggestion is a regulation based on function requirements as this

provide greater flexibility and less technical limitations. Function-based requirements also do not hinder technological development. Our proposal also includes a support system based on self-monitoring to verify compliance with requirements. Enabling heavier loads over bridges in winter would have positive consequences for society in the form of energy efficiency and reduced environmental impact, as well as contribute positively to traffic safety. During winter 23/24 we will do a new pilot and test how a regulation with self-monitoring would work in practice. To learn more about our research project – a project rapport from the first year is published [4].

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AITHENA: Towards a Trustworthy AI for CCAM Development

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Abstract. Connected and Cooperative Automotive Mobility (CCAM) solutions harness the power of Artificial Intelligence (AI) to develop driving functions that outperform humans under specific conditions. However, AI faces challenges in terms of explainability, privacy preservation, ethics, and accountability, which are essential for establishing trustworthy AI. Explainable AI (XAI) has gained prominence as users seek to understand how AI systems function and behave. It encompasses interpretability (comprehensibility by humans) and completeness (exhaustive explanations). AITHENA proposes a human-centric methodology for the development, deployment, and testing of AI models within CCAM functions. This methodology focuses on trustworthiness and human acceptance, with a strong emphasis on XAI and Data Management. This paper presents an ongoing development effort focused on the methodology and guidelines for a specific research area. The work primarily centers on methodological approaches and the forthcoming presentation of guidelines.

Keywords: Explainable AI · Trustworthy AI · Perception · Decision Making · Testing and Validation · Data management

1 Introduction

The advent of Connected, Cooperative, and Automated Mobility (CCAM) solutions owes much to the breakthroughs in Artificial Intelligence (AI) [1]. AI can now be trained on massive datasets, enabling it to surpass human performance in specific driving scenarios. Despite these advancements, AI remains relatively uncharted territory concerning critical aspects such as explainability (comprehending how models function), privacy preservation (safeguarding sensitive data), ethics (addressing bias and intended/unintended behaviors), and accountability (establishing responsibilities for AI outcomes). These facets are instrumental in establishing trustworthy AI, a novel paradigm that seeks to fully

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comprehend and trust AI in operation while harnessing its full potential for societal benefit. Within the scope of the EU Horizon 2020 AITHENA project, efforts are underway to enhance Explainable AI (XAI) within CCAM development and testing frameworks. This research focuses on three primary AI pillars: data management (real/synthetic data), model development (data fusion, hybrid AI approaches), and testing (physical/virtual XiL setups with scalable MLOps).

2 Analysis of Trustworthiness Requirements

The European Commission's AI High Level Expert Group (HLEG) defined the following requirements for trustworthiness: (1) lawful, i.e. compliant with all applicable laws and regulations, (2) ethical, i.e. adhering to ethical principles and values, and (3) robust from a technical and social perspective to prevent unintentional harm [2]. Next subsections expand on these requirements.

2.1 Lawful/Legal

To ensure compliance and public trust in AI-based CCAM systems, adherence to laws and guidelines is crucial, prioritizing safety. Continuous review of legal and ethical compliance is essential, with international regulations and standards being developed. Initiatives like Holistic AI and ConnectedAutomatedDriving.eu provide comprehensive overviews of trends in AI regulation. The human rights perspective underscores protecting fundamental rights throughout technology development and deployment, aiming to align advancements with human rights principles and reduce inequalities. Mechanisms like human oversight, transparency, and accountability are essential for upholding these rights. Despite progress, human-centered legal gaps remain, including data protection, bias, transparency, safety, and accountability. Addressing these requires collaboration among legal experts, policymakers, ethicists, and stakeholders to prioritize human rights and fairness, ensuring AI benefits society.

2.2 Ethical

The Responsible Innovation approach emphasizes morally relevant functionality in technological innovations, requiring interdisciplinary collaboration and anticipatory ethical analyses during design. Value Sensitive Design integrates systematic ethical analysis and value integration to preempt and resolve conflicts. The Responsible Research and Innovation Approach (RRI) enhances these frameworks with inclusiveness, anticipation, reflexivity, and responsiveness. These frameworks bridge human-centric AI with ethical aspects in trustworthy AI-enabled CCAM applications. Machine ethics research identifies concerns like moral dilemmas, system failure, moral patients, distributive justice, and moral responsibility. AI introduces specific ethical challenges including privacy, surveillance, behavioral manipulation, transparency, explainability, bias, discrimination, meaningful human control, and employment. Autonomous vehicles raise concerns about safety, obligations, liability, and privacy, impacting power dynamics and public space privatization.

2.3 Robust

The concept of robustness is closely tied to the principle of harm prevention, which significantly influences user acceptance (EC JRC 2022) [1]. Robustness encompasses both social and technical dimensions. Social robustness entails a thorough consideration of the system's operational context and environment. Meanwhile, technical robustness involves ensuring the system's resilience within a specified context, such as its application domain or life cycle phase (EC AI HILEG 2019) [2]. From a technical standpoint, it also pertains to the system's capacity to maintain its performance and accuracy when encountering anticipated or unforeseen variations in input data[1].

3 Evaluating Trustworthiness in AI Based CCAM Applications

3.1 Evaluating Fairness

Recent AI fairness research emphasizes societal fairness over narrow perspectives, considering equality, non-discrimination, and procedural fairness. Distributive fairness, addressing equitable resource distribution, adds complexity beyond discrimination or bias. Non-discrimination requires meticulous examination of model impacts on demographic groups, crucial for societal well-being. Comprehensive measures, including data handling and model evaluation, are vital to mitigate biases. Procedural fairness emphasizes objective standards in decision-making processes. Transparency is key in evaluating AI fairness within various contexts. Bias in AI systems, stemming from human behavior and training data, poses significant risks, requiring rigorous testing and diverse systems. Practitioners rely on best practices and tools to address bias, promoting fairness in autonomous systems. Fair ML tools aid developers and auditors in assessing and correcting biases in AI algorithms.

3.2 Evaluating Transparency

Transparency in AI refers to the degree to which the inner workings and decision-making processes of an AI model can be easily understood. It is closely related to, and often used interchangeably with, the terms explainability and interpretability. In the context of AI, transparency can be defined at different levels:

Model Level: providing insights into how an AI model operates, the significance of input data for a specific task, and transparently communicating insights from the model to diverse user groups. Transparency focuses on making the model's behavior understandable and interpretable.

Input Level: AI models take input data, such as images or data points, and process them to make interpretations, such as classifications or predictions. When the model offers an explanation about its interpretation in relation to the input data, it adds significant value. This type of transparency helps users understand why the model made a specific decision based on the input observations.

[1] https://future-ai.eu/principle/robustness/

Model Architecture Level: transparency at this level involves identifying the most important neurons or neuron sets for a particular task. Models that can select or highlight specific neurons considered crucial for their interpretations provide explanations for their behavior.

Dataset Level: datasets define the knowledge space of the model. Their quality and representativeness are crucial. Transparency at this level involves careful dataset selection, analysis of data distribution, and addressing any imbalances in class distribution.

Transparency in all these dimensions is essential to ensure that AI models are not treated as black boxes. It promotes understanding, trust, and the ability to identify and address potential biases or shortcomings in AI systems, making them more accountable and reliable.

3.3 Evaluating Accountability

In AI systems, accountability relies on understanding user roles, often clarified through the Responsibility Assignment Matrix (RACI matrix). This matrix defines roles like responsible, accountable, consulter, and informed. While "responsibility" and "accountability" are sometimes used interchangeably, in this document they are treated synonymously, emphasizing accountability. Liability is closely related, emphasizing legal responsibility for outcomes, focusing on rectifying or mitigating harm caused. Certification and audit processes shape accountability, ensuring compliance with defined requirements, pinpointing stakeholders' responsibility and accountability, particularly in challenges or issues. The EU AI Act, anticipated in 2024, is central to the European data strategy, categorizing AI applications by risk levels and imposing obligations accordingly. High-risk systems like self-driving cars face stringent pre- and post-market requirements, while limited-risk applications adhere to existing legislation. Certification for CCAM systems follows the V-Model methodology, integrating ISO standards for functional safety. However, AI challenges traditional safety assessment methods, requiring new norms like ISO/PAS 21448 SOTIF to ensure intended functionality safety. Certification processes for AI in CCAM are evolving, with the EU AI Act employing a risk-based evaluation approach. Standardization initiatives like IEEE's Certi-fAIEd™ address compliance and ethics, promoting trust in autonomous systems.

3.4 Evaluation Privacy

Privacy in AI systems is critical, requiring careful consideration from design to implementation. Upholding individuals' integrity and protecting personal data is essential, with responsible collection, processing, and usage. Users should maintain control over their information, understanding its use and by whom. GDPR emphasizes user control over personal data, limiting collection to specific purposes with explicit consent. Developers must comply with GDPR, assuming responsibility for handling potentially personal data. Privacy concerns extend to all road actors, including smart devices and edge servers, necessitating GDPR compliance to safeguard user privacy.

The European Data Protection Board's Guidelines 01/2020 on processing personal data in the context of CCAM provide a comprehensive framework for addressing privacy

challenges. These guidelines underscore the need to: collect personal data only when absolutely necessary, activate data collection or processing based on specific functionality requests rather than by default, define limited data storage periods and provide data deletion instructions, exercise caution when collecting biometric data, avoid processing or sharing data revealing criminal offenses or infractions unless authorized by competent authorities, specify data processing purposes explicitly and obtain user consent for data collection, processing, and sharing, implement data minimization by identifying the minimum data required for system functionality, prioritize data protection, anonymize data, and provide users with detailed information about data collection, usage, recipients, legal bases, and how to request data deletion.

3.5 Evaluating Accuracy and Robustness

Robustness and accuracy validation are pivotal for ensuring the dependability and effectiveness of AI (Artificial Intelligence) systems across diverse CCAM (Connected, Cooperative, and Automated Mobility) application domains. These evaluations are essential to ascertain how well these systems function under varied and challenging circumstances and to confirm the precision of their predictions. Notably, AI robustness and accuracy validation via testing are prominent methodologies that underscore the significance of comprehensive assessments to establish trust in AI systems. Different techniques can be used: adversarial testing, cross-validation, out-of-distribution testing, stress testing, etc. Despite the undeniable importance of robustness and accuracy validation through testing, several challenges need to be considered: data quality, adversarial attacks, generalization, complex models, etc. In summary, robustness and accuracy validation through testing are indispensable for establishing the reliability and trustworthiness of AI systems. The methodologies highlighted, including adversarial testing, cross-validation, out-of-distribution testing, and stress testing, offer crucial insights into system behavior under diverse conditions. Addressing the challenges related to data quality, evolving threats, generalization, and the complexity of model behavior necessitates continuous research and vigilance. Comprehensive testing methodologies play a pivotal role in constructing robust and accurate AI systems that can be relied upon in real-world applications.

4 AITHENA's Guidelines

The AITHENA methodology compiles a set of common guidelines distilled from the previously presented methodology, providing a practical roadmap for AI practitioners.

One notable feature of the AITHENA methodology is the incorporation of questionnaires. These questionnaires are designed to guide developers through the intricacies of trustworthy AI development. Each questionnaire is structured with a series of pertinent topics framed as questions. To facilitate a systematic evaluation of AI systems, checkboxes and accompanying guidelines are integrated into the questionnaire format. This approach empowers developers to methodically assess their AI systems, pinpoint potential issues, and employ corresponding guidelines to rectify them.

By leveraging the AITHENA methodology and its associated questionnaires, AI practitioners can navigate the complexities of AI development with greater ease. The

methodology serves as a valuable resource for enhancing trustworthiness in AI systems, ultimately contributing to their responsible deployment across diverse application domains. This paper not only introduces the methodology but also demonstrates its practical utility, making it an indispensable tool for the AI community striving to create AI systems that align with ethical, transparent, and reliable AI development standards.

The guideline will be published in the deliverable D1.1 that can be accessed through the official website[2].

5 Conclusions

In an era characterized by the rapid proliferation of AI technologies, the development of trustworthy AI systems has emerged as an imperative. The AITHENA methodology, presented in this paper, represents a significant stride towards achieving this goal for CCAM applications. This methodology provides a comprehensive and structured framework that encompasses key facets of trustworthy AI development, including ethics, transparency, and reliability. One of the standout features of the AITHENA methodology is its versatility and adaptability. It caters to AI practitioners across diverse CCAM domains, offering a common set of guidelines extracted from the broader methodology. These guidelines, presented in the form of questionnaires with checkboxes and actionable directives, empower developers to methodically assess and enhance the trustworthiness of their AI systems. Through a combination of ethical considerations, robustness validation, and adherence to best practices, the AITHENA methodology paves the way for AI systems that not only perform effectively but also uphold fundamental ethical principles. It provides a roadmap for responsible AI development, enabling practitioners to navigate the intricate landscape of AI with confidence.

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An Innovative Design Process for a Safe and Active Lightweight Chassis

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Abstract. Lightweight design is still very important for an all-electric vehicle especially when used in urban areas. A new active chassis suspension designed for such an urban car is in development at the DLR (German Aerospace Center). The first main component is a composite transverse leaf spring, where a new (partly) automated design and dimensioning process is in development. The second component is an orbital wheel bearing with an optional integrated electrical drive. The third component is an innovative wheel independent two axis steering actuator changing the toe and camber angle. This enables an increase of the active and passive safety of the occupants. First simulations proved the benefits of the concept regarding enhanced crashworthiness. The modular concept of the system allows to use the same wheel at each corner of the vehicle without changing a single part, thus reducing vehicle part variants and costs.

Keywords: Wheel integrated electric drive · wheel independent two-axis steering actuator · automated design process

1 Basic Idea – The Orbital Wheel Concept

The idea of the orbital wheel is not new. The Italian designer Franco Sbarro invented it and holds several patents on it. His first European patent (FR000002633877B1) is from 1988 and was republished as world patent (WO90/00477) two years later. The main idea is, to put the wheel bearing into the rim base without any visible hub and give the wheel and vehicle new design possibilities, to reduce the rotating mass and friction. Only some motorbike customizers still use this concept for show and a formula student racing team used it once on their car in combination with an innovative wire ball bearing for weight benefit in 2014. [1]. But the orbital wheel concept has other benefits in addition to the aesthetical, as illustrated in Fig. 1. In conventional suspensions for the front axle, the forces take long and indirect ways into the body of the car (Fig. 1a). The orbital wheel concept simplifies the path of the forces and leads them nearly direct into the wheel guiding parts: lower wish bone and the suspension strut (Fig. 1b). Due to direct force routing, which leads to reduced mass and reduced parts, a light-weight potential is obvious. Even for all-electric vehicles, a lightweight design is of high importance, due to the scarce resources of regenerative energy. [2]. If a single point of connection is used to route all the loads to the wheel-guidance components, an active cardan like

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joint can take the part for steering and adjustment of the camber angel. By an additional substitution of the lower wishbone and the coil spring through a traverse leaf spring an innovative new compact and active chassis concept can be developed.

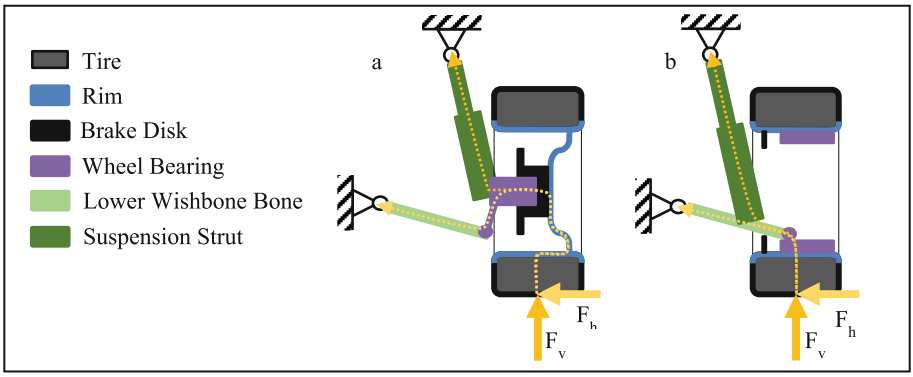
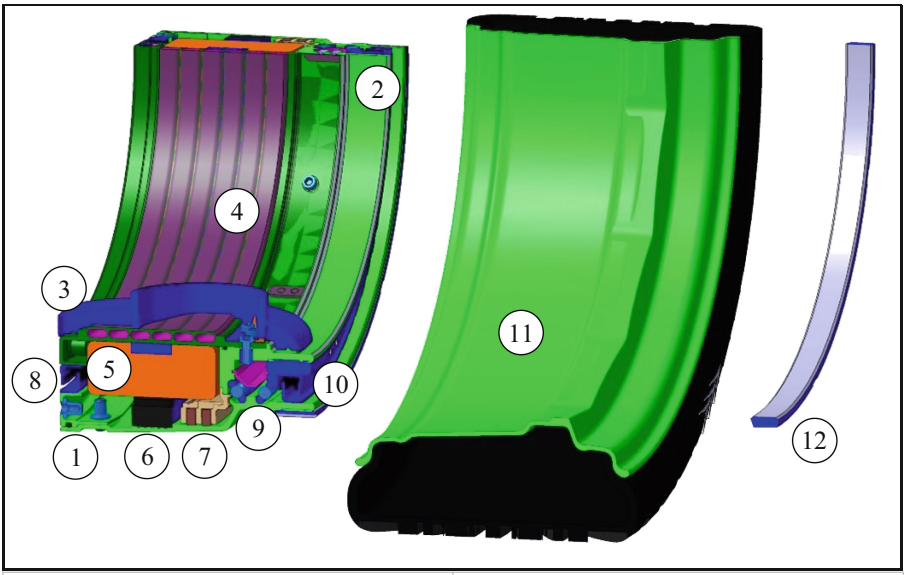


Fig. 1. (a) conventional MacPherson suspension; (b) orbital wheel with MacPherson [own figure]

In order to gain as much space as possible within the wheel center and at the same time reduce unneeded mass, the outer shell of housing of the bearing, as well as the base of the rim, are designed as thin walled cones. A splined hub in the rim is used to reduce the stress within the thin walled rim and bear the loads of misuse. The flexible and known wire bearings from the company Franke like in the Formula Student car [1] were chosen, for they can be adapted very easily regarding diameter and loads. In the sectional view of Fig. 2 the detailed design done with Catia V5 without breaking disc and brake caliper can be seen. A highly integrated, but easy to maintain, in-wheel electric drive module is the result of the development process.

2 Virtual Dimensioning Process for a GFRP Transverse Leaf Spring

The efficient dimensioning of a fully or partially wheel-guiding transverse composite leaf spring is a technical challenge. On the one hand, the kinematics of the wheel must be ensured under typical loads, such as compression and rebound or cornering. On the other hand, overloads caused by pothole driving, for example, must be endured. The efficient and economical finding of at least one geometric design including layer structure points to the necessity of using automated virtual process chains. The goal of these process chains is to propose at least one concept for a leaf spring design. Additionally, this concept can be subjected to a virtual verification by subsequent simulations, such as multi-body simulations (MBS). The challenge at this point of the process chain is to transfer the highly nonlinear elasto-kinematics from the FE into the MBS. Machine learning approaches can be utilized to mimic the structural behavior at certain forces. Optimization algorithms are used to determine the concept from the large number of



1. Outer housing for bearing	7. Labyrinth sealing rings
2. Inner housing for bearing	8. Radial shaft sealing rings
3. Link to wheel guidance comp.	9. Wire bearings
4. Cooling jacket	10. Adjusting ring
5. Electric stator	11. 7x20 rim with tire
6. Permanent magnetic rotor	12. Central locking nut

Fig. 2. Sectional view of the wheel assembly [own figure]

design variables, such as geometry parameters, number of layers or fiber angles. In particular, this process involves the combination of shape and size optimization. Besides the handling of the large solution space, the increased computation time due to necessary non-linear simulations compared to linear simulations can be challenging. The search for suitable concepts is further complicated by mandatory multi-objectives due to different load cases. The mesh quality of the generated models must be consistent, so that the simulation results of different models are comparable. Depending on the fiber angles and ply thicknesses, the laminate plies influence objective functions such as kinematics. The drapability of different ply semi-finished products such as unidirectional or bidirectional plies and the projection of the fiber angles in the FE model must be considered. In finding solutions, it is important to maintain (economic) manufacturability. Process chains of this type are being developed in the GEM-EF research project and the DLR Next Generation Car project. The focus is, among other things, on the coupling of CAD, FE and, for example, MBS tools, as well as the use of evaluation, analysis and assessment routines. For the implementation it is necessary that the corresponding tools have a script language to pass parameters via ASCII files and to generate and simulate models. With a programmed software-architecture it is possible to couple and control these tools. Furthermore, implicit or explicit FE tools like Optistruct, Radioss, LS-Dyna

or Pam-Crash can be exchanged or inserted into the process chain. Essential are programmed evaluation, analysis and assessment routines. Thus, errors can be detected quickly and raw calculation results can be processed and visualized efficiently. Figure 3 shows an exemplary process chain for generating leaf spring concepts.

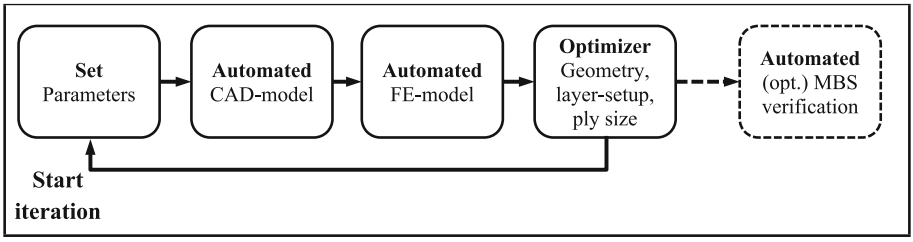


Fig. 3. Exemplary process chain with optional subsequent MBS verification. [own figure]

The first step is the definition of the design space, which is used to define the maximum dimensions of a fully parameterized CAD model of the leaf spring. Furthermore, the type of laminate structure, such as fabric and/or unidirectional layers, must be selected, as well as possible numbers of layers. After that, connection elements and the load cases have to be defined. With this set of parameters, the CAD and the FE model are automatically created in a second and third step. The layer-setup and plies are then optimized. If the optimization results in leaf spring designs whose current kinematics are similar to desired kinematics, for example, this model is saved. After completion of the laminate optimization, a new parameter set and thus a new iteration is started. In parallel, the verification process for multi-body simulations in the complete vehicle or the chassis suspension can be started automatically. If the models meet the evaluation criteria (i.e. strength criteria, deviations in kinematics), they are declared as leaf spring concepts and can be reviewed by the engineer.

3 The Two-Axis Independent Steering System

Tests with the DLR Robomobil from the Institute of Robotics and Mechatronics in Oberpfaffenhofen showed that 240 degrees per second at the wheel is more than sufficient to cope with all driving situations at speeds of up to 100 km/h. The Robomobil is a research demonstrator using wheel independent full electric steering and drives [3], as it is supposed to be in the NGC-UMV. When there is just one single point, where the wheel is connected to the chassis control arm, a cardan like joint can even be used to influence the camber angle as well as the toe angle for steering. There is now the chance to integrate a simple camber angle actuator. No complicated hydraulics or expensive linear actuators are needed to change the length of one control arm for the same effect. As a negative camber angle is positive for a better grip of the tire at cornering, this can be adjusted and optimized by the active system individually for each wheel. Though there is only a small angle range of $\pm 10°$ needed to improve the driving stability effectively, small high-revving motors with a high gear transmission ratio can be chosen to cope

with the requirements of a high torque at estimated 100°/s or ~17 rpm. The research engineers of Daimler showed in their concept car "F400 Carving", that the maximum effect of driving stability and agility would be by an angular range of ±20°. They realized an increase of 30% cornering force compared to a conventional car's suspension and a lateral acceleration improvement of up to 28% compared to sports car with a passive suspension [4]. As safety is within the chassis at highest priority, all electronic systems should be deployed redundantly. This can be achieved by electric motors using double rotor windings and doubled circuit points. The gears are unlikely to fail, if dimensioned with a safety factor high enough. The early concept of a two-axis steering system able to bear all loads is still very massive and complex due to the desire to use as much components already available on the market. All the gearboxes and motors were taken from re-known partners. As the standard gearboxes are not designed to take heavy axial and radial forces, a new bearing housing had to be developed. The massiveness of the needed bearings have to be redesigned to fit into the previously presented wheel.

4 The Wheel as Deflection Shield is Enough for an Improvement in Passive Safety

The possibility to combine wheel individual steering and pre-crash sensors offer new ways to enhance occupants' safety. Deflection is a very effective way to reduce the effects of impact at a small overlap crash. For a stable deflection mechanism within a car often heavy additional or complicated structures were needed. [5, 6]. If the wheel itself as a massive structural part can be used as a deflection shield, no additional heavy structure or complex body stiffeners are needed for this purpose. The steering components, with their high turning speed of at least 240 degrees per second, only need to be activated, when the opponent is less than 1.5 m away. This means, that the wheels are turned by the steering motors or the steer-by-wire-system only an eighth of a second before the crash occurs. Both wheels turn to a toe-in in order like a plough to stabilize the car and give it the right direction. As there are many sensors built in the car today, e.g. for parking, future vehicles with autonomous driving systems will provide even more possibilities to trigger the steering mechanism in a crash scenario. These sensors will be connected to the cars' safety systems and will detect, when a crash is inevitable. The sensors in today's cars are ultrasonic for parking assistance or even radar for automatic distance control and can give the exact timing for the actuation even now. The electronic control units (ECUs) just have to be enabled to act in a proper way. There is a big improvement in reduction of the intrusions within the structure of the simulation of the NGC-UMV during a small overlap crash test scenario firstly introduced from the IIHS. [7]. The displacement of the a-pillar is significantly lower by an overall reduction of more than 25% at the hinge plates, which results in less risk of the jamming of the door after a crash. Also, the overall reduction of the intrusion in the foot area is approx. 25% [8].

5 Conclusion and Outlook

The new NGC-UMV suspension concept is bringing together the individual existing concepts orbital wheel bearing and transverse leaf spring. It is furthermore combining these concepts with the new and innovative two axis steering system. The modular

concept of the systems allows to use the same wheel at each corner of the vehicle without changing a single part, thus reducing vehicle part variants and costs. This new chassis concept is giving a promising answer to the demands of new electric vehicles. With such active steering systems and even partly automated driving including intelligent trajectory planning it is also possible to enhance the crash safety. These systems can also be used to steer the vehicle more into the opponent vehicle in order to use more crash structure of both cars to absorb the crash energy better. This applies in such cases, if the crash is inevitable, but there is no safe place to steer. The DLR proved the feasibility by first static and dynamic simulations and is now investigating further to develop the concept in more detail. The final virtual integration of the suspension system into the NGC-UMV CAD model with all joints and at least the dynamic crash simulation of the whole concept within the car is the last step before a full functional demonstrator is build.

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Impact of ITS Traffic Lights with Speed Displays on Speed Management
Case Study: Croatia

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Abstract. Vehicles' speed is one of the most significant factors affecting the probability of traffic accidents and the severity of their consequences. The correlation between the number of severe traffic accidents and the operating speed of the traffic flow is particularly pronounced in urban areas. One of the main groups of measures aimed at increasing traffic safety includes the application of various methods and equipment for traffic calming. In recent years, the accelerated development of ITS systems and modern systems based on the application of artificial intelligence can effectively influence the increase of traffic safety. The subject of this research is to analyze the efficacy of an ITS system for automatic display of vehicle speeds and speed-activated traffic lights control which is already in operation on selected road sections in the Republic of Croatia. With the aim of increasing the quality of the results and a proper understanding of the effectiveness of the ITS system, the research included four different categories of traffic flow management in similar traffic situations as well as the traffic-technical characteristics of the road. The research was conducted in areas of isolated pedestrian crossings where, as a rule, higher speeds are expected. The system proved to be effective since it significantly affects the calming of the speed of the traffic flow throughout the day. The 85th percentile speed analysis showed that at locations with implemented ITS traffic calming system, the 85th percentile speeds are, in average, about 17–22% lower compared to other researched different pedestrian crossing type locations. Also, the research shows that the presented solution contributes to the harmonization of traffic flow, which, therefore, has a positive impact on traffic safety.

Keywords: Road Safety · Operating Speed · Speed Management

1 Introduction

The Republic of Croatia's National Road Safety Plan (2021) [1] revealed that speed played a role in 39% of severe traffic accidents, with direct involvement in about 17% of cases. Addressing speeding is crucial for road safety, and methods like education, enforcement, and engineering solutions, including speed humps, are commonly used. However, research by Vaitkus et al. (2017) [2] suggests that speed humps may not always be effective.

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An emerging engineering solution is the use of speed display radar devices, which provide real-time speed feedback to drivers. While some display only speed, Gehlert et al. (2012) [3] explored devices that offer engaging messages like “Slow down!” or display emoticons based on driver behavior. Dadić et al. (2003) [4] emphasized the importance of timely information in enhancing traffic safety, making these devices noteworthy for improving road safety.

Bloch’s 1998 study [5] compared two speed reduction systems: photo-radar and speed display radar. Photo-radar detects speeding vehicles and notifies owners, while speed display radars show vehicle speed to alert drivers. In Riverside, California, speed display radars proved somewhat more effective, reducing speeds by 9.3 km/h or 6.6 km/h. Stern et al. (2010) [6] found speed display radars reduced speeds by 1.8 km/h to 4.2 km/h in urban areas, with the 85^{th} percentile speed decreasing by 2 to 6 km/h. Malin and Louma (2020) [7] studied speed display radars at pedestrian crossings, noting a mean speed reduction from 5 to 2.9 km/h, persisting over five months. Ardeshiri and Jeihani (2014) [8] saw temporary speed reductions in various speed zones. Mattox et al. (2007) [9] discussed speed control measures, including speed display radars, with their 2004 Nebraska study showing significant speed reductions after device placement in rural work zones. Similar results were seen in other work zone studies. Lee et al. (2006) [10] reported an average speed reduction of 8.2 km/h in school zones with speed display radars. A recent study by Vlakveld et al. (2022) [11] found road signs displaying children’s book illustrations reduced speeds significantly on urban roads, promoting caution and care among drivers.

The subject of this research is to analyze the efficacy of an ITS system for automatic display of vehicle speeds and speed-activated traffic lights control (hereinafter: the ITS system) which is already in operation on selected road sections in the Republic of Croatia. The working principle of the system is turning the red traffic light on in case the vehicle is moving at a speed higher than the one configured by the system (usually the speed limit). Considering that the ITS solution in the Republic of Croatia is characteristic for isolated pedestrian crossings, for the purposes of the research, measurement of traffic flow speeds was performed at a total of six locations, whereby the locations were categorized into four types.

Based on the results of collected speeds at certain locations during the characteristic days of the week, a comparative analysis was performed to determine the efficacy of the ITS system. Following analysis results it was found that the use of the ITS system can affect the calming of the traffic flow. Also, the research shows that the presented solution contributes to the traffic flow harmonization, which also has a positive impact on road safety.

The ITS system was designed in 2008 by the Croatian company Elektromodul-promet Ltd. The goal was to increase pedestrian safety and reduce the average vehicle speed on the road section, which would consequently increase the safety of all road users on wider road section.

The ITS system was analyzed at two locations in the Republic of Croatia, in Ljubešćica and Patkovac. The locations are set near schools and kindergartens, i.e. in areas with an increased number of pedestrians, especially children.

For the ITS system to work, it must have the following implemented (Fig. 1):

- Traffic lights system
- Vehicle speed radar
- Speed display

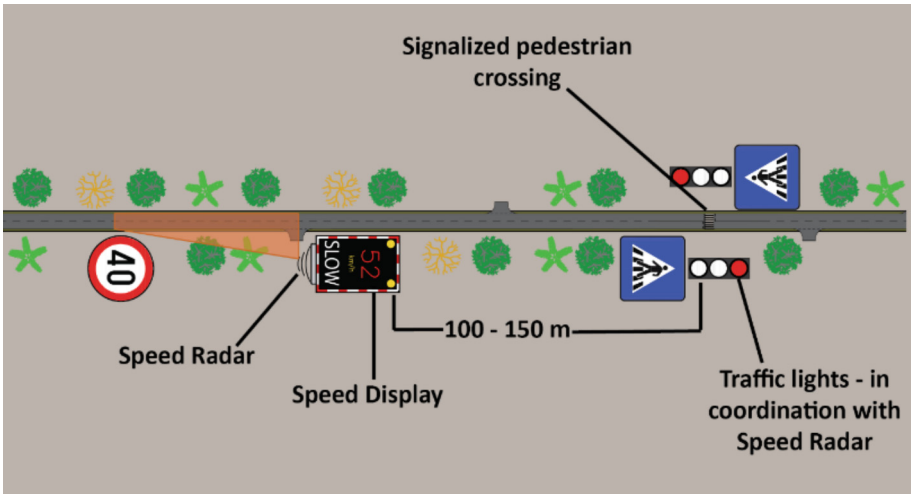


Fig. 1. ITS System Operation Scheme (Author's design)

As a starting point, there is a necessity for coordination of the traffic lights system and vehicle speed radar which should be placed at 100 to 150 m from the traffic lights system.

The system works on the principle that it turns on the red light in case the vehicle is moving at a speed higher than the one configured by the system (speed limit/tolerated speed, etc.). Vehicle speed radars detect the speed at a large distance (depending on the speed limit) and display it to give drivers information of their speed. If the vehicle is moving at a speed higher than the limit, the speed display gives the information with the instruction on slowing down ("SLOW"). If the vehicle continues to move at a speed higher than the one configured by the system, the traffic light, which is connected to the radar and speed display, automatically turns on the red light, forcing the vehicle to stop. It should be noted that traffic light system for pedestrians is equipped with pedestrian announcement system-push button so that pedestrians would not depend on vehicle traffic flow speed.

2 Methodology

To test the efficacy of the ITS system, measurements of traffic speeds were performed both in cases where the ITS system is or is not implemented.

The research methodology can be divided into three basic steps: (1) Selection of locations for conducting field research, (2) Conducting field research, (3) Processing/comparison of collected data.

Considering that the ITS system in the Republic of Croatia is characteristic for isolated pedestrian crossings where higher collision speeds are expected, in the first step the traffic and technical characteristics of the locations where the system is implemented were analyzed. Based on the previously conducted analysis, the selection of locations with similar traffic and technical characteristics which do not have the ITS solution implemented was carried out. During the field analysis, a different way of identification of the characteristic of the location of the ITS solution was determined, so that locations, where the data collection was carried out are categorized into four basic location types:

- P1 - Pedestrian crossing with only horizontal and vertical signalization (traffic signs and/or road markings);
- P2 - Pedestrian crossing with horizontal and vertical signalization, as well as with implemented speed display;
- P3 - Signalized pedestrian crossing with a pedestrian announcement system (push button);
- P4 - Locations with implemented ITS system for automatic vehicle speed display and speed-activated traffic lights control (also including a pedestrian announcement system-push button).

In the second step, traffic flow speed was measured at selected locations using a traffic counter during two characteristic days of the week (Wednesday and Thursday). The reason for choosing Wednesday and Thursday was previously recorded the smallest deviations in AADT at the country at those days.

In the last, third step, the collected data on traffic flow speed was processed according to defined types. After processing, to determine the efficacy of the ITS system, a comparative analysis of traffic flow speed according to defined types was performed.

2.1 Characteristic Location Selection

Traffic and technical characteristics analysis of locations where the ITS system for automatic vehicle speed display and speed-activated traffic lights control has already been established has determined that these locations are usually isolated pedestrian crossings and road sections where higher collision speeds are expected (e.g. urban area entrances, straight routes in an urban area).

For the research, two locations were selected where the system was implemented and four locations where it was not. There are two P4, two P1 and one P2 and P3 location type.

To obtain objective and credible results of comparative analysis, and thus the efficacy of the system, when selecting research sites, the condition was that they have similar traffic and technical characteristics. The analysis of basic traffic and technical characteristics according to locations including site view is shown in Table 1.

2.2 Traffic Flow Speed Data Collection

Traffic flow speed data collection was carried out using automatic traffic counters that record information about the time, speed and length of the vehicle. The measurement was performed over two characteristic days during the week (Wednesday and Thursday).

Table 1. Basic traffic and technical characteristics of the analyzed location

Location	Location type	Speed limit	AADT	Pavement width	Urban area entrances	School zone and similar	Straight route/curve
Čazma	P1	50 [km/h]	3900 [veh/day]	6.50 m	No	No	Straight route
Sirač	P1	50 [km/h]	2163 [veh/day]	6.50 m	Yes	Yes	Straight route
Velika Trnovitica	P2	50 [km/h]	787 [veh/day]	4.90 m	Yes	Yes	Straight route
Rovišće	P3	50 [km/h]	7396 [veh/day]	5.50 m	Yes	Yes	Straight route, curve
Patkovac	P4	50 [km/h]	5521 [veh/day]	6.50 m	Yes	Yes	Straight route, curve
Ljubešćica	P4	40 [km/h]	2849 [veh/day]	6.50 m	Yes	Yes	Straight route, curve

For the purposes of the research, it was important to determine the exact measurement positions at a particular location (similar technical elements of the road, distance from the pedestrian crossing, etc.) to obtain comparable results. Therefore, the exact position of traffic speed measurement at a particular location is defined so that it corresponds to the position at which the ITS system detects the operating vehicle speed and regulates the status of the traffic light device. In practice, this was 100 to 150 m from the pedestrian crossing, depending on the specifics of the location and the legally regulated speed limit.

It is also important to note that when collecting data, traffic load, vehicle lengths and vehicle speeds were measured for both driving directions, while the vehicle speed analysis was performed only for the "inbound" traffic direction (it is considered that vehicle speeds tend to be higher when entering urban zone area from an extra-urban, country road).

2.3 Data Processing

The processing of the collected data was performed using the SAS statistical tool according to the following steps:

1. Downloading the raw data from a traffic counter;
2. Determining atypical values of data collected at a particular location, according to two categories: vehicle speed and vehicle length, and in a way that all values of speed and length that could not be logically explained (e.g. speeds over 140 km/h, and length greater than 40 m) were not used in processing. Less than 1% of such values were recorded at each location. The logical assumption is that, considering the traffic and technical elements of the road, it is difficult to achieve speeds greater than 140 km/h. Also, vehicles of such lengths have not been recorded in Croatia.

3. Analytical and graphical comparison of average hourly speed by location type;
4. Implementation of descriptive statistics of measured speed according to location type;
5. Determining a statistically significant difference in average hourly speeds by location type;
6. Interpretation of the obtained results.

When processing and understanding the results, it is important to note that fine tolerance of +10 km/h is present within traffic regulations in the Republic of Croatia, which means that driver would not be fined if driving, for instance, 70 km/h in 60 km/h limit zone (the tolerance of + 10 km/h refers to speed limits below 100 km/h).

3 Results

The level of efficacy of the ITS system for automatic vehicle speed display and speed-activated traffic lights control was determined based on the established results of descriptive and inferential statistics.

As previously mentioned, the field research included a total of six locations where vehicle speed was measured over a period of two full characteristic days of the week (Wednesday and Thursday).

Pedestrian crossings with horizontal and vertical signalization were analyzed at two locations, Čazma and Sirač. It should be mentioned that the traffic load in Čazma is almost twice comparing to the one in Sirač. Furthermore, the analyzed location in Sirač is set in urban area whereas the one in Čazma is set outside of urban area, at the entrance of urban area.

The maximum average hourly speed is 67 km/h, which is 17 km/h above the speed limit and 7 km/h above the tolerated speed. It should also be noted that even the minimum average hourly speed of the vehicle (54 km/h) exceeds the speed limit (50 km/h).

A pedestrian crossing marked with horizontal and vertical signalization with implemented speed display for both driving directions was analyzed in Velika Trnovitica. The research determined a significantly higher maximum average hourly vehicle speed compared to the previously described type of pedestrian crossing, which was 80 km/h as well as the hourly average on the day which was 63 km/h. The minimum average hourly speed is 56 km/h, which is also an important fact considering the speed limit of 50 km/h and the tolerated speed of 60 km/h.

A signalized pedestrian crossing with a pedestrian announcement system using push-buttons was analyzed in Rovišće. Unlike the previously described two types of pedestrian crossings, lower vehicle speed was recorded at this type of crossing, so the highest average hourly speed was 63 km/h, and the lowest 44 km/h. It is important to note that the hourly average per day speed is only slightly higher than the speed limit and lower than the tolerated speed.

Pedestrian crossings with implemented ITS system for automatic vehicle speed display and traffic lights control were analyzed at two locations, Ljubešćica and Patkovac. It should be mentioned that the traffic load in Patkovac is almost twice comparing to the one in Ljubešćica. However, both locations are set at similar locations considering urban area and school/kindergarten presence nearby the site.

As for the previously analyzed signalized pedestrian crossings (P3), average hourly vehicle speed was lower compared to the analyzed non-signalized crossings (P1 and P2). The highest average hourly speed was 58 km/h, the lowest 52 km/h and the hourly average was 53 km/h.

After conducting the analysis of all four types it is obvious that P1 and P2 have significantly higher values of average vehicle speed throughout the day. It is also a fact that P2 records higher values of average vehicle speed, when comparing to P1, despite being equipped with speed displays, however, they have been implemented for a longer period and it can be assumed that such systems are less efficient after a certain period. When comparing non-signalized pedestrian crossings (P1 and P2), P3 and P4 record lower values of average vehicle speed (Fig. 2).

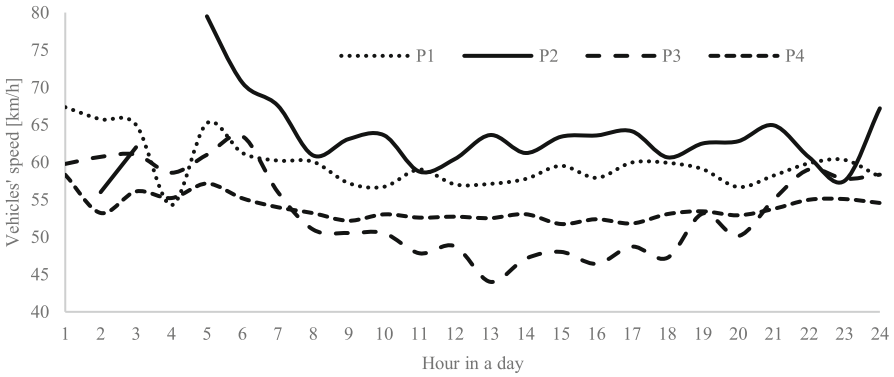


Fig. 2. Speed comparison of all analyzed types

The total sample on which the survey is based is 27628 vehicles. It should be noted that P1 and P4 were analyzed at two locations whereas P2 only at one, which is the reason for such a small number of samples (especially when considering a modest AADT; Rovišće (P3) recorded the highest AADT of all locations). The data needed for descriptive speed statistics is shown in Table 2.

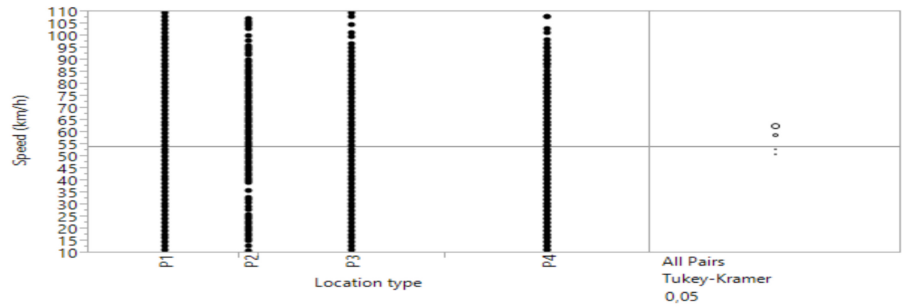
Table 2. Descriptive statistics data for each crossing type

Location type	Number of samples	Average hourly speed	Mean speed	85th percentile speed	Standard deviation
P1	7422	59 [km/h]	60 [km/h]	71 [km/h]	13
P2	926	63 [km/h]	63 [km/h]	76 [km/h]	14
P3	9209	51 [km/h]	51 [km/h]	61 [km/h]	12
P4	10071	53 [km/h]	53 [km/h]	59 [km/h]	9

When average, median and 85th percentile speed is analyzed per each location type, it is clear that there is no substantial difference between the average and median traffic

speed per individual location. As determined by graphical analysis, the lowest value of average speed was recorded in P4 and P3, followed by P1 and P2. On the other hand, the analysis of 85th percentile speed showed that at locations with implemented ITS traffic calming system, the 85th percentile speed is lower by an average about 17–22% than P1 and P2 and about 2% than P3. If the standard deviation is analyzed, the minimal deviation of the traffic speed was recorded at the P4 that has implemented the ITS system for automatic display of vehicle speed and speed-activated traffic lights control. The standard deviation is 30 to 35% smaller compared to P1 and P2 and 25% compared to P3. This indicates a better harmonization of traffic flow speed by implementing the ITS system in relation to all other types.

To determine the statistical significance of the difference in the average traffic speed per certain type, the analysis of the difference in the average speed was performed using the Tukey-Kramer test. The results showed the existence of a statistically substantial difference in speed per location type, which is in accordance with the conclusions of the graphical analysis of the obtained results and the descriptive statistic results. The test results are shown in Fig. 3.



Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2,56919	0,05

LSD Threshold Matrix

Abs(Dif)-HSD

	P2	P1	P4	P3
P2	-1,332	2,773	8,568	10,877
P1	2,773	-0,470	5,342	7,646
P4	8,568	5,342	-0,404	1,899
P3	10,877	7,646	1,899	-0,422

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level		Mean
P2	A	62,602592
P1	B	58,830735
P4	C	53,050013
P3	D	50,737425

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
P2	P3	11,86517	0,3845839	10,87710	12,85324	<,0001*
P2	P4	9,55258	0,3830772	8,56838	10,53678	<,0001*
P1	P3	8,09331	0,1740137	7,64624	8,54038	<,0001*
P1	P4	5,78072	0,1706579	5,34227	6,21917	<,0001*
P2	P1	3,77186	0,3887910	2,77298	4,77073	<,0001*
P4	P3	2,31259	0,1608429	1,89935	2,72582	<,0001*

Fig. 3. Analysis of the difference in the average traffic flow speed

4 Conclusion

Based on the research on the effectiveness of the ITS system for automatic vehicle speed display and speed-activated traffic lights control, measurements of traffic speeds were carried out at different locations where the system is or isn't implemented. To the quality of results and proper understanding of the effectiveness of the ITS system, the research included four different location types of traffic flow management in seemingly similar traffic situations as well as traffic and technical characteristics of the road. The research was related to the traffic regulation in the zone of isolated pedestrian crossings where higher speeds are expected (e.g. urban area entrances, straight routes in urban areas, etc.).

According to the conducted statistical analysis, the highest hourly average speeds per day were recorded in the pedestrian crossing zones marked only by horizontal and vertical signalization with or without speed display (P1 and P2). At the locations with those types of pedestrian crossings were also recorded the highest maximum average hourly speeds (compared P3 and P4). At the location with the signalized pedestrian crossing which includes a pedestrian announcement system (P3), smaller hourly average speeds per day and smaller maximum average speeds were recorded when comparing to P1 and P2, especially during the day when there is substantial pedestrian activity. During the evening and morning hours when there is no walking activity, speeds are substantially higher. According to previously mentioned, it is obvious that pedestrian flows (pedestrian announcement system) do affect vehicle speeds near the pedestrian crossings. Pedestrian crossings with implemented ITS system for automatic vehicle speed display and traffic lights control (P4) substantially affect the calming of traffic speeds throughout the day. The 85^{th} percentile speed analysis showed that at locations with implemented ITS traffic calming system, the 85^{th} percentile speeds are, in average, about 17–22% lower compared to P1 and P2 and about 2% when it comes to P3. According to the analyzed standard deviation, the smallest deviation of the traffic flow speed was recorded at the locations which have implemented ITS system for automatic vehicle speed display and speed-activated traffic lights control (P4). The standard deviation is 30 to 35% lower compared to P1 and P2 and 25% compared to P3. This indicates a more substantial harmonization of traffic flow speed by implementing the ITS system in relation to all other situations which are the subject of the research. Statistical significance was also determined for the previously described results.

In accordance with the research, it can be concluded that average speeds were the lowest at locations with ITS system for automatic vehicle speed display and speed-activated traffic lights control. Lower speeds may have an impact on traffic calming and to the harmonization of traffic flow, which has a positive impact on traffic safety, especially on pedestrian safety.

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A Quick Novel Approach for Analysing an Aging Infrastructure

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Abstract. This paper presents a quick novel approach for analysing bridges. The approach uses finite element modelling, in Excel VBA, whereby bridge and train data is inputted directly into the VBA code; thus, allowing the user to analyse multiple bridges in a single execution. To keep the analysis simple, the train is represented by a series of moving forces; hence, the train inertia effects are ignored. The assessment tool moves the point forces at finite intervals along the bridge to determine the maximum internal forces in the bridge from a particular train configuration. These internal forces are then compared with the bridge capacity to determine an ultization factor for the bridge, completing the Level 0 Bridge Assessment.

Keywords: Level 0 Bridge Assessments · Excel VBA · Finite Element Analysis

1 Introduction

Iarnród Éireann-Irish Rail (IÉ) has an aging infrastructure as most of its rail network was largely constructed in the mid-1800s [1]. The role of the Chief Civil Engineer (CCE) department in Irish Rail is to maintain all infrastructure assets and, wherever possible, extend the life of the asset through planned maintenance. The aging assets include tracks, earthworks, buildings, tunnels, bridges, and culverts; however, this paper only focuses on the bridges that carry train traffic, which are also known as underbridges. With the likelihood of increasing axle loads and train speeds into the future, all the underbridges need to be structurally assessed to ensure they can safely carry new and existing train loads. Omitting closed and disused lines, the authors have over 1400 underbridges that need to be assessed, of which 22% are metallic bridges and are best suited to demonstrate the novel approach developed by the authors in this paper.

Traditionally, one would undertake hand calculations to assess a single bridge subject to a single vehicle using influence lines. This method becomes very onerous considering over 300 metallic bridges need to be assessed for multiple different train configurations (various axle spacings and loadings). Instead, the authors have developed a finite element approach in Excel to reduce the analysis burden. To also reduce the complexity of the analysis, dynamic effects are omitted, and the train axles are modelled as a series of point forces traversing a two-dimensional bridge.

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Engineers have been using Excel for years to undertake bridge assessments, using the finite element method within Excel is nothing new. Usually, the heaviest point force is applied at mid-span of the bridge to find maximum internal forces. This is not a reliable method if one must assess multiple train axles with different loads and axle spacings crossing a bridge. In this paper, the authors move a series of point forces along the bridge at finite intervals to find the maximum internal forces.

2 Beam Element Subject to a Moving Point Force

In its simplest form, the governing equation for analysing an elastic beam subjected to a point force can be written as follows:

$$[k][u] = P \tag{1}$$

where k is the stiffness matrix, u is the nodal displacement, P is force. The wheel which is represented as a point force is globally (X) located from the left-hand support as well as being locally (x) located from the left-hand side of each beam element is illustrated in Fig. 1. The bridge length is L and distance between beam nodes is l.

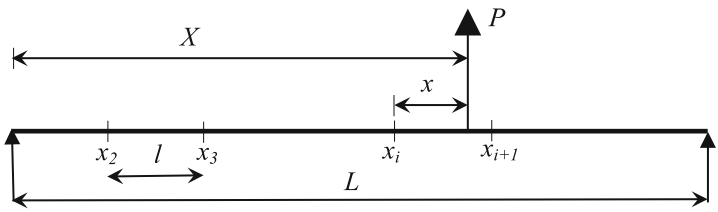

Fig. 1. Beam subject to a point force

With the aid of Bowe [2], the internal forces in a single beam element is written as:

$$\begin{Bmatrix} Q_1 \\ M_1 \\ Q_2 \\ M_2 \end{Bmatrix} = \frac{EI}{l^3} \begin{bmatrix} 12 & 6l & -12 & 6l \\ 6l & 4l^2 & -6l & 2l^2 \\ -12 & -6l & 12 & -6l \\ 6l & 2l^2 & -6l & 4l^2 \end{bmatrix} \begin{Bmatrix} v_1 \\ \theta_1 \\ v_2 \\ \theta_2 \end{Bmatrix} - P \begin{Bmatrix} N_1 \\ G_1 \\ N_2 \\ G_2 \end{Bmatrix} \tag{2}$$

where Q_1, M_1, Q_2, M_2 are the internal nodal shear forces and bending moments, subscript 1,2 refer to beam element local nodes, E is the Young's modulus of the beam; I is the moment of inertia of the beam, v is the vertical nodal displacement, θ is rotation nodal displacements, and N_1, G_1, N_2, G_2 are weighting shape functions that can be described as:

$$N_1 = 1 - \frac{3x^2}{l^2} + \frac{2x^3}{l^3}; G_1 = x - \frac{2x^2}{l} + \frac{x^3}{l^2}; N_3 = \frac{3x^2}{l^2} - \frac{2x^3}{l^3}; G_2 = -\frac{x^2}{l} + \frac{x^3}{l^2} \tag{3}$$

Combining force P with Eq. (3) gives the nodal forces and nodal moments that are then applied to the beam element at local node 1 and local node 2, when a wheel is between these two local nodes.

Moreover, using the weighting shape function N_1, G_1, N_2, G_2 along with the local beam displacements v_1, v_2 and rotationsθ_1, θ_2 one can find the vertical position of each point force as it traverses the beam v_b as follows:

$$v_b = \begin{bmatrix} N_1 & G_1 & N_1 & G_2 \end{bmatrix} \begin{Bmatrix} v_1 \\ \theta_2 \\ v_1 \\ \theta_2 \end{Bmatrix} \tag{4}$$

3 Bridge and Train Model

3.1 Bridge Model

As a case study, the authors have selected the underbridge UBM695 located on the Athlone-Westport line. This bridge is constructed of a pair of 914 × 305 × 289 kg UB with a clear span length of 11 m. For the two-dimensional analysis, a single UB is selected and sub-divided into 10 elements, each element 1.1 m in length. Ballast and the bridge self-weight amount to an additional force of 20 kN applied to each beam node (halved at the end nodes) before any train axle arrives onto the bridge.

3.2 Train Model

For the train model, the authors have selected a single 201 locomotive along with two HOBS ballast wagons traversing the bridge. The train axle spacing, and loadings are shown in Fig. 2. Distance from front to rear axle is 50.741 m. The train is also modelled two-dimensionally, so the axle loads are halved in the analysis.

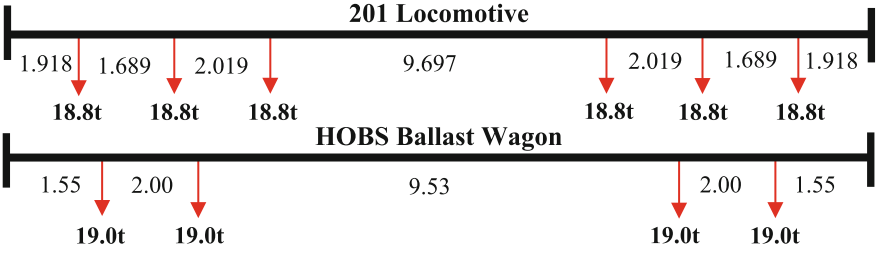

Fig. 2. 201 locomotive and HOBS ballast wagon axle spacings and loadings

4 Bridge-Train Assessment in Excel

4.1 Beam Model Built in Excel

Within Excel, the process is as follows: (1) compute local stiffness matrix for each beam element; (2) build global stiffness matrix; (3) apply simply supported boundary conditions to the global stiffness matrix; (4) invert global stiffness matrix; (5) multiply the inverted global stiffness matrix by the external forces to find the beam displacements; (6) find reaction forces by multiplying original global stiffness matrix by beam displacements; (7) compute internal forces by multiplying local stiffness matrix by local beam displacements and subtract external forces.

4.2 Train Model Built in Excel

For numerical reasons, the front wheel of the train is positioned 0.1 mm off the left-hand support at the start of the analysis, as this allows the user to see the deflected shape and internal forces, from the ballast and bridge self-weight, before any train arrives onto the bridge. The train is then moved at short intervals along the bridge. At each train movement, the global (X) and local (x) position of each wheel is updated along with their respective weighting shape function N_1, G_1, N_2, G_2. The weighting shape functions are then multiplied by the point force P to find the nodal forces and moments that are applied to beam. Triggers within Excel, alert the user when the maximum internal forces are found. For the train configuration, as described in Sect. 3.2, the train is advanced in 618 movements across the bridge until the last wheel passes the right-hand support. This single assessment takes approximately 2–3 min to complete. If one then considers that 300 metallic bridges need to be assessed, this method can take several hours for a single train configuration. Instead, the authors have coded the bridge-train assessment in Excel VBA and the 300 bridges for multiple train configurations can be completed in minutes in a single execution.

5 Demonstrating the Assessment Tool

Returning to UBM695 (as described in Sect. 3.1), initial loads are applied to the bridge before the arrival of the train. The train loads are then moved along the bridge at short intervals. It is found that the maximum bending moment occurs when Wheel 1 is positioned at 21.3 m from the left-hand support (LHS). At this stage, Wheels 1 to 3 are no longer on the bridge, but Wheels 4, 5, 6, and 7 are globally positioned at 7.895 m, 5.876 m, 4.187 m and 0.719 m, respectively from the LHS. Using Eq. (3), Table 1 presents the weighting shape function values along with the calculated nodal forces and moments that generate the maximum bending moments on the bridge.

Similarly, it is found that the maximum shear force on the bridge occurs when Wheel 1 is positioned at 24.4 m from the left-hand support (LHS). At this instant, Wheels 4, 5, 6, 7 and 8 are globally located at the following positions 10.995 m, 8.976 m, 7.287 m, 3.819 m and 1.819 m, respectively from the LHS and their calculated weighting function values and nodal forces and moments can be seen in Table 2. It should be noted, in

Table 1. Calculated values (bending) when Wheel 1 is 21.3 m from the LHS.

Wheel Positions			Weighting Shape Functions				Nodal Forces & Moments			
W	Global X	Local x	N_1	G_1	N_2	G_2	PN_1	PG_1	PN_2	PG_2
4	7.895	0.195	0.917	0.132	0.083	–0.028	–84.6	–12.2	–7.7	2.6
5	5.876	0.376	0.729	0.163	0.271	–0.085	–67.3	–15.0	–24.9	7.8
6	4.187	0.887	0.098	0.003	0.902	–0.139	–9.0	–3.1	–83.2	12.8
7	0.719	0.719	0.277	0.086	0.723	–0.163	–25.8	–8.0	–67.4	15.2

Table 1 and 2 that Wheels 4 to 6 have a wheel force P of 92.2 kN (rear wheels of the 201 locomotive), while Wheels 7 and 8 have a wheel force P of 93.2 kN (front wheels of HOBS wagon).

Table 2. Calculated values (shear) when Wheel 1 is 24.4 m from the LHS.

Wheel Position			Weighting Shape Functions				Nodal Forces & Moments			
W	Global X	Local x	N_1	G_1	N_2	G_2	PN_1	PG_1	PN_2	PG_2
4	10.9949	1.0949	0.000	0.000	1.000	–0.005	0.0	0.0	–92.2	0.5
5	8.9759	0.1759	0.931	0.124	0.069	–0.024	–85.9	–11.4	–6.3	2.2
6	7.2869	0.6869	0.317	0.097	0.683	–0.161	–29.2	–8.9	–63.0	14.9
7	3.8189	0.5189	0.542	0.145	0.458	–0.129	–50.5	–13.5	–42.6	12.1
8	1.8189	0.7189	0.277	0.086	0.723	–0.163	–25.8	–8.0	–67.4	15.2

The maximum internal forces (shear and bending moments) are found to be 375.3 kN and 896 kNm for this train configuration. For comparison purposes, the authors undertake hand calculations to validate the developed system and the results differ by less than 1% as shown in Table 3.

Table 3. Computed nodal moments and forces from train on the bridge.

Node	Bridge	Position	Maximum Shear Force		Maximum Bending Moment	
			By hand	Numerical	By Hand	Numerical
1	LHS	0	-286.8	-286.7	0.0	0.2
6	Mid-span	5.5	-0.4	9.6	890.5	896.0
11	RHS	11	376.3	375.3	0.0	0.1

Recalling to Eq. (4), the vertical displacement of any wheel can be computed using the weighting shape functions along with the beam's local displacement. As an example, the vertical position of Wheels 5 is calculated and graphically displayed along with Wheels 4, 6 and 7 in Fig. 3 when Wheel 1 is 21.3 m from LHS.

$$Wheel5 = \begin{bmatrix} 0.729 & 0.163 & 0.271 & -0.085 \end{bmatrix} \begin{Bmatrix} -0.01043 \\ 0.00001 \\ -0.00993 \\ 0.00091 \end{Bmatrix} = -0.01037 \text{ m}$$

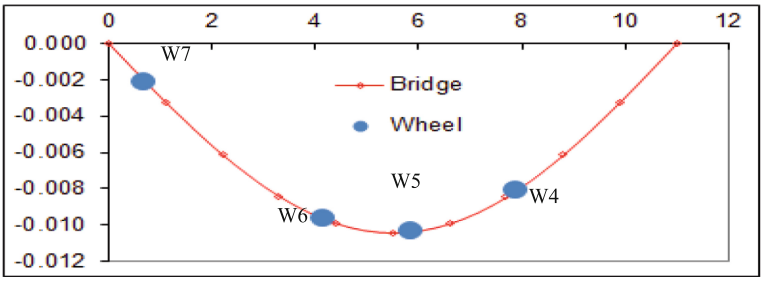

Fig. 3. Wheel horizontal and vertical position tracked in Excel (Max Moment)

Similarly, the vertical position of Wheels 5 is calculated and graphically displayed along with Wheels 4, 6, 7 and 8 in Fig. 4 when Wheel 1 is 24.4 m from LHS.

$$Wheel5 = \begin{bmatrix} 0.931 & 0.124 & 0.069 & -0.024 \end{bmatrix} \begin{Bmatrix} -0.00608 \\ 0.002346 \\ -0.00321 \\ 0.002815 \end{Bmatrix} = -0.00566 \text{ m}$$

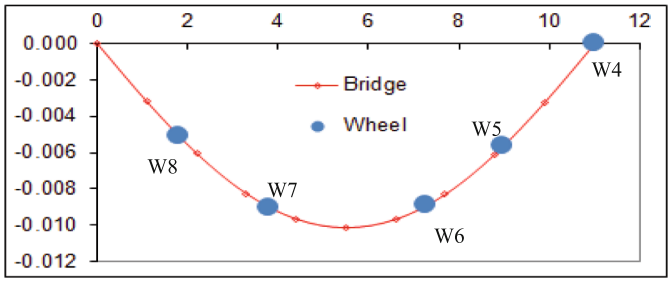

Fig. 4. Wheel horizontal and vertical position tracked in Excel (Max Shear)

The final step of our assessment is undertaking a structural capacity check by comparing the maximum internal forces with the structural capacity of the beam examined. If one finds the utilization factor (for shear and bending moment) to be below 80% threshold value, the bridge passes the Level 0 structural assessment process.

6 Conclusion

In this paper, the authors present a simple quick solution for undertaking bridge-train assessments in Excel VBA. Each train wheel is represented as a moving point force. The point force is multiplied by a weighting shape function to determine the nodal forces and moments that are applied to the beam. The weighting shape functions are also used to graphically track the vertical position of each wheel on the bridge. Results show the developed numerical solution to be within 1% of hand calculations, making it a quick accurate method for analysing bridges. The next step is to undertake field experiments using sensors attached to a bridge to verify the numerical solution.

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Traffic Flow Breakdown Prediction for the M50 Motorway in Ireland

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Abstract. Traffic flow breakdown, characterized by the abrupt transition from smooth traffic to congestion, impacts motorways globally, causing delays, fuel wastage, and stress for drivers. Detecting and forecasting these incidents is crucial for motorway safety and efficiency and in aiding Intelligent Transport Systems like automatic incident detection and variable speed limits in mitigating traffic breakdowns. Ireland's M50 motorway, accommodating around 115,000 daily vehicles, frequently experiences traffic breakdowns. Manual variable speed limits have been implemented to enhance traffic management, and the M50 is equipped with real-time data collection sensors like induction loops and weather sensors. While deep neural networks have gained prominence in predicting traffic breakdowns, their data-intensive nature and longer training times still make artificial neural networks a compelling option due to their simplicity. This paper uses data collected on the M50 motorway in 2019 to train an artificial neural network to forecast traffic breakdowns within the next five minutes on specific M50 sections. Using a genetic algorithm approach, the input parameters for the neural networks were optimized, resulting in a significant improvement from 20% to 62% accuracy over naive parameter selection. Notably, the study reveals that critical features for predicting traffic breakdowns are detectable as early as 30 min before occurrence.

Keywords: Traffic Breakdown · Traffic Theory · Breakdown Prediction · Intelligent Transport Systems

1 Introduction

The M50 (Dublin Ring Road) was built in the 1990s and widened between 2005 and 2010 to solve the traffic problems caused by the daily influx of people into the capital city. Some sections of the road see over 115,000 vehicles on average per day. In an effort to alleviate the impact of incidents and delays, traffic management solutions such as Variable Speed Limits (VSLs) and Lane Control Systems (LCS) are being trialled at various points along the M50. However, these

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systems are currently manually operated from a control centre. Designing efficient automatic VSLs requires incorporating data that can provide an overview of the current state of the motorway, including the current conditions and the possibility of an imminent breakdown in traffic conditions.

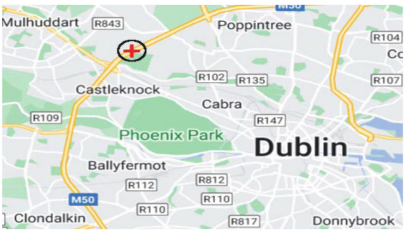
Previous studies [2,5,7,9–12] have investigated various machine learning techniques and statistical methods for predicting an imminent breakdown in traffic conditions. Each approach has advantages and disadvantages that are primarily influenced by the specific characteristics of the motorway and the data available for that motorway. Other works focus on pre-processing traffic data to improve model performance, such as by removing intra-day trends that emerge on motorways [1,7], or using per-vehicle trajectories to predict overall traffic flow [6]. Three major trends are visible in the literature. Firstly, simpler machine learning techniques such as Artificial Neural Networks (ANNs) feature heavily, likely due to the results achieved using them. Secondly, most works predict traffic flow breakdown within the next minute. Thirdly, the trend of moving towards more advanced machine learning techniques such as Long Short-Term Memory networks (LSTMs) [7] and deep neural networks (DNNs) [9,10,12].

This paper focuses on traffic breakdown prediction using machine learning techniques. Traffic breakdown can be defined as an abrupt change from free-flowing to congested traffic conditions. We refine this definition by using the definition of a congested state from the US Highway Capacity Manual [8], where a congested state is defined as greater than 22 vehicles per kilometre per lane (veh/Km/lane) or an average speed less than 60Km/h. Congestion is then defined as a sequence of congested states over a period of 5 min. The first 5 min of congestion is referred to as the change from a smooth to a congested state (SCS5). Each motorway section is equipped with double-inductive loops and has a weather sensor nearby. In this paper, we implement a simple ANN to predict whether or not traffic breakdown will occur within the next 5 min on the M50 motorway. The ANN was trained using data collected on the M50 during 2019, and optimal input features were selected by using a genetic algorithm approach.

2 Experiments

Traffic data and weather data recorded on the motorway were leveraged to provide an extensive database for testing. Traffic data is collected using double-inductive loops spaced at approximately 500 m intervals along the M50 motorway in Dublin, Ireland. These loops provide data such as speed, flow, vehicle length and occupancy every 20 s for each carriageway lane. Alongside the induction loops, several weather sensors are located along the M50. These weather sensors record data such as road surface temperature, visibility, and precipitation. Data for 2019 was used to avoid using any data collected during the COVID-19 pandemic. This paper focuses on one location surrounding Junction 6 on the M50, shown in Fig. 1a

Pre-processing of Data: The collected data is first bucketed into 5-min intervals totalling 105120 5-min samples. A significant issue with this approach is



(a) Location of interest on the M50.

ID	Description
1	All year
2	2hr before congestion and SCS5
3	Density > 21 and SCS5
4	2hr before congestion and Density > 21 and SCS5

(b) Different configurations of the input training and evaluation data.

Fig. 1. .

the ratio of positive SCS5 (congestion occurring) samples to negative samples (congestion not occurring). This is not unsurprising due to the prevalent state of traffic being uncongested; most of the day congestion is not occurring. Due to the negative samples significantly outnumbering the positive samples, the classification task will be imbalanced, and further pre-processing necessary. Negative samples in the two hours before congestion occurs are taken to improve the sample imbalance. While this significantly increased the positive to negative samples ratio, it increased the number of false positive predictions, where congestion is predicted to occur but does not. This was caused by short-lived congestion, i.e. where the thresholds for congestion are met but only last for a short period. A slight revision of the definition of congestion was necessary to address these short-lived congestion states. To prevent false positives like those mentioned, congestion must last at least 10 min and be at least 10 min apart from another occurrence of congestion. For each induction loop entry, the data set was augmented with the corresponding weather, time of day and day of the week.

3 Traffic Flow Breakdown Prediction

To predict traffic flow breakdown, an ANN was used since they have shown promising results in several works. The selection of input parameters for an ANN can depend on many characteristics, such as road specific characteristics, weather condition, time and day of the week, etc. To make the input parameter selection more efficient and avoid heuristically choosing the parameters, we propose using a genetic algorithm approach to select the input features and how much data is contained per sample, for example, data from five minutes before congestion vs. data from ten minutes before or how many neighbouring induction loops to include. The selected input parameters and ANN are the "genetic representation", while the utility function is F1-Score resulting from the ANN across the test data set. During each iteration, 500 ANNs were randomly generated in terms of their input parameters and amount of data per sample. At the end of each generation, the top 10 performing ANNs (measured under the F1-Score) were selected for use in the next generation. The genetic algorithm was run for a maximum of 200 generations. However, it converged after approximately

90 generations. This approach can be particularly helpful when the impacting parameters might be hard to identify due to specific setting of a road network and its environment.

4 Results

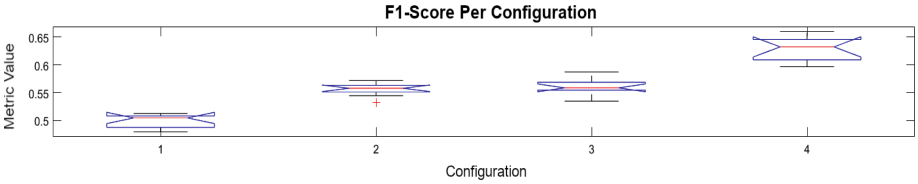
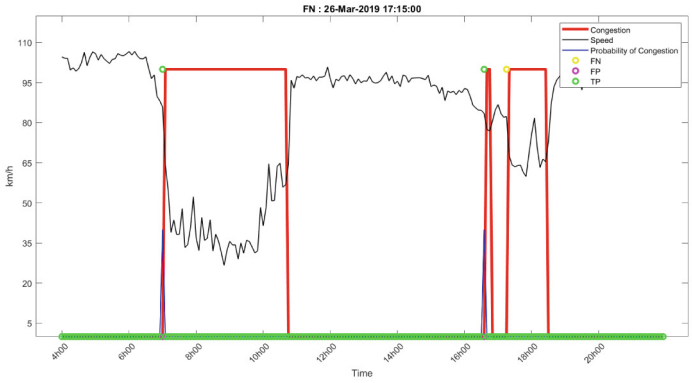
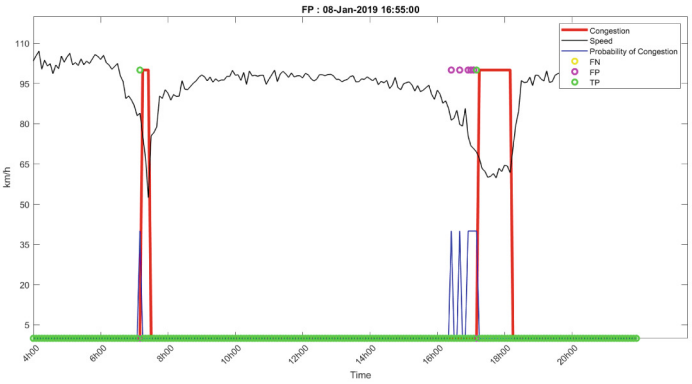


Fig. 2. F1-Score for each configuration (See Table 1b).

The F1-Scores for each configuration are presented in Fig. 2. **Configuration 1** has a significant class imbalance problem. Most of the time, there isn't any congestion on the road, so the number of positive congestion samples is very low compared to the negative, no-congestion samples. t. The ANN correctly predicted the onset of congestion approximately 50% of the time, which is a random guess for a binary classification task. **Configuration 2** significantly improves the class imbalance in the data set. This change led to improvements across all performance metrics, with the model correctly predicting the onset of congestion approximately 55% of the time. **Configuration 3** results of this configuration were similar to that of configuration 2. However, it was observed to produce more false positives, likely due to the absence of samples at the density threshold, which were present in configuration 2. **Configuration 4** combines the previous two and produces the highest performance metrics. The configuration can correctly predict the onset of traffic breakdown approximately 62.5% of the time. **To further understand** the performance capabilities of the trained ANN, we investigated cases where the model produced false positives and negatives using the graphs presented in Fig. 3. We observe the presence of false negatives when a congested state is followed by another in a short period of time (Fig. 3a). We observed that false positives occur recurrently 5, 10 and 30 min before an SCS5 (Fig. 3b). The presence of false positives in the lead-up to congestion would suggest that the information necessary to predict the onset of congestion is present up to 30 min before it occurs.



(a) False negative after recent congestion.



(b) False positives immediately before congestion.

Fig. 3. Investigation of false positives and false negatives produced by the ANN.

5 Conclusion

We have presented the experimental results of training an ANN to predict whether or not a breakdown in traffic will occur within the next 5 min on the M50 motorway. We described the pre-processing conducted on the M50 data and how the various pre-processing steps impacted the performance of the final model. The final model correctly predicted the onset of traffic breakdown within 5 min 62% of the time. The results highlight the impact of how congestion is defined on the sensitivity of models trained to predict it. Several avenues can be explored in future work. Further investigations into the increased amount of false positives occurring up to 30 min before congestion occurs could lead to being able to predict congestion occurring much further in advance, which will provide more time for automated systems to modify traffic behaviour. Other works [3,4] indicate that weather conditions can impact drivers' behaviour. However, data

from weather stations was determined unimportant during the feature selection stage, so a further investigation into the impact of weather conditions could prove insightful. Finally, a simple ANN was used for prediction. Switching to a more advanced method, for example, DNNs, Convolution Neural Networks or LSTMs, might yield higher performance metrics.

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Women Perceptions in Transient Environments and the Need for AI to Drive Safer Travel: An Inclusive Mobility Study in India

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Abstract. Women of all ages face higher risks than men when travelling and during public transport waiting times. This risk is higher for women living in India than their counterparts residing in the Western world.

The primary objective of this study was to understand women's perception of safety while travelling in India and how it affects their travel behaviour.

A mobility survey was designed to cover various aspects of travel, such as travel experience, built environment characteristics, and their impact on women's safety perception. The subjective data was examined to explore the link between safety perception, built environment, and changes in travel behaviour.

Respondents consider that security and safety are the top two factors influencing women's travel mode in their everyday journeys in India. The present study also found that over 80% of women are likely to change their travel behaviour after experiencing fear, anxiety, or danger during their everyday journeys.

These findings have important implications for policy and best practice regarding safer and more gender-inclusive transport provision.

Keywords: Women · safety · travel behaviour

1 Introduction

Women tend to use cars less frequently than men, rely more on public transportation, and have more destinations to reach daily [1, 2]. However, women are more vulnerable to risks in transport due to unequal access to resources, education, and job opportunities [3]. Questionnaires are often used to explore the issue of gender-based violence and women's mobility [4–6]. In Colombia, women accounted for over 50% of public transit users, and they were more afraid of sexual harassment - a type of crime they are more likely to experience than men, which often goes unreported [5]. In Colombia, 47% of women changed their mobility travel choice or behaviours when a gender-based violence incident occurred [4]. In India, 91% of women felt that public transport was unsafe [7]. Another study across many Indian cities suggested that 60% of women felt insecure while travelling to work or by public transportation [6].

In India, despite the risks women face while using urban transport systems, most gender-based incidents go unreported. It is unclear how these incidents might affect

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women's travel behaviour. Moreover, existing literature does not provide much insight into how perceived safety impacts women's travel behaviour in India, especially after they have experienced uncomfortable situations or become victims of verbal and/or physical gender-based violence in transient environments. Our study aims to bridge this gap by examining how perceived safety may influence women's travel behaviour in India.

2 Methodology

2.1 Questionnaire

A mobility survey was designed to gather participants' opinions on travel experience in India. The mobility survey included 14 questionnaire items grouped as follows: 1) Travel behaviour; 2) Perception of the built environment during travel; 3) Solutions to reduce gender-based violence in transient settings; 4) Future travel preferences; and 5) Socio-demographic characteristics. Questions items were presented as multiple-choice questions to facilitate data collection.

The survey was written in English. Sensitive questions about being a victim of gender-based violence during travel were excluded to prevent any discomfort to the participants. The survey was deployed on Google's free forms platform (Google Forms), and invitations to participate in the survey were sent via colleagues at the Symbiosis Institute of Technology (SIT), India and via social networks (e.g. LinkedIn).

To participate, individuals had to meet the eligibility criteria approved by Aston University Ethical Approval and regulations, which included being at least 18 years old, having a sufficient understanding of the English language, and living in India.

2.2 Data

The online survey was carried out in India. Data was collected between June to September 2023. Fifty-five participants consented to participate, and following a data quality check, 14 observations were excluded.

This study aims to understand women's perception of safety while travelling in India and how it affects their travel behaviour. The analysis is focused on questionnaire items from groups 1, 2, and 5 (presented in Sect. 2.1) as follows:

- Group 1 questionnaire items to explore the frequency of use of different travel modes.
- Group 2 questionnaire items to explore the characteristics of the built environment that may make women less comfortable on their everyday journeys.
- Group 2 and Group 5 questionnaire items to explore the impact of experiences and fear during journeys on women's travel behaviours and the potential influence of socio-demographic factors on the perceived travel change.

The analysis was performed for the overall sample without gender stratification due to the low number of respondents. Given the high prevalence of gender-based violence in India, it is reasonable to assume that the "non-female" participants are sensitive to women's safety risk exposure while travelling in India. The analyses were conducted

using IBM SPSS Statistics version 26. Spearman correlation rank-order correlation coefficients (ρ) were calculated between respondents' travel mode choice, reason for mode choice, influence of the built environment and travel safety perception impact on travel behaviour.

3 Results and Discussion

3.1 Respondents

The study comprises responses from 41 participants, with 33 women (accounting for 81% of the participants), seven men, and one individual identifying with the gender category "other". The original aim was to examine safety perception differences between men and women. However, due to the limited number of responses, non-binary individuals were also included in the analysis.

The average age of the participants was 27.9 years old (SD = 9.3), indicating that they were young adults. Although all the questionnaire items related to socio-demographics were optional, the participants must provide their age and gender information to comply with the study design. According to the results, most participants were either full-time employed or students, with 46.3% and 39.0% respectively. Therefore, participants require daily mobility modes to commute to their study or work locations over other social or care-related mobility needs. While 4.8% were homemakers or stayed at home, 2.4% were retired, and 2.4% preferred not to say. Regarding education level, most responders had a university degree (80.49%), and 2.44% had Technical/vocational training. Therefore, participants require daily mobility modes to commute to their study or work locations over other social or care-related mobility needs.

3.2 Mobility Survey Results Analysis

The means, standard deviation, and frequency distributions of the travel behaviour and travel experience questions that are the focus of this research are presented in Tables 1 and 2. The study examines how women's perception of safety in India might impact their travel behavior.

Regarding the travel mode, it seems that walking was the most popular option, with 42% of participants choosing this mode for everyday travel. Motorcycles came in second with 29%, while public transport was used by 20% of the respondents.

As evidenced by the data in Table 1, which displays questionnaire items (Q3_1-Q3_7), mean, standard deviation, and frequency distributions, the most important factors for deciding on a travel mode were travel security and safety, with 57% and 46% of respondents rating them highly. Among the respondents, those who prioritized the securest travel mode to avoid crime, violence, or harassment (Q3_5, M = 4.32, SD = 0.93) and those who chose the safest travel mode to avoid traffic accidents (Q3_4, M = 4.17, SD = 0.95) had the highest mean ratings, on a scale from strongly disagree (1) to strongly agree (5). Interestingly, some participants also believed that physical exercise and affordability played a role in their mode of transport choice, with 17% strongly

Table 1. Frequencies for the reasons linked to choosing the travel mode.

Reason (Q3_1-Q3_7)	M	SD	Relative frequencies				
			Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
Q3_1: Choosing the most low-cost travel mode	3.34	1.11	2.40%	24.40%	26.80%	29.30%	17.10%
Q3_2: Choosing the fastest travel mode	3.93	1.01	2.40%	4.90%	24.40%	34.10%	34.10%
Q3_3: Choosing the most comfortable travel mode	4.02	1.06	2.40%	7.30%	17.10%	31.70%	41.50%
Q3_4: Choosing the safest travel mode to avoid traffic accidents	**4.17**	0.95	0.00%	7.30%	14.60%	31.70%	**46.30**%
Q3_5: Choosing the securest travel mode to avoid crime/violence/ harassment	**4.32**	0.93	2.40%	2.40%	9.80%	31.70%	**53.70**%
Q3_6: Choosing an active travel mode to physically exercise (walking/cycling)	3.27	1.16	4.90%	24.40%	26.80%	26.80%	17.10%
Q3_7: Choosing the most environmentally friendly travel mode	3.22	1.27	7.30%	29.30%	17.10%	26.80%	19.50%

agreeing (Table 1). Ultimately, it is essential to prioritize safety and security when selecting a travel mode while also considering other factors relevant to one's preferences and women's needs.

All attributes related to built environment factors that could impact women's perception of fear or discomfort were considered relevant (Q4_1-Q4_7). Most participants (76%) believed that the presence of suspicious individuals in a public space would increase the risk of danger and make women feel fear or discomfort. Poor street lighting and being in lonely places without surveillance, such as CCTV, were also significant factors linked to the perception of safety while travelling and identified by 65% of

the respondents. Finally, 61% of participants pointed out that deserted streets or roads contributed to women's sense of fear or discomfort.

Table 2. Frequencies for travel safety perception.

Question	Relative frequencies
How may the built environment influence the women's perception of safety during travel? (Q4_1-Q4_7)	
Q4_1: Poor street lighting	65.90%
Q4–2: Deserted streets or roads	61.00%
Q4_3: Characteristics of sidewalks (e.g. poor line of sight due to walls/trees)	43.90%
Q4_4: Public space occupied by suspicious people (e.g. rewording)	**75.60%**
Q4–5: Stations/train platforms deserted or without surveillance	61.00%
Q4_6: Bus stop in lonely place or without surveillance	65.90%
Q4_.7: Other	9.80%
How feelings of fear during everyday journeys would change women's travel? (Q5_1-Q5_7)	
Q5_1: Travelling accompanied	63.40%
Q5_2: Avoiding walking at night	65.90%
Q5–3: Avoiding cycling at night	29.30%
Q5_4: Change route	**51.20%**
Q5_5: Using taxicabs or private vehicles	43.90%
Q5–6: Not going out for a while	26.80%
Q5_7: No change, keeping the same travelling habits	12.20%

In this study, we also explored the impacts on women's travel behaviour due to potentially experiencing any gender-based violence incident during their everyday journeys (questionnaire items Q5_1-Q5_7). Based on the respondents' perceptions, women who have experienced a feeling of fear or anxiety during their travel on their travel behaviour would prefer to travel with a companion (63%), avoid walking at night (61%), and take a different route (51%), as shown in Table 2. This finding corroborates a study in Colombia that reported that 47% of the women changed their mobility travel choice when a gender-based violence incident happened [4]. Women chose longer walking routes, where they felt safer, avoiding public transit when it was empty or full [4].

It is worth noting that only 12% of respondents (5/41) have considered that even though women could have been exposed to such uncomfortable travel experiences, they would not change their travel (Table 2). However, when investigating those responses further, it was found that three of them have also chosen other responses (e.g. "Travelling accompanied." or "Using taxicabs or private vehicles."). This means an incoherent response for those three participants as if they had chosen "No change"; no other option should have been chosen. As participants' contact information (e.g. email) was

not gathered, it was not possible to clarify whether this contradiction was a typo or a misunderstanding of the change or no change in travel behavior.

Spearman correlation rank-order correlation coefficients (ρ) were run to determine the relationship between respondents' travel mode choice, reason for mode choice, built environment and safety perception impact on travel behaviour. Results showed a significant positive correlation between participants with considered green options while choosing the travel mode choice was a significant correlation with using the bike ($\rho(41) = 0.485$, $p = 0.01$). There was a significant positive correlation between comfort and walking ($\rho(41) = 0.404$, $p = 0.01$) and comfort and using the bike ($\rho(41) = 0.367$, $p = 0.05$). It was interesting to notice the impact of the built environment, its relationship with travel mode, and the reasons for mode choice. The presence of suspicious people was negatively correlated with use using the bike and using public transport ($\rho(41) = -0.317$, $p = 0.05$) and $\rho(41) = -0.321$, $p = 0.05$), respectively. Additionally, the presence of suspicious people in the transient environments (while walking or waiting for a bus or train) negatively correlated with participants' perception of comfort. It is also worth noticing that those who choose the travel mode to favour physical activity (exercise, Q3_6) showed a negative correlation with 'not going out for a while', in case feelings of fear during everyday journeys would change women's travel, ($\rho(41) = -0.381$, $p = 0.05$). Hence, this suggests the influence of how the built environment and fears and safety perception may impact travel behaviour, which is in alignment with previous research in Colombia showing that women changed their mobility travel choice when a gender-based violence incident happened [4].

The study's limitation of having a low number of responses ($N = 41$) prevented the authors from conducting the planned gender-stratified analysis on the travel behaviour mobility needs and differences between females and males. This was due to the small number of male participants (only 7 responded) and the relatively small number of female participants ($N = 33$). It has been reported that survey samples from lower-income countries tend to contain a higher proportion of males [8]. Therefore, it is reasonable to conclude that Indian men perceived this study as women-focused and did not prioritize participating. This could have contributed to the low response rate for male participants.

It is important to note that even if a larger sample size were available, we expect that the key factors affecting travel experience, such as safety, security, and built environment, will remain unchanged.

4 Conclusion

Based on our mobility survey, this study indicates that the two prevalent factors behind women's choice of travel mode in India are security and safety, 57% and 46%, respectively. The built environment plays a significant role in shaping their perception of safety when travelling, with 76% citing the presence of suspicious individuals in transient environments as a major anxiety factor. Our study also found that 88% of women are likely to change their travel behaviour based on their perceptions of safety and security while travelling.

It is important to recognize the built environment's impact on how human perceptions and feelings of insecurity and fear are developed. To gain a better understanding, future

research could supplement subjective data that rely on the participants' ability to recall past experiences and perceptions (e.g. questionnaires) with other data like social media posts with AI-supported sentiment analysis to unpack what the participants mean by 'safety,' 'security,' and 'suspicious people.' This will then help inform policymakers to implement appropriate interventions to promote safer and gender-inclusive travel for women.

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Shun Ha Sylvia Wong: Reviewing and editing.

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Layering Tailored Shape Memory Alloys into Carbon Fibre-Reinforced Polymer Composites for Enhanced Frontal Impact

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Abstract. The automotive industry's pursuit of lightweight components presents a challenge in balancing weight reduction and structural integrity. Shape Memory Alloys (SMAs) offer a promising solution, capable of altering their properties when triggered, enhancing the crashworthiness of front-end vehicle components such as bumper beams and crash boxes. This research integrates SMA elements into carbon fiber-reinforced polymer (CFRP), forming an advanced composite material. To validate this approach, crashworthiness testing will use finite element analysis (FEA) software like LS-DYNA. Physical crash tests, though reliable, are costly and time-consuming. FEA simulations provide a cost-effective, time-efficient alternative, crucial for developing automotive components. LS-DYNA's SMA material data cards will accurately model SMA behavior, aiding in the optimization of these composites.The innovative crash box design, incorporating ten SMA wire layers within CFRP, demonstrates significant improvements: a 79% weight reduction compared to standard steel versions, a 60% decrease in peak force, and a 97% increase in specific energy absorption. This cutting-edge research highlights the potential of SMAs to revolutionize automotive component design, achieving superior performance and efficiency.

Keywords: First Shape memory alloys · advanced composite · weight reduction · finite element analysis · automotive · crashworthiness

1 Introduction

To optimize the crashworthiness of automotive front-end structures (FES) while reducing weight, various innovative approaches have been proposed. These include material selection, structural modifications, and new element introduction.

[7] replaced steel with aluminum alloy 6060, TRIP800, and DP800 in the bumper, crash box, and front rail, achieving a 10.1% increase in energy absorption and an 11.1% decrease in mass. Carbon fiber-reinforced plastic (CFRP) offers significant potential due

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to its superior specific stiffness, strength, and fatigue properties compared to metals [1]. CFRP provides advantages such as weight reduction, enhanced crash resistance, and aesthetic appeal.

[9] used CFRP to redesign the crash box, enhancing crashworthiness by 52%. [8] reported increased specific energy absorption with CFRP compared to steel, and [7] reduced bumper beam weight by 35.57% using CFRP. Material selection is crucial for optimizing crashworthiness and achieving weight reduction, with composite materials enabling weight reductions exceeding 50% [4].

To further enhance FES crashworthiness and reduce weight, integrating shape memory alloys (SMA) like nickel-titanium (NiTi) into the material composition is promising. SMAs revert to their original shape after deformation, improving crash resilience while maintaining weight reduction goals.

Finite element analysis (FEA) software, such as LS-DYNA, offers a cost-effective and efficient alternative to real crash tests, expediting vehicle component development and conserving resources.

2 Methodology

The developed model incorporates a conventional crash box design from [10], using CFRP with integrated shape memory alloy (SMA) wires. CFRP's mechanical properties are specified in Table 1. SMAs are layered at 90 degrees and 0 degrees. At 0 degrees, 5 wires are used per face, resulting in a 2mm total CFRP thickness. Two configurations are tested: one with 10 SMA wires and another with 20 wires per face. NiTi is the selected SMA, with key properties in Table 2.

In LS-DYNA, MAT 54/55 is used for CFRP and MAT 30 for SMA elements. The NiTi SMA is modelled in its austenite phase with a Young's modulus of 83 GPa. A Mesh Sensitivity Analysis determined the optimal element size to be 5 after testing sizes from 2 to 10. The ideal Node Integration Points (NIP) value was found to be 10 through trial and error, testing values from 1 to 15.

Collision simulations use a planar moving forces rigid wall with an 800 kg mass and a velocity of 20 mph [3]. The crash box's opposite end is anchored with specific boundary conditions to prevent movement. Three crash box versions are simulated: a standard steel version (properties in Table 3), a CFRP model with SMA wires on the outer face, and another with SMA wires embedded within the CFRP.

The SMA wires are layered between 1mm CFRP sheets at a 0° angle, contacting both CFRP layers via tied node surface contacts. The CFRP sheets act as solid components with automatic surface-to-surface contact, defined as a single integrated part in LS-DYNA. The simplified collision simulation focuses on the crash box, excluding other components like the bumper beam, to independently assess the effectiveness of the SMA-CFRP layering.

Table 1. Material properties of CFRP [5]

Properties	CFRP
Density (kg/mm^3)	1.6×10^{-6}
Longitudinal Young's Modulus (GPa)	70
Transverse Young's Modulus (GPa)	70
Shear Modulus (GPa)	5
Poisson's ratio	0.1

Table 2. Material properties of NiTi [7]

Properties	NiTi
Poisson's ratio	0.33
Austenite Young's Modulus (GPa)	83
Martensite Young's Modulus (GPa)	28 - 41
Density (kg/mm^3)	2.7×10^{-6}
Yield Stress (GPA)	1.45

Table 3. Material properties of steel [2]

Properties	Steel
Poisson's ratio	0.3
Young's Modulus (GPa)	200
Density (kg/mm^3)	7.83×10^{-6}
Yield Stress (GPA)	0.36

3 Results and Discussion

After comparing the specific energy absorption (SEA) of different quantities of shape memory alloy (SMA) wires, it was concluded that the optimal configuration consists of 10 wires. The 20-wire configuration experienced premature failure due to brittleness and element deletion in the simulation. Despite minimal SEA differences, the 10-wire setup showed better impact endurance. The 20-wire configuration increased peak force by 0.2%, so 10 wires were used for both CFRP designs, with wires layered between the CFRP and on the crash box's outer faces.

The standard steel version showed a peak force of 239.57 kN, reduced by 51% when switched to CFRP with SMA wires on the outer faces (Fig. 1). This force was further reduced to 96.47 kN, a 60% decrease, with SMA wires layered within the CFRP structure. The force-displacement curve for layered CFRP showed a gradual increase in force, with the peak occurring at the end of the collision, unlike the other designs where peak force occurred initially. This gradual deceleration improves occupant safety by avoiding sudden jolts.

Specific energy absorption for the three crash box versions was also compared (Fig. 2). The CFRP version with SMA on the outer faces increased SEA from 2949.57 J/kg (standard steel) to 84967.74 J/kg, a 96.5% increase. The CFRP crash box with SMA layered between the CFRP materials further improved SEA to 87174.47 J/kg, a 97% increase compared to steel and a 0.5% increase over the non-layered CFRP version. The weight comparison for the three crash box versions showed that the CFRP designs, differing only in SMA integration, had the same weight (Fig. 3). The weight reduced from 1.75 kg (steel version) to 0.36 kg for CFRP designs, a 79% reduction. A lighter crash box maintains or enhances energy absorption and crashworthiness, reduces vehicle inertia, improves handling and stability, and lowers rollover risks.

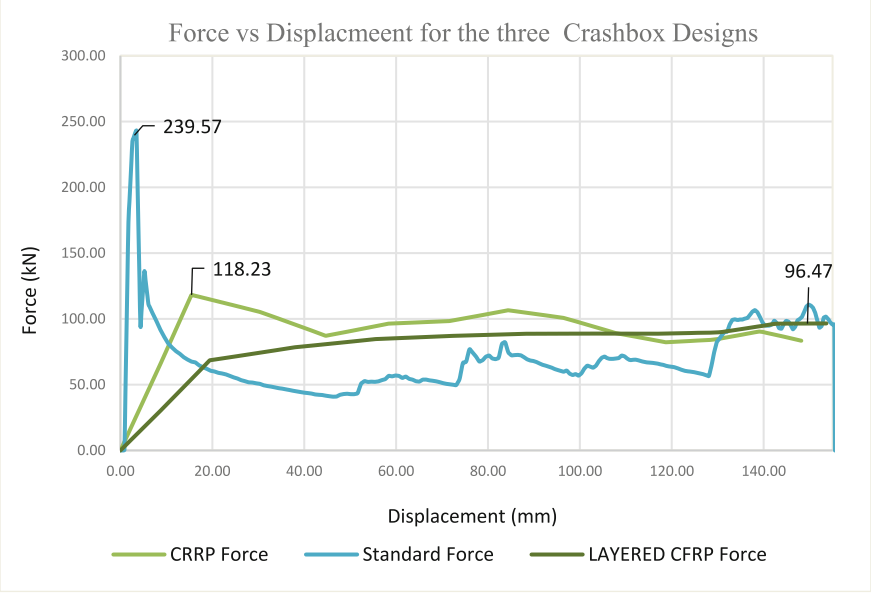

Fig. 1. Force against displacement curve for the three version of the crash box simulated.

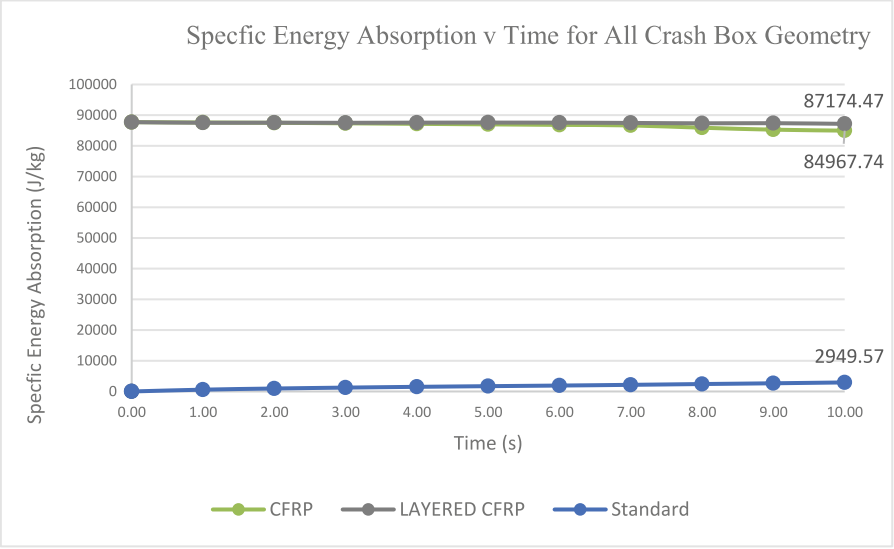

Fig. 2. Specific energy absorption comparison for the three version of the crash box simulated.

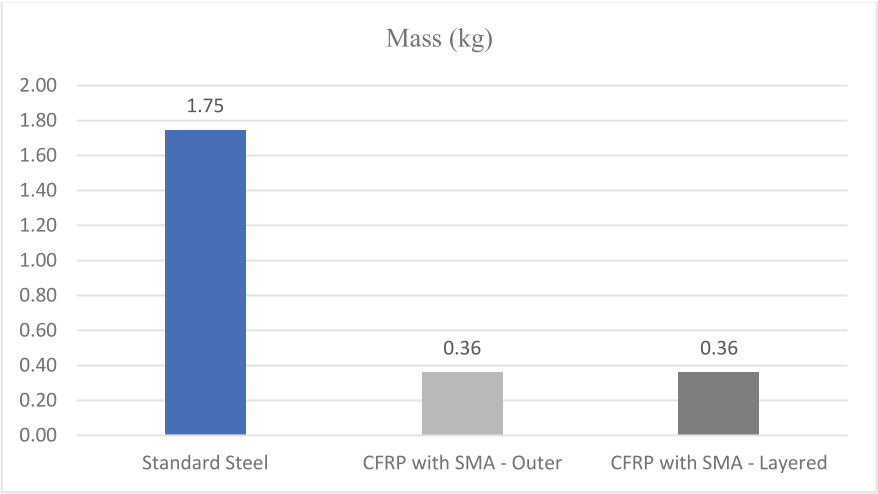

Fig. 3. Weight comparison for the three version of the crash box simulated.

4 Conclusions

In conclusion, our study examined the specific energy absorption (SEA) of shape memory alloy (SMA) wires in crash box designs. We found that 10 wires was the optimal configuration, as the 20-wire setup experienced premature failure due to material brittleness.

Despite minimal SEA differences, the 10-wire design showed better impact endurance and only a 0.2% increase in peak force compared to the 20-wire configuration. Thus, we chose the 10-wire setup for CFRP-integrated designs.

Force-displacement analysis indicated that CFRP with SMA wires significantly reduced peak forces during collisions. The layered CFRP design showed a gradual force reduction, enhancing occupant safety by avoiding abrupt deceleration.

Comparing SEA, the CFRP version with outer-facing SMA wires increased SEA by 96.5%, and the version with layered SMA wires improved SEA by 97% over the standard steel version. This higher energy absorption reduces impact forces on occupants, promoting road safety.

Both CFRP designs reduced crash box weight from 1.75 kg (steel) to 0.36 kg, a 79% reduction. This weight reduction, while maintaining or improving safety, benefits vehicle dynamics, maneuverability, and rollover prevention.

In summary, layering SMA wires within CFRP crash box designs enhances SEA and reduces weight, offering improved vehicle safety and performance.

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Development of an Optimum Quantitative Approach to Assessing and Classifying Lane Marking Durability Performance

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Abstract. Maintenance of road infrastructure assets is integral to providing a safe environment for road users. The performance of lane marking material is vulnerable to deterioration due to factors including traffic volume, lane marking material and pavement degradation. The aim of this research was to develop a systematic method of assessing and classifying lane marking durability performance i.e. the level of material wear, through analysis of Mobile Laser Scanning point cloud data and to compare its effectiveness against current visual assessment procedures. The extraction of lane marking point cloud data was undertaken using the intensity values of the lane marking material and the percentage of material wear was subsequently calculated. A Defect Classification System was developed with input from industry experts and allocated to the percentage of wear results. This provided georeferenced durability performance defect severity results along the extracted section of lane marking point cloud data, for use by Infrastructure Asset Managers when targeting the remediation of lane marking assets.

Keywords: Infrastructure Asset Management · Lane Markings · Durability Performance · Point Cloud Data · Mobile Laser Scanning · Defect Classification

1 Introduction

Road markings (delineation) are fundamental infrastructure assets featured on roadway networks, helping vehicles to navigate in a uniform and safe manner [1] by conveying warnings and guidance information to road users [2]. Infrastructure asset inspection and maintenance including lane marking assets, play a significant role in the delivery of a safe environment for road users [3]. While technologies exist for assessing lane marking retro-reflectivity, chromaticity and skid resistance, an objective method for assessing lane marking durability performance is lacking. Durability performance describes the level of wear of the material i.e. when the road surface becomes visible under the material, as illustrated in Fig. 1.

Measuring the durability performance of lane markings is conventionally achieved using a standard index as a guide to measure the level of lane marking material uniformity and wear. An examination of durability/wear indexes from Transport Infrastructure

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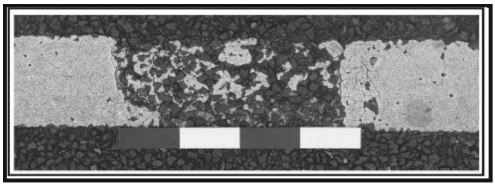

Fig. 1. Evidence of lane marking wear; the durability performance of the markings. Image: Siobhán Tierney

Ireland's (TII) Specification for Road Works Series 1200 [4] and the UK's Design Manual for Roads and Bridges (DMRB) [5] found that these only provide guidance on how to undertake these assessments visually. While the UK DMRB includes imagery based on a level of wear index, the image quality is poor. Regardless of image quality however, any assessment is subjective and dependent on the professional making the assessment. Processing software currently enables the extraction of lane marking point cloud data due to its high intensity value. By utilising such data, captured using a Trimble MX9 MLS and building on the information provided in the above indexes, this research aims to contribute to lane marking durability performance assessment by providing a semi-automated, objective approach to assessing and quantifying lane marking durability performance, including the development of a Defect Classification System (DCS).

2 Methodology

This research takes a systematic approach to the development and application of lane marking durability performance assessment and defect classification and is predominantly quantitative. It includes the capture and processing of lane marking MLS point cloud data. The suitability of this data for durability performance analysis was assessed by comparing it against ground truth imagery collected from within a study area.

It was important that the index provided in the DCS reflected the true nature of lane marking durability. This was achieved through the contribution of knowledge generated from a semi-structured interview with experts from TII's National Delineation and Signage Programme Management Team (NDSPMT). The DCS was subsequently tested on Delineation Infrastructure Management experts in other agencies within Ireland via an online survey.

A number of software packages were used to develop the assessment and quantification processes during this research. Atlas Survey Control Centre (SCC) was used to process the point cloud data when determining durability performance and automatically generated results in CSV format. Autodesk was used to cleanse and prepare the data prior to importing to Esri ArcGIS Pro (version 2.9.0) for geo-referencing the defect classification results and presentation in Esri ArcGIS StoryMap.

2.1 Study Area and Defect Classification System

For this research, a road section located along a northbound section of the N61 (national secondary road) in County Roscommon, Ireland was selected from the MLS data. This

section was 860m in length and consisted of continuous, 150 mm wide centreline markings containing visible varying degrees of wear.

The DCS provided an index classifying the severity defect of lane marking durability performance depending on the percentage of material coverage i.e. the level of wear. This DCS could be used in the future to assess the durability of lane marking performance from which remedial actions could be determined based on the severity rating.

2.2 Point Cloud Data Processing and Assessment

This section details the data processing, assessment and ground truth validation undertaken during this research. The road section point cloud data was processed using SCC, which can identify features based on their intensity values. Lane marking material has a high intensity value [6] making it possible to extract markings from the point cloud data using those values. The process involved rescaling the dataset using the lowest and highest lane marking intensity readings and normalizing the results [7]. The markings were extracted in stages to isolate all lane marking points from within the point cloud data model and included the removal of features and noise from outside of the lane marking intensity range. This resulted in a lane marking point cloud model containing centreline point cloud data only, which was used in the subsequent analysis.

From the centreline lane marking point cloud model, an 860m central alignment string was generated, with the northern end of the alignment recorded as Chainage (CH) 0m. At CH18m, a section of marking was identified with no material wear i.e. 100% material coverage. This was used as a 'benchmark polygon' for all future lane marking assessments and involved overlaying a polygon measuring 750 mm × 150 mm at CH18m and calculation the number of point cloud points (hereinafter referred to as points) within the polygon. One hundred and seventy-three polygons (750 mm × 150 mm) were then overlaid along the central alignment at five-meter intervals, starting at CH.0m. The number of points within each polygon was calculated to determine their percentage of lane marking coverage when compared against the 'benchmark polygon' point count. This data was exported to a CSV file and assigned a durability performance defect severity based on the DCS. Further processing involved exporting the polygon data into AutoCAD to cleanse and prepare each polygon, before importing them into ArcGIS Pro where it was joined with the defect classification (CSV) data. The results were displayed geographically based on their defect severity, with each severity represented by a different colour. The ability to geo-reference infrastructure assets is an integral element of Infrastructure Asset Management [8]. An ArcGIS StoryMap with the defect classification data was created to enable further examination of the results at specific sections of the markings, which could be shared with other Stakeholders.

The suitability of the point cloud data for assessing lane marking durability performance was evaluated by comparing results against images of lane marking material captured from within the study area. A method of quantifying material coverage using imagery was developed. This involved placing a 750 × 150 mm polygon over a lane marking image taken from the UK DMRB. The polygon was divided into 125 squares, with each square sub-divided into quadrants. Quadrant count methods are widely used in point pattern analysis [9] and in this instance facilitated the calculation of the percentage of material present within the polygon, taking the distribution of the material into

account. The level of wear within the polygon was quantified by reviewing each square and assigning a negative rating where it met one or both of the following criteria: a) lane marking material is missing over an entire quadrant, b) varying degrees of lane marking material is missing in three out of four quadrants.

A ground truth validation process was developed to compare the results produced from the point cloud defect classification analysis with the imagery analysis. Due to Traffic Management (TM) constraints, it was not possible to capture 173 corresponding images at the same location as the point cloud polygons. Consequently, images were captured for seven identical polygons of lane marking material along the road centreline, for comparison with their corresponding point cloud data. The defect classification was calculated for the seven locations using both the point cloud and imagery analysis methods and their results compared.

3 Results and Analysis

The lane marking DCS was developed based on TII and UK DMRB documentation and feedback provided from the semi-structured interview with TII's NDSPMT and the online survey with industry experts as illustrated in Table 1.

Table 1. Lane Marking Durability Performance Defect Classification System.

Defect Classification	Description	% of wear	Maintenance Action Required
Severity 1	Critical defect	>45%–100%	Full reinstatement required
Severity 2	Medium critical defect	>25%–45%	Requires spray + extrude treatment
Severity 3	Medium noncritical defect	>10%–25%	Requires spray treatment
Severity 4	Noncritical defect	>5%–10%	Monitor for future maintenance
No Defect	As per Design Spec	0%–5%	No Action Required

Over eighty percent of respondents stated that the DCS would be extremely useful for assessing lane marking durability performance. An analysis of the benchmark polygon at CH18m identified that 1331 points represented 100% material coverage. The percentage of material coverage was then calculated for the 173 polygons and their defect classification was determined using the parameters detailed in Table 1. An extract from defect classification results is shown in Table 2.

The results provide valuable information regarding the durability performance of the lane marking material using point cloud data and were also geo-referenced, thus providing decision makers with a more effective assessment of the level of wear occurring along the centreline lane marking. The full geo-referenced results of the point cloud defect classification can be found in ArcGIS StoryMap https://arcg.is/0D88Dr.

Table 2. Extract from point cloud polygon defect classification results

Chainage	Points per Polygon	% of marking coverage	Defect Classification
250	562	42%	Severity 1
255	1119	84%	Severity 3
260	1217	91%	Severity 4
265	1137	85%	Severity 3
270	887	67%	Severity 2

The assessment of the durability performance of marking material using images and the introduction of a ground truth validation process enabled the direct comparison of images versus point cloud data when assessing durability defect classification. A visual comparison of both methods is illustrated in Fig. 2. The results indicate that fifty seven percent of the ground truth validation results matched across both assessment methods when classifying durability performance.

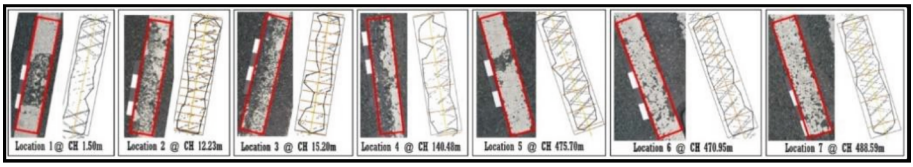

Fig. 2. Visual Assessment of Ground Truth Analysis Result. Image: Siobhán Tierney

Although this demonstrates inconsistency when comparing the result of both methods, there are key factors to note. Where the defect fell within the severity 1–2 range (locations 1, 2, 3 & 4), results were consistent across both methods. In contrast, narrower bands with lower defect severities (3 & 4) had more disparity in results, with analysis of the imagery judging the level of wear more harshly. The ground truth validation results were limited to a sample of seven locations within the study area, but it is assumed are reflective of the results achievable at the other locations along the roadway.

4 Discussion and Conclusions

The key findings from this research confirm the benefits of using MLS point cloud data together with GIS technologies to firstly assign a defect classification to lane marking durability performance and then determine their location within the road network. This approach provides a more effective and efficient solution to lane marking asset management from a durability performance perspective, thus enabling asset management resources to be targeted at specific locations within the road network that require maintenance. In addition, unlike the current approach of capturing imagery for assessment which requires TM, this is not required when collecting using MLS.

The analysis of the ground truth images took the distribution of material into account, which allowed for a more accurate assessment of the level of wear. However, this method is done manually and is time-consuming. In contrast, the point cloud analysis method is semi-automated although it was most suitable for identifying lane marking with more critical severity 1 and severity 2 defects. Further work is recommended to fully automate the point cloud analysis method and to consider the distribution of material, including incorporating the quadrant count approach to provide more accurate results across the less critical defect severities. The ground truth validation aspect of this research was limited to seven locations due to TM constraints. Further research should include a broader sample of ground truth locations within the study area to allow for enhanced comparison against the point cloud analysis results.

Noteworthy progress has been made during this research and the objective method of assessing and classifying durability performance may be applied to other sources of point cloud data. With the increase in Autonomous Vehicles (AV) comes the potential to apply this workflow to point cloud data captured by AV sensors. Further research would benefit from the analysis of such data when assessing durability performance using the method developed during this study, with the results having the potential to provide infrastructure asset managers with real-time durability performance data.

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Innovative Interchange Design: The Diverging Diamond Interchange (DDI) on the Irish National Road Network

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Abstract. Diverging Diamond Interchanges (DDIs) are an innovative form of grade separated interchange which have proven to deliver operational and safety benefits, as well as substantial cost savings in their successful implementation around the world. DDIs provide an opportunity to efficiently upgrade existing grade separated interchanges on the national road network through retrofitting, providing safety and operational benefits which align with evolving policy for sustainable road infrastructure development, and promoting the safe, efficient and sustainable mobility of people and goods in Ireland.

Keywords: DDI · Innovative Interchange · Sustainable Design · Safety

1 Introduction

Road authorities are facing the challenge of addressing the mobility needs of an ever-increasing population, with increased congestion and high collision rates a key area of concern. This paper studies the applicability of Diverging Diamond Interchanges (DDIs), an innovative form of grade separated interchange, on the Irish National Road network. These types of interchanges have proven to deliver operational and safety benefits, as well as substantial cost savings when compared with traditional grade separated interchange upgrades. With the rapid development of policy in Ireland to support sustainable infrastructure development and optimizing the re-use of existing assets, the DDI offers an innovative interchange solution which aligns with policy and offers an opportunity to support the advancement of safe, efficient and sustainable mobility of people and goods in Ireland.

2 Background/Context

The Irish Government's long-term strategy for the country is outlined in Project Ireland 2040 and the National Planning Framework [1] which ensures alignment of investment plans with the stated National Strategic Objectives (NSOs) for 2040. The strategy is aligned with European and Global Policy towards addressing climate change, in recognition of the threat that it poses to the achievement of the Sustainable Development Goals (SDGs). This alignment is reinforced throughout several government policy documents.

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The National Development Plan 2021–2030 [2] and National Planning Framework [1] establish the National Strategic Outcomes (NSOs) for delivery of Project Ireland 2040. The National Investment Framework for Transport in Ireland (NIFTI) 2021 [3], translates the NSOs to a transport investment context. NIFTI outlines a hierarchy of intervention for the Irish transport network which priorities maintaining, optimizing and improving existing infrastructure ahead of building new infrastructure. The DDI offers the opportunity to retrofit and upgrade existing conventional diamond interchanges to extend their serviceable life, with widening and re-alignment works only, and without the need for demolition of existing and reconstruction of new bridges/interchanges, in line with the optimizing/improving levels of the NIFTI intervention hierarchy. National Roads 2040 (NR2040) [4] is TII's long term strategy for planning, operating and maintaining the National Roads network. NR2040 [4] notes that the management of National Roads must balance increasing mobility demands and finite road space. The DDI solution provides an opportunity to unlock congestion at existing conventional diamond interchanges, without the need for major interventions, aligning with the aims and goals of National Roads 2040.

The Irish Government's Road Safety Strategy (RSS) 2021 – 2030 [5] has a new ambition at its core, guiding Ireland towards a 'Vision Zero', with the long-term goal of eradicating road traffic deaths and serious injuries by 2050. The RSS will be delivered by adopting the Safe Systems Approach, which emphasizes the need to focus on all elements of the road traffic system to successfully improve road safety. At a high level, the innovative design principles of DDIs removes right turn conflict points and associate high-risk collisions. The comparison of pre and post-implementation data at existing DDIs has confirmed that significant reductions in collisions can be expected, resulting in an overall improvement of safety which is aligned with the objectives of the RSS.

3 Literature Review of Existing DDIs Internationally

A literature review has been undertaken into the successful implementation of DDIs internationally – there are more than 135 DDIs currently in operation in 9 countries worldwide, with several others currently in the planning and design phases. The literature review has drawn from published studies, assessments and reports from a variety of sources. The key findings of the literature review are backed by post-implementation studies on the DDI and these are summarized below:

3.1 Safety

One of the primary safety features of the DDI is the significant reduction in the total number of conflict points at the interchange in comparison to conventional diamond interchanges. While there are 26 possible conflict points contained at a conventional diamond interchange, the DDI contains only 14 as illustrated in Fig. 1 [7].

In addition, the most critical crossing conflict points at the interchange (i.e. right turn crossing conflicts) are reduced from 10 to 2. The right turn movements are converted into free-flow right turn movements utilizing the innovative geometry of the crossover intersections at the DDI. This has proven to considerably reduce collisions at the interchange as outlined in some of the post-implementation safety evaluations listed below.

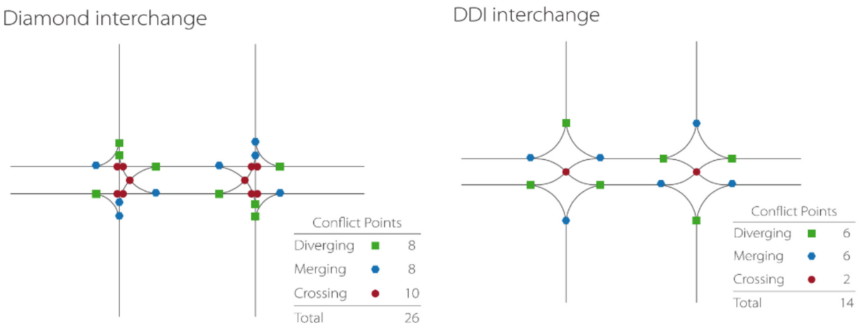

Fig. 1. Comparison of conflict points between a conventional diamond interchange and DDI [7]* NB this is based on a right-hand drive scenarios. Source: UDOT7

- *Safety Evaluation of Diverging Diamond Interchanges in Missouri* [10] evaluated crash data over a five-year period before, and one-year after the introduction of the DDI. The evaluation concluded that overall crashes decreased by 46%, while right angle crashes were eliminated.
- Research carried out by Missouri Department of Transportation on 6 DDIs in the US [9] compared crash data for a three-year period before and after the DDI was introduced. The evaluation concluded that overall crashes decreased by over 40%, while serious injury/fatal crashes decreased by over 60%.
- *Safety Evaluation of Seven of the Earliest DDIs* [14] was an evaluation carried out to determine a Crash Modification Factor (CMF) for the conversion of a conventional diamond interchange to a DDI. The evaluation recommended a CMF of 0.67, meaning that the introduction of a DDI to replace a conventional diamond interchange is expected to reduce overall crashes by 33%. The reduction in severe crashes was even larger, with the team recommending a CMF of 0.59, translating to a 41% expected reduction in severe crashes.

3.2 Operational Performance

As a result of changing traffic patterns and increased demand, many conventional interchange arrangements can no longer accommodate growing traffic demands and heavy turning movements. Due to the removal of right turn conflicts as outlined in Sect. 3.1, the DDI can operate a coordinated set of crossover intersections with just two signal phases. The reduced number of signal phases also reduces the amount of inter-green time, allowing shorter cycle times to be implemented and unlocking substantial green time for the efficient operation of the interchange. Figure 2 illustrates the benefits of reduced signal phases on green time and efficiency.

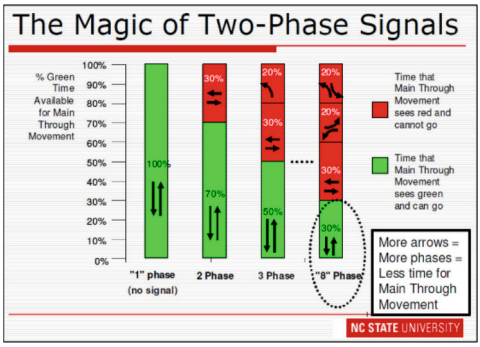

Fig. 2. Benefits of less opposing movements/fewer signal phases [15]. Source: Hummer15

3.3 Geometry/Space Proofing

One of the most distinctive features of a DDI is its innovative geometric design, allowing left-hand traffic to temporarily cross to the right-hand side of the road, facilitating free-flow right turn movements onto the motorway on-ramps. The overall footprint of a DDI is generally less than that of traditional interchange arrangements which achieve similar levels of capacity. Due to the conversion of right turn movements into free-flow movements, auxiliary right turn lanes are not always required, and a reduced footprint is generally achieved on the bridge in comparison with existing conventional diamond interchanges [7]. It is noted that alternative traditional interchange arrangements which may achieve similar levels of capacity such as partial cloverleaf interchanges, Single Point Urban Interchanges (SPUI) typically require substantially larger footprints, increased new ramp construction, wider bridges and cost in comparison with a DDI.

3.4 Pedestrian/Cyclist Facilities

Cycle facilities can be provided with a cycle lane adjacent to the traffic lanes to allow bicycle crossover movements at the same time as vehicular crossover movements. It is noted that it may be preferable to cater for Active Travel users away from major interchanges, which interface with larger strategic traffic volumes, in order to ensure safer and more secure transport for Active Travel users. Pedestrian facilities can be provided as footways on the verge side of the interchanges or as a footway through the central median of the interchange. Additionally, crossings of islands can be signal controlled to ensure pedestrian and cyclist safety is maintained.

4 Applicability Within the Irish Road Context

As outlined in Sect. 3, the DDI has been successfully implemented within right-hand drive environments in USA, with substantial safety and operational benefits achieved. These benefits and lessons learned remain applicable in left-hand drive scenarios. In addition to its success in right-hand drive environments, the DDI has been successfully implemented in left-hand drive environments including in Australia and South Africa both in new build and retrofit scenarios:

- Bruce Highway/Caloundra Interchange DDI – Queensland, Australia.
- Gympie Arterial/Strathpine Road DDI *(retrofit)* – Queensland, Australia.
- Pacific Motorway/Southport Burleigh Road DDI – Queensland, Australia
- Kwamushu DDI *(retrofit)* – Durban, South Africa [12, 13]
- Sefako Makghato DDI *(retrofit)* – Gauteng, South Africa [13]

Further to the literature review, a study is being undertaken into the feasibility of the DDI concept at an identified junction on the Irish national road network. The existing conventional diamond interchange at the identified site has been classified as a High Collision Location (HCL) due to the high frequency of right turn collisions occurring at the interchange with vehicles attempting to access the major road using the on/off-ramps. There are also significant traffic volumes using the existing interchange, with the worst-case individual junction within the interchange operating at 96% Flow to Capacity (RFC). This results in congestion issues that can largely be attributed to the high right turn demand at this junction during the busiest peak period. Furthermore, the congestion leads to reported queuing on the off-ramps with queuing spilling back onto the motorway mainline, creating further road safety concerns at the interchange.

The DDI concept eliminates the conflict points associated with the critical right turn movements, leading to a safer operation of the interchange. It also provides substantial operational benefits due to the efficiency of the two-phased signal phasing configuration. The DDI arrangement can be retrofitted at the site (subject to further detailed investigations), optimizing the use of existing infrastructure and aligning well with National, Regional and Local policy in relation to sustainable development. An initial options assessment has been undertaken which involved a multi-criteria assessment of the DDI versus traditional grade separated interchange arrangements including a conventional diamond interchange and partial cloverleaf interchange. The assessment concluded that the DDI was the preferred arrangement, and the concept is being progressed through a more comprehensive design and options appraisal process. The ultimate aspiration is to implement the DDI as a Pilot Project, subject to further detailed investigations. This process will provide a further evidence base for the applicability of the DDI on the Irish national road network, and inform the development of new standards/guidelines for the wider implementation of DDIs on national roads in Ireland.

5 Conclusion

The DDI concept has been delivered successfully internationally, and proven as a safe and sustainable solution for efficiently upgrading existing interchanges to achieve safety and efficiency benefits. Initial studies have found that these benefits and positive outcomes would be applicable on the national road network in Ireland. Furthermore, the potential of a DDI on the Irish national road network has been specifically assessed at an identified junction on the Irish national road network. Initial studies have found that substantial safety and operational benefits can be achieved with a lower degree of intervention to a typical major grade separated junction upgrade. Further detailed investigations may ultimately lead to the implementation of the DDI as a Pilot Project. It is intended that this would be monitored for a period with lessons learned disseminated and result in specific design standard being published for the wider implementation of DDIs in Ireland.

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Road Weather and Safety Services Tailored Individually to Heavy Vehicles

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Abstract. Wintertime traffic accidents involving heavy traffic often cause major effects on the whole traffic entity. Accidents involving heavy road vehicles cause operational losses, human casualties, infrastructure losses, and negative environmental impacts. New Eureka Xecs SafeTrucks-project (Heavy traffic safety improvements by advanced dynamics and road weather services) develops real-time vehicle-specific weather and safety services tailored to each vehicle, based on the vehicles' own observations combined with data from the service systems and an analysis of the vehicle's own dynamics. Data is analysed by Digital Twin modelling and communicated to the driver through a hardware system in real-time. The Finnish Meteorological Institute (FMI) is the coordinator of the project, with an authority expertise in the development of the ITS-enabled road weather services in long-term basis.

Keywords: Road weather · safety · vehicle dynamics · Digital Twin

1 Introduction

The SafeTrucks project's [1] objective is to improve the safety by providing warning and information data directly to the heavy vehicle driver. The data is based on real-time conditions in road weather, traffic entity and vehicle's individual dynamic conditions. The driver is alerted about the emerging risks before they turn into critical hazards.

The existing traffic environment possesses various risks. Falling off/ rolling over the road due to an unexpected local road condition change may happen especially on smaller roads, where the road maintenance is slow to respond. General slipperiness warnings in vehicles tend to activate too often and too inaccurately to be taken seriously enough. Crosswinds are a special risk not affecting normal passenger vehicles, but heavy vehicle combinations would benefit from a specific warning as it can be extremely risky for them.

The SafeTrucks objectives are shown in Fig. 1. Starting from the top, we collect high variety of environment and vehicle dynamics data from roadside instrumentation and analysis systems. This information is built into the up-to-the-date status of the vehicle trailer sliding/rollover risk due to slipperiness or heavy crosswind. A special active

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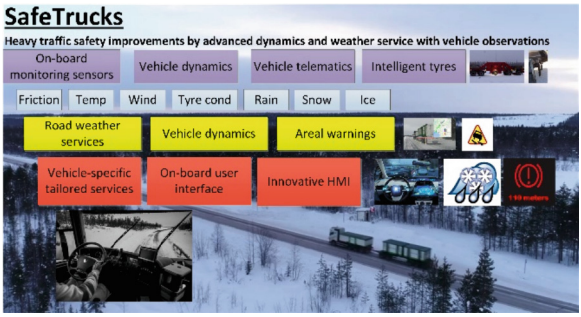

Fig. 1. SafeTrucks platform overview (Image by Timo Sukuvaara)

control systems for very long trailer and vehicle combinations turning capabilities are developed by Canadian partners in simulation modelling. These are presented as service extensions within Digital Twin traffic model, and they interact closely with physical pilot system operated by Finnish partners.

This paper gives an overview of the SafeTrucks project's main architecture. The project provides vehicle-tailored real-time safety services for heavy traffic. The architecture will be implemented in the pilot system operating in Finland and parallel Digital Twin entity composed in Canada during years 2023–2026. The main goal is to create advanced safety systems for improved traffic safety, especially in harsh winter conditions typical both in Finland and Canada.

2 Architecture

In the first stage, we have started to develop a system to produce individual vehicle-specific warnings. It involves combining vehicle's on-board observations of its dynamics and environment with wide-area weather and safety services, which are also enhanced with vehicle- and roadside-inherited sensor data.

The envisioned SafeTrucks architecture is presented in Fig. 2. Starting from the bottom, we collect a high variety of environmental data from roadside instrumentation and on-board road surface monitoring sensors. On the tyre-road interaction level, the on-board sensors installed on tyres give road interaction related information. Vehicles' own monitoring data comes from CAN-bus, FMS-data and driving analysis systems. An on-board unit with V2X communication capabilities combines this data, exchanges it with external service data systems (especially road weather and safety service systems of FMI) and receives up-to-date, localized weather and safety data. This data is further tailored based on the vehicle-specific dynamics information to present vehicle-specific warnings in the user interface of the vehicle. Accurate safety-related alerts will only be presented in the area they emerge and in a way that they don't disturb the driving operations. Special active control systems for trailer and vehicle combinations are developed by Canadian partners in simulation modelling, with Human-in-the-Loop (HIL) and Driver-In-the-Loop (DIL) modelling. They will be presented as service extensions within Digital Twin traffic model and interact closely with physical pilot system operated by Finnish partners.

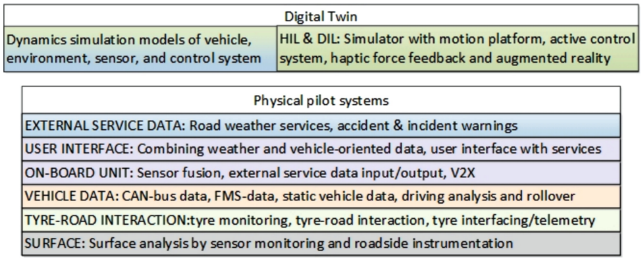

Fig. 2. System architecture

The base of the architecture is a system providing real-time vehicle-specific warnings and services based on forecast data, sensor data and models of the vehicles' dynamic behavior. This data is used to enhance the accuracy of the real-time road weather services of FMI and Canada's Digital Twin entity along with HIL and DIL modelling. The weather services are tailored for special vehicle environments that include heavy vehicles and autonomous vehicles. The first pilots in Finland include truck braking distance, crosswind and roll-over data indications. Similar activities will also be done in Canada, in addition to collecting historical and live data to develop a predictive road analysis Digital Twin system, which can be used for planning, scheduling, dispatching, procurement, and risk analysis. The real-time vehicle data that is based on vehicle's dynamic behavior modelling and is tailored for different types of trucks on the road is used to develop wide-ranging services. Autonomous vehicles exploitation of tailored weather and safety services will be evaluated in separate pilot testing scenarios.

Excessive research is directed to tyre behavior in truck-trailer combinations in demanding winter conditions. Tyre tread wear, effects of studs, pressure and variations based on temperature are all considered to optimize tyres, improve safety and efficiency, and reduce emissions.

3 Road Weather and Safety Services Individually Tailored for Heavy Vehicles

FMI provides a variety of weather- and safety-related services for all the citizens and society of Finland. FMI has also long history in the development of vehicular road weather services, especially for harsh winter conditions [2]. FMI is coordinating SafeTrucks project, with road weather and safety services as its key expertise areas. The main objectives are the further development of road weather services based on available data sources, as well as tailoring road weather services for heavy vehicles that require very sophisticated weather data. All possible friction estimates based on the on-board data are collected to enhance road weather services. The delivery of updated services (and the collection of vehicle data) is conducted with standard cellular networking.

The concept of tailored road weather services has already been studied within autonomous vehicles. In the preliminary model [3, 4], there are four driving mode (1–4) suggestions based on estimation of sensors' weather-dependency, later fine-tuned for more accurate suggestions. In SafeTrucks project, tailoring is targeted at heavy vehicles

with human drivers, which changes the structure of the services. Instead of suggesting driving modes, specific alerts are provided with accurate vehicle-specific estimates of the risk, which are based on vehicle dynamics combined with local weather conditions.

Within the vehicle, the collected dynamics information is combined with road weather data in the vehicle on-board unit, which produces the vehicle-specific real-time braking distance alerts, side wind - and trailer rollover risk warnings (to be supplemented during the project). The service concepts are outlined in Table 1. The active braking distance alert presents the real-time estimate of the braking distance shown in color-coding related to the distance. Red color presents the longest braking distance and the highest risk. For example, with the normal size passenger car the braking distance in dry asphalt conditions with 60 km/h speed is roughly 14 m, while with truck-trailer combination weighing 70 tons, the distance is already 70 m in winter conditions, as stated in [5]. The higher speeds expand the distances exponentially. These estimates exclude the reaction time, typically around 1 s, which increases the actual stopping distance easily to triple size in slippery winter conditions. Our heavy vehicle active braking distance warning will be presented in green font when the distance is less than 100 m, yellow font when between 100m and 150m, and finally red when above. These are the preliminary estimates of proper warning levels and will be further analysed within the project. With smaller vehicles, the levels are completely different.

Table 1. Vehicle-tailored safety services envisioned.

Service	Contents	Presented data
Active braking distance	Real-time estimate of braking distance, based on road friction (estimate & forecast), tyre conditions, vehicle speed, weight and axel-level weights	Braking distance in meters, in red font when critical
Side wind warning	Real-time estimate of side wind effect to the vehicle and trailer, based on localized road weather forecast, vehicle and trailer dimensions and weight and speed of the combination	Extreme, high and moderate side wind warning as blinking text or symbol
Trailer rollover risk	Real-time estimate of trailer rollover risk, based on friction (estimate & forecast), vehicle dynamics (speed, tyre condition, trailer weight and axel-level weights, lateral movement of vehicle and trailer)	Extreme, high and moderate trailer rollover risk as blinking text or symbol

The second service, side wind warning, is more complicated to define. The risk of side wind affecting the truck is a combination of truck and trailer physical dimensions (the wind surface), the weight of the vehicle and trailer, the wind speed and direction,

and the geographical structure of the road. The last topic refers to the fact that locations like a road passing from a forest area to a field or from a big building-fenced area to a bridge have potentially higher risks for sudden wind gusts. The color-coding is used for the warning level, but the triggering levels cannot be presented directly with numbers. The detailed triggering-level evaluation will be carried out within the project. The service will be generated based on road weather forecast data specifically tailored to wind-risk locations of monitored road stretch, weather radar and road weather station measurement data used as a supplement whenever available. We will use 2 road weather station positions and 2–3 additional pre-defined wind-risk positions to further analyse the service, during the project. On-board vehicle data analysed so far has not been found appropriate, on-board wind sensors are too expensive and complicated to maintain and vehicle throwing data too inaccurate to be used for this purpose. Additional data sources will be further analysed within the project.

The third and final pre-defined example service is trailer rollover risk that is rather similar to the side wind warning. The meaningful parameters are the tight corners on the road, the speed and the weight of the trailer, measured and forecasted road weather and friction, tyre conditions and lateral movement of the trailer and the vehicle. On-board data sources are any tyre-originated information related to sliding (to be defined within project) and trailer load-balance measurements generated by the project partner during the project. Again, the triggering levels cannot be presented directly as simple numbers, but the detailed triggering-level evaluation will be done within the project. Similarly with second service, we have defined few locations with tight corner on the road, into which we generate pilot warning and compose analysis of operation. Additional data sources Additional data sources will be searched for and further analysed within the project. The sketch of services in three levels is presented in Fig. 3.

The second and the third services could be presented as a single service as well, but in that case, we would lose information about special cases. For example, when there is a trailer rollover risk due to tight corner, slipperiness and condition of tyres, or a side wind warning due to unloaded high-dimension vehicle combination. The plan is to develop a collective set of road weather and safety services that will be ready to be integrated in commercial vehicle fleets and tailored for different special purposes like heavy vehicles, general road users and autonomous vehicles. We are also developing the underlying road weather services. One development step has already been taken by publishing parts of the FMI road weather model as an open-source library.

4 Conclusions and Future Work

The heavy vehicles and trailer combinations are vulnerable to severe winter weather conditions. Furthermore, a heavy vehicle involved in an accident always means a higher risk of fatalities, material damage or total traffic stops. SafeTrucks targets to reduce these risks by introducing more sophisticated road weather and safety services tailored individually to each heavy vehicle unit and its dynamics. This paper overviews the general goals of the project and provides a first envisioning of the vehicular services realizing these objectives. Future work consists of fine-tuning the services, installing them into the pilot heavy vehicles along with the on-board road- and vehicle measurement systems, and ultimately evaluating them in the harsh winter conditions.

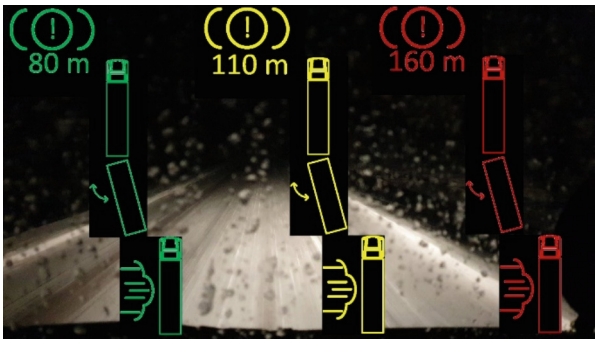

Fig. 3. The sketch of three levels of SafeTrucks alerts active braking distance (top), trailer rollover risk (middle) and side wind warning (bottom). Image by Timo Sukuvaara

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A Study on Charging Behavior in an Urban Area in Italy

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Abstract. The analysis of the charging behavior is of fundamental importance for the correct planning of the charging infrastructure, the choice of optimal charging management strategies, and the application of policies aimed at promoting the penetration of electric mobility and the integration of charging demand with the electricity distribution network. To evaluate the charge demand, aggregated or disaggregated analyses can be conducted using different data and information sources. In particular, the present study investigates the charging habits of actual electric vehicles drivers in Italian urban areas through the administration of a revealed preferences (RP) survey and illustrates some of the main outcomes. The results of this survey were used as preliminary input for designing an SP survey aimed at identifying the charging profile of future electric vehicle (EV) users; given the multitude of factors influencing charging profiles, a look at the early adopter category was deemed useful for selecting the factors to consider for a medium-term forecast.

Keywords: Charging behavior; electric vehicles · plug-in vehicles · charging infrastructure · EV users

1 Introduction

Electric mobility is spreading quickly, although not at the same speed in all countries. According to national statistics [1], in 2022, Italy had 1.3 million registered vehicles, with 3.7% being battery electric vehicles (BEVs). This is compared to 4.6% in 2021, 2.3% in 2020, and 0.5% in 2019. Incentives and more EV options have caused an upward trend in EV registrations for the first half of 2023. If properly supported by charging infrastructure (CI) development, the EV market may well follow the technology diffusion curves that are usually characterized by initial sudden growths until a plateau is reached, in accordance with Bass's model [2]. To facilitate the introduction of electric mobility, maximize the use of CIs and minimize the impact on the electricity grid, it is necessary to evaluate the energy demand for charging EVs. The number and type of charging points (CPs) needed to promote the development of Electric mobility, depend on the charging

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requirements, which are determined by factors such as the user's profile [3], travel frequency [4], distance [5], speed [6, 7], and average stop duration [8]. Besides these endogenous factors, the deployment of CIs depends also on exogenous variables, such as available surface areas, energy distribution network, technological context, availability of private charging surfaces and/or private charging possibilities [9].

The present study focuses on the influence of endogenous factors on users' charging behavior.

The literature examines two approaches to studying charging behaviors: detecting charge behaviors from available station data or using vehicles' onboard instrumentation [10–13] and conducting dedicated surveys [14, 15].

The stated preferences (SP) survey approach can prove particularly useful in investigating how endogenous factors can affect charging habits; however, the complexity of the problem makes it necessary to reduce, where possible, the variability of these factors, as well as to focus on the most relevant application contexts. In this perspective, we carried out the RP survey, which is the focus of this paper, to investigate the charging preferences of early adopters in Italy. The RP survey explores charging behavior versus location, charging mode, fees, frequency, and preferred state of charge (SOC) at the beginning and the end of the charging process. We investigate preferences to charge at the origin/destination or during scheduled stops, as well as socio-demographic aspects of the respondents. The information gathered will streamline the number of contexts, identify factors, and reduce variability in the SP survey.

In the following, we will present some results of the RP survey and discuss the implications of the findings.

2 Results

The survey was carried out online on the Survey Monkey platform among Italian EV users, with a focus on metropolitan areas. The survey was administered with the Computer Assisted Web Interviewing technique. It was disseminated at various plug-in EV focused fairs held in Italy between June and July 2023 and through mailing lists of EV owners. Sampling occurred voluntarily EV owners, without any form of incentive. The final dataset includes only respondents from metropolitan areas. 1574 people accessed the survey page. There were 1263 complete responses, corresponding to 80.24% of the total accesses. BEV users account for 82.35% of the valid questionnaires collected, while plug-in hybrid EV (PHEV) users ac-count for 17.26%.

Table 1 summarizes the availability of private CI among respondents. Most BEV users have access to domestic charges, while nearly one-third depend on public CI. The percentage of PHEV users who cannot charge at home or work is even higher.

This distribution of CIs influences the charging location preferences: 45.89% of the respondents declare to charge mainly at home, 33.89% predominantly at destinations and 20.21% indifferently at home or elsewhere.

2.1 Charging at Home

Among domestic CIs, 93.77% of interviewees have a CP installed in their own spaces, while the rest are in common spaces such as condominium car parks. Charge power

Table 1. Availability of CPs distribution among EV users.

CI at home	Yes	Yes	No	No
CI at work	Yes	No	Yes	No
Full-electric (% BEV)	9.23%	52.31%	10.50%	27.96%
Plug-in Hybrid (% PHEV)	7.08%	23.33%	23.33%	46.25%

levels at home are usually up to 7.4 kW (87.11%). Most home charges usually start during night-time (11 pm–7 am) or in the evening (7 pm–11 pm), while charges in the morning are rare. Charge power levels at home are usually up to 7.4 kW (87.11%). 56% of home charges usually start during night-time (11 pm–7 am) and 23% in the evening (7 pm–11 pm), while charges in the morning are rare.

The SOC at the beginning of the charge is usually in the 50–20% range (see Fig. 1) and rarely above 75%, which shows an attention not to charge the battery at high SOC.

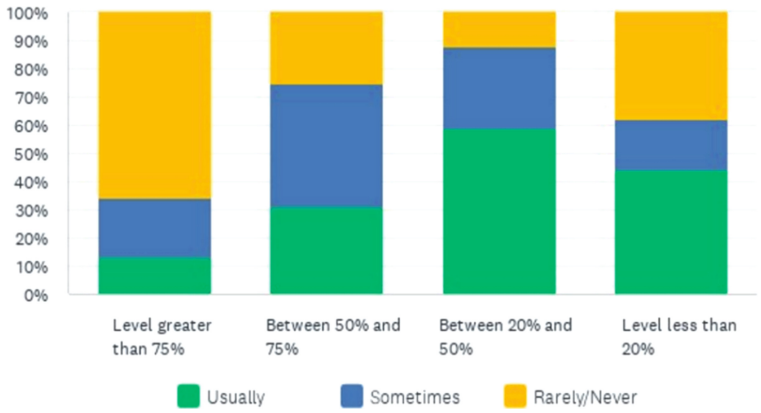

Fig. 1. SOC distribution for home charges.

2.2 Charging at Work

Usual power levels for work CPs are included in the range 11–22 kW, while CPs of more than 22 kW are rare (Fig. 2). Almost 60% of interviewees declared that charges are free. Charges at work start usually in the 7.00 am–1.00 pm range (66.79%) or between 1.00 pm and 7.00 pm (27.68%). Typically, people leave their car parked while charging at work between 1 and 4 h (47.06%) or between 4 and 8 h (38.24%), which coincide with the duration of work activities in Italy. The distribution of initial charge SOC is very similar to that for home charges.

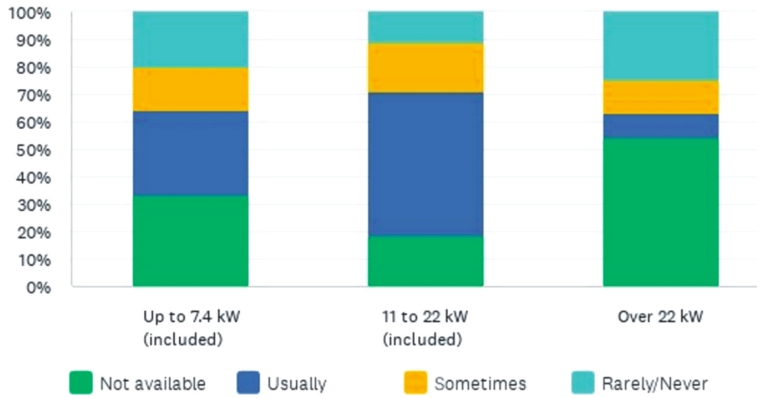

Fig. 2. Percentage of usage for different power level chargers at work.

2.3 Charging at Public Stations

Based on the survey results, public CIs are not utilized frequently. Indeed, only 23% of the respondents use them three or more times a week, and 27% once or twice a week. Additionally, 14% of the respondents declares to never use public charging stations. Nevertheless, 67.36% state possessing a subscription and/or flat rate agreement with some public charge operators. Figure 3 displays the use of public stations during different time slots. The maximum attendance at public stations is between 1 pm and 7 pm, while the frequency of use is lower during the night.

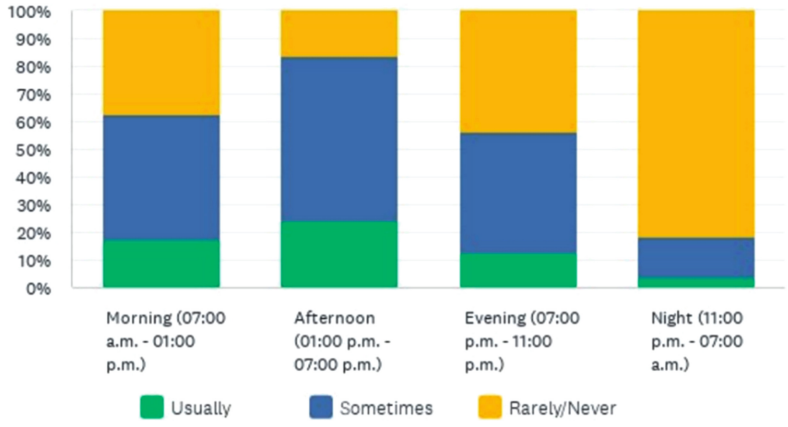

Fig. 3. Distribution of the frequency of use of public stations in different time slots.

Dwell times at public CIs are typically between half an hour and an hour and a half (40% of responses), while 38% is between an hour and a half and three hours. Only 10% of the responses indicate dwell times typically less than half an hour. Users declare that they mainly use chargers with powers between 11 and 22 kW (43%) and above

22 kW (29%). People usually tend to charge at public charger when the SOC is below 50% (62% of respondents). The survey shows that people usually charge their car during trip-planned stops, and only a minority (22.74%) stop specifically to recharge.

3 Discussion

Choosing when and where to charge an electric vehicle depends on several factors. One significant factor is the availability of charging infrastructure at home. Other crucial factors are the distribution of public charging stations, fees, dwell times, vehicle SOC, user's profile, travel frequency, distance to travel, speed, and average stop duration. Although the RP results refer to the limited category of early adopters and current charging infrastructure distribution, they allow determining the variability for the aforementioned factors, helping to limit the SP investigation to more widespread behaviors, which presumably will dominate in the immediate future.

The survey found that charging behavior is consistent with prior studies. Factors affecting willingness to charge include range anxiety, limited access to charging stations, and preference for maintaining a specific SOC interval. No clear correlation was found between SOC at the start of charging and the attitude to stop-to-charge. The absence of domestic chargers affects willingness to stop to charge. The charging frequency correlates positively with higher starting SOC, which can indicate a range anxious attitude. The preferred charging start time depends on the CI considered and appears to be closely related to travel habits, as also found in [16].

Different clusters of EV drivers exhibit varying charging behaviors. People that have access to domestic or work chargers favor them over public charging, probably due to a perceived availability, proximity to their destinations, and more competitive rates.

The findings indicate that 28% of BEV owners exclusively depend on public CI. Recognizing the significance of these percentages and anticipating the future growth of electric mobility, the results have prompted a refinement of the SP survey in investigating the behavior of the 'private users and public charging' group, emphasizing the need to ensure a sufficient number of CPs and diverse charging types aligned with the personalized travel needs of this specific user segment.

Another interesting result is related to the SOC at the beginning or ends of the charge process. To maximize batteries life, manufacturers recommend maintaining the SOC between 20% and 80%. Several studies [17, 18] have shown that, on average, the most anxious users begin charging their cars around a SOC of 70%, still keeping the final charge SOC below 80%. Our study revealed the SOC at the beginning of the charge is usually in the 50–20% range and rarely above 75%, with slight variations if the users don't have access to a private CI. This aspect suggested focusing in the 50–20% starting SOC range for the design of follow SP survey.

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People-Centred and Inclusive Transport

Enhancing MaaS Personalisation Through Synthetic Data Generated from a Tabular Large-Scale Mobility Dataset

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Abstract. In recent years, the concept of Mobility-as-a-Service has significantly impacted the transportation sector by integrating diverse modes of transport into a user-friendly experience. The advancement of human mobility patterns has been facilitated by the utilisation of mobile sensing technologies, but this progress has also raised concerns regarding privacy and the management of data. This study suggests increasing the applicability of human mobility data by generating synthetic data with deep learning models trained on the existing dataset. Our approach aims to enhance the practicality of human mobility data. The produced synthetic data encompasses real-world dynamics and give possibility to develop and evaluate the algorithms for personalised travel recommendations, while safeguarding sensitive information. Exploring this domain has the potential to bring about a paradigm shift in the field of mobility solutions that prioritise privacy, efficiency, and user satisfaction, ultimately leading to the development of a sustainable urban mobility framework.

Keywords: Human Mobility Data · Personalisation · Generative Artificial Intelligence · Utility · Fidelity

1 Introduction

The concept of Mobility-as-a-Service (MaaS) has gained significant attention in recent years, revolutionising the way people move by integrating various modes of transportation into a seamless user experience. The mobile sensing technologies continuously collect a wealth of data about people's movements, interactions, and behaviours, resulting in a massive influx of data. However, while this abundance of data has enormous potential for improving our understanding of human mobility patterns, it also poses privacy, data security, and data management challenges.

The introduction of *synthetic data generation* (SDG) techniques opens a wide range of transformative possibilities in the field of mobility research, especially when it comes to delivering personalised travel recommendations. *Synthetic data* (SD) can be defined as artificially generated data that uses pre-existing datasets or models to accurately

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emulate the statistical attributes and characteristics present in real-world data [1]. This is especially useful in situations where obtaining actual data would be prohibitively expensive, time-consuming or impossible [2]. Its importance originates from the intrinsic adaptability in addressing a set of problems such as data augmentation [3], imputation of missing data [4], restoring "fairness" in biased data [5], and ensuring confidentiality [6]. Furthermore, it enables researchers to develop and test algorithms and applications in a controlled environment, removing the need to expose sensitive data.

Current advances in SDG are becoming popular in various domains including ecology, computer vision, industrial engineering etc. However, it isn't yet extensively explored in the mobility area. In this study, we propose a approach to increase the applicability of human mobility data by generating synthetic data with deep learning (DL) models trained on the existing dataset. Next Section describes applied research methods and Sect. 3 is devoted to results' presentation. The final goal of this research is to analyse the place of SDG techniques within the realm of personalised travel recommendation algorithms. By intertwining real data from actual trips with synthetic data, the research creates a dynamic and adaptable framework for future travel suggestions.

2 Data and Methods

Data Description. The rapidly growing field of human mobility data (HMD) benefits from the Sussex-Huawei Locomotion (SHL) dataset, which captures the human movement in various contexts and environments [7]. The latter explores human locomotion from running and walking to biking and public transport. The data collection process involved three people and reflected the spontaneity and unpredictability of human mobility through everyday activities like long-distance travel and museum visits. For complete movement data capture, Huawei Mate 9 smartphones were placed at the hands, torso, hips, and bags, with the purpose of measuring pressure, ambient light, acceleration, and GPS coordinates. The dataset's annotations, which describe movement modes, environmental and situational contexts like road conditions, traffic scenarios, and social interactions, demonstrate its high variability.

Personalising services means adapting to an individual's behaviour. Therefore, focusing on a single user's (*User 1*) GPS locations and activity labels is crucial in this context. Due to its narrow focus, the dataset contains every move, turn, and pause, as well their unique behaviours, routines, and social habits. The study's 391 h over five months show its focus on User 1's mobility's complexities and patterns. This longitudinal method considers seasonal fluctuations, changing habits, and external mobility influences, giving a more complete picture than short-term datasets. It also allows a more in-depth analysis without the noise and disparities of a multi-user dataset by removing the broader variability introduced by multiple users.

SDG Model Architecture. A notable development in the field of unsupervised machine learning is the introduction of *generative adversarial networks* (GANs) [8]. GANs consist of two neural components: the *discriminator*, which verifies the authenticity of the SD by comparing it to real data, and the *generator*, which generates SD. The training process continuously improves both the discriminator and the generator. A model capable in tabular data synthesis is of course necessary when it comes to the SHL dataset,

which integrates location and activity labels. On the other hand, the *conditional tabular generative adversarial network* (CTGAN), is a model specifically designed to handle categorical attributes found in tabular data and ensuring consistent and stable learning [9, 10], which makes this model an ideal candidate for generating data that closely resembles the characteristics of our mobility dataset (Table 1).

Table 1. Data structure of input data for SDG task

Attribute	Timestamp	Latitude	Longitude	Activity label
Type	Datetime format (YYYY-MM-DD hh:mm:ss)	Float	float	String
Example	2017-03-01 13:58:18	50.86075	−0.09689	Still_Sit_Inside

The model is initialised with a *random noise vector* (sampling from a *standard Gaussian distribution*) that is the primary input for the generator. The vector is propagated over multiple *fully connected* layers. The *Rectified Linear Unit* (ReLU) is the *activation function* that is used in each of these layers. It is essential for introducing the non-linearities that the generator needs to properly represent complex data distributions. Each layer has *Batch Normalisation* (BN) applied to it to improve training stability and convergence. BN standardises intermediate activations and reduces the problem of internal *covariate shift*. To accommodate the intrinsic heterogeneity of tabular data, the generator's terminal layer uses a bifurcated activation strategy. For discrete attributes, such as "activity label", the *Gumbel-Softmax* activation is employed because it facilitates gradient-based methods that allow for optimisation in discrete spaces. The *hyperbolic tangent* (tanh) function is utilised for continuous attributes as "latitude", which precisely mirror the distributions found in actual data.

By using the same amount of densely connected layers, the discriminator is made to switch to its adversarial counterpart. Each layer in the model makes use of the *LeakyReLU* activation function, which is an altered form of the standard ReLU. Including this function allows for the possibility of a slight negative gradient during the times when the unit is not in use. This choice solves the problem of "diminishing neuron" activation, ensuring that gradients flow consistently during the *backpropagation* process. These layers also include *dropout* mechanisms that, with each training cycle, probabilistically deactivate a subset of neurons.

Ultimately, to guarantee *Lipschitz continuity*, CTGAN uses the *Wasserstein loss function with gradient penalty*, which enables the synthesised data to statistically match the original dataset and adhere to the intricate spatial "coordinates-activity" dynamics present in actual activity recordings.

To evaluate the *coherence* of suggested approach was used set of metrics proposed in [11] and investigated the quality of SD generation on HMD. First metric is ***Absolute Semantics***, which refers to the understanding of the meaning of each location in a trajectory. This can be evaluated by analysing the locations and types of activities

present in both types of data and by comparing their distributions to assess representativeness. ***Marginal Distributions*** evaluates the distribution of individual variables in the SD compared to the original dataset. If these distributions are similar, it suggests that the SD maintains the statistical properties of the original data. The ***Maximum Mean Discrepancy*** (MMD) measures the difference between distributions of SD and the original. ***Jensen-Shannon Divergence*** (JSD) quantifies the similarity between two probability distributions and is a symmetrized and smoothed version of the *Kullback-Leibler divergence.* A smaller MMD and JSD mean the distributions are more similar. ***Relative Semantics*** entails understanding a location's meaning relative to other locations in a trajectory, involving transitions analysis between different types of locations and evaluating their logic. *Pairwise semantic distances*, involving distances calculations between location pairs based on their semantic meanings, can measure this. By ensuring that SD closely mirrors real data in terms of semantics and spatial-temporal patterns, ensure that personalised mobility algorithms are built on robust and meaningful data.

3 Results

The following results demonstrate the DL model's ability to generate SD.

Absolute Semantics: the scatterplots on Fig. 1 depict the spatial distribution of activities in datasets. The original dataset exhibits distinct clusters of activities, suggesting specific geographical zones where certain activities predominantly occur. For example, certain latitudes and longitudes have a high concentration of "Bike" activities, which could imply popular biking routes or parks. Other clusters might indicate residential or commercial areas based on the nature of the activities. The generated by CTGAN SD aims to replicate these patterns. While it does capture the general spatial structure and distribution of activities, there are subtle differences. Some activity clusters in the SD are more dispersed than in real, while others are denser. This divergence can be attributed to the inherent randomness and generative nature of SD production. However, the overall spatial semantics are largely preserved in the SD, making it a valuable resource for analysis that doesn't compromise individual data points from the original set.

Marginal Distributions: the Kernel Density Estimation plots for marginal latitude and longitude distributions show distinct patterns that demonstrate the SD generation process's accuracy (Fig. 2). Blue curves represent the original data and show peaks and distributions of key geographical areas where activities are concentrated. The SD's red curves closely match these patterns, indicating that the SD generation captured the original dataset's spatial nuances. Although some latitude and longitude ranges deviate, the overall congruence is good, and the distributions are similar.

MMD and JSD: values are presented in Table 2. "Latitude" has a very low MMD, indicating that the original and SD sets have similar means. JSD value of 0.35, which is not negligible, but not excessive, supports this. It means that the probability distributions for this attribute are similar. The MMD value for "Longitude" is slightly higher, but still small, indicating close means and the JSD value of 0.42 suggests that the distributions differ, but the SD still closely matches the original data. For the "Activity label" MMD and JSD are extremely low. Hence, the distributions of this categorical variable in the

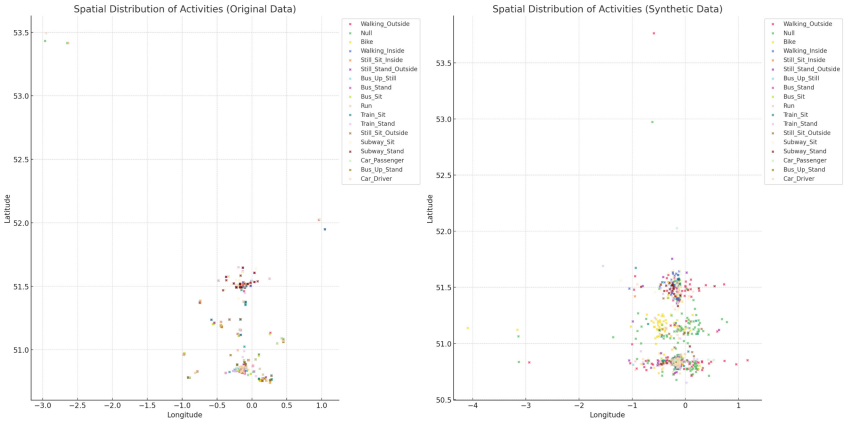

Fig. 1. Spatial distribution of activities: real user (left), simulated agent (right). Created by Authors in Python.

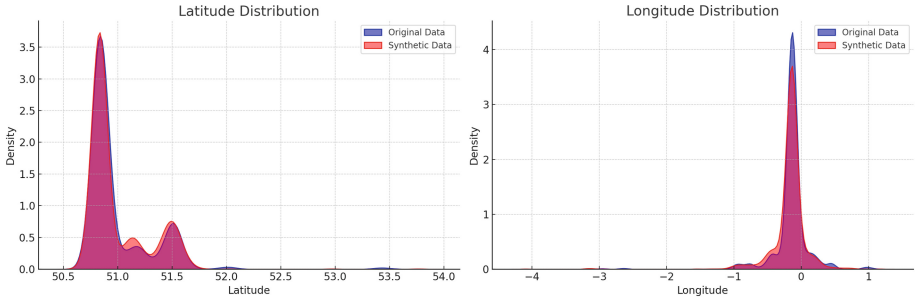

Fig. 2. Kernel Density Estimation plots for Latitude and Longitude distributions. Created by Authors in Python.

original and SD sets are very similar, which means that CTGAN replicated well the activity label distribution from the original dataset.

Table 2. Summary of MMD and JSD for all attributes.

Attribute	MMD	JSD
Latitude	0.000077	0.35
Longitude	0.00052	0.42
Activity label	0.00072	0.02

Relative Semantics: the matrices (Fig. 3) capture the transition probabilities between different activity labels. In the original data heatmap, distinct patterns of activity transitions can be discerned, with certain activity combinations exhibiting higher probabilities,

as indicated by the deeper shades of blue. These patterns provide insights into the inherent structure and sequence in which activities tend to occur. The SD heatmap seeks to emulate these patterns. Most of the transition patterns in the original data are mirrored in the SD, as evident from the consistency in colour shades. This suggests that the CTGAN has effectively captured the dynamics of activity transitions, preserving the intricate relationships and sequences between activities.

4 Conclusion

There results outlined in this paper highlight the capabilities of CTGAN, in generating synthetic human mobility data of exceptional quality. These datasets accurately reflect the inherent characteristics and dynamic patterns of mobility, providing a solid basis for future research. Within this framework, the reliability of the generative task was assessed by comparing the artificial dataset with the real dataset using statistics-based metrics. This serves as a pivotal reference point for evaluating the accuracy and efficacy of GAN-based models. Hence, this model has potential applications in the field of Mobility as a Service (MaaS), which include the ability to enhance route planning, analyse individual mobility patterns, identify preferred modes of transportation, and simulate user behaviour in various transportation scenarios.

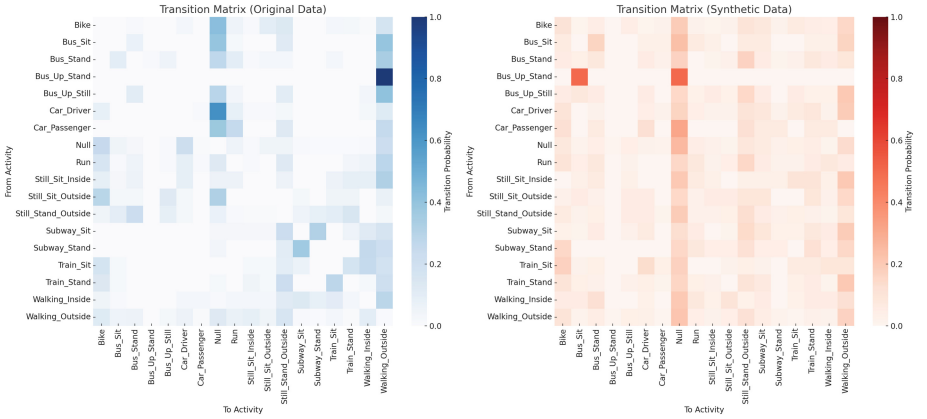

Fig. 3. Heatmaps highlighting activity changes for real and synthetic dataset. Created by Authors in Python.

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Promoting Cycling Skills of Schoolchildren – Participatory Impact Evaluation Methods as Nudges for Active Mobility

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Abstract. Participatory evaluation methods may increase the legitimacy and acceptance of mobility measures, in addition to acquiring relevant data on measure performance. However, the potential added value of these evaluation methods in acting as nudges has been overlooked. In this study, an inclusive sustainable mobility activation model was designed, tested and evaluated in two kindergartens and four schools in Turku, Finland. The model aimed to increase the skill sets of children and families on sustainable transport modes. Focus was particularly placed on targeted communication activities, on inclusive mobility services, and on having a designated person to coordinate cycling activities in the city. Cycling skills were objectively measured with a test track and ex-post and ex-ante data were gathered. Based on the impact evaluation results there is indication that participatory data collection method can work as an activating measure in its own right.

Keywords: Cycling skills · Nudging · Participatory evaluation

1 Introduction

The project SCALE-UP is a H2020 funded Innovation Action focusing on 3 European urban nodes (Madrid, Antwerp, Turku), exploring options to render them better connected and climate resilient while further developing complex multi-modal transport systems. 28 innovative mobility measures are implemented in the project to ensure vertical (governmental) and horizontal (dimensional) upscaling of urban mobility. All the measures are subject to extensive impact and process evaluation.

In the measure "Speeding up inclusive cycling in Turku" an inclusive sustainable mobility activation model was designed and tested in two kindergartens and four schools. The model aimed to increase the skill sets of children and families on sustainable transport modes. In addition, the physical conditions were mapped and improved at the test units to support the activation. Focus was particularly placed on targeted communication activities, on inclusive mobility services, and on having a designated person to coordinate cycling activities in the city. The model included activities such as information days,

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a cycling skills test track and cycling related activities during or right after the school day organized by the city of Turku. The measure aims at a 10% increase (year-round average) in cycling among the activation model participants (parents and children).

For the purpose of measure evaluation, ex-ante and ex-post data was collected e.g. with surveys to both parents and children on indicators such as modal split, acceptance of sustainable transport, average walking and cycling time and the perception of safety. Cycling skills were objectively measured with a test track on the premise that children's ability to perform cycling skills can play an important role in cycling accidents as well as the willingness to cycle. An additional survey was conducted for those who took part in an ex-post skill measurement and for some of their parents.

2 Approach

2.1 Active Mobility and Nudging

The notion of nudging was initially coined by Sunstein and Thaler (2021) to characterize a component within choice architecture that effectively and simply adjusts individuals' behaviors in a predictable manner, without removing options or incurring additional costs. In simpler terms, nudges facilitate the selection of the generally preferred course of action without coercion. Nudging has become a common method for promoting various goals, such as lifestyle changes (Ledderer et al. 2020), modal shift (Zimmermann et al. 2023; Loidl et al. 2023), cycling promotion (Kovaceva, Wallgren & Dozza 2022) or energy conservation (Soomro et al. 2021; Colasante et al. 2021). The effectiveness of nudging has been studied by, for example, Mertens et al. (2022) who went through over 200 nudge interventions. Their research shows some indication that the effectiveness of nudging varies depending on the technique used and the field of operation: nudging seems to have a positive effect especially in comparison to traditional lifestyle interventions (e.g. educational campaigns) if the targeted behaviour is related to low-impact and habit-driven decision-making.

Another experiment (Lieberoth, Hold & Bredahl 2018), compared the efficacy of various nudging, gamification, and rational information approaches to promote a shift from private car usage to public transportation. While nudging and gamification often lead to immediate effects on simple behaviors, determining whether a change in travel behavior is specifically attributable to nudging or gamification, or another factor, is challenging due to the complexity of travel behavior. According to Kovaceva, Wallgren & Dozza (2022), the effect a simple visual nudge had on cycling speed depended largely on the context and location of the intervention. Cellina et al. (2019) concluded that a web-based mobility related nudging tool may be useful as a complementary tool for harder infrastructure-based measures. Thus, nudging in itself may not be enough to result in lasting changes but can have a positive impact if paired with other measures.

2.2 Cycling Skills and Traffic Safety

According to studies by Zeuwts et al. (2015, 2016), most cycling accidents are due to external factors (such as other road users or cycling infrastructure), the bicycle itself

(such as malfunctioning brakes) and the intrinsic factors of cyclists themselves. The intrinsic factors are stated to be a combination of 1) motor skills (e.g., the ability to coordinate steering, balancing, pedaling, braking, etc.), 2) perceptual-motor skills (e.g., hazard perception, time-to-contact, attention, planning, judgment, decision making, etc.) and 3) knowledge of traffic rules and 4) correct attitudes (e.g., the willingness to obey the traffic rules or risky behavior) (Zeuwts et al. 2020). According to a review article by Zeuwts et al. (2020), children under the age of 10 lack the skills of i.e. looking backwards, cycling between the lines and one-handed cycling. On the other hand, as children grow older, their willingness to adhere to rules tends to decrease.

2.3 Participatory Evaluation

Participatory monitoring and evaluation approaches offer a more inclusive possibility for assessment and learning from change from traditional data collection methods. Participatory evaluation means involving the stakeholders of a program or those directly affected by a policy in some part of the evaluation process (Guijt 2014; Cousins & Earl 1992). The interest in applying participatory approaches at any stage of the evaluation process has arisen from the recognition of the importance of taking the perspectives of those affected into account. Participatory approaches are thus pragmatic as they may help generate better data, or provide a better understanding of the data collected, and more ethical as they are the "right thing to do" (Guijt 2014, 2).

Participatory evaluation methods may, at best, increase the legitimacy and acceptance of mobility measures too, in addition to acquiring relevant data on measure performance. However, what has so far been overlooked is the potential added value of these evaluation methods in acting as nudges.

3 Methods

Cycling skills of 5–12-year-old children were measured twice on a standardized cycle track that consisted of seven different test points. The test track was adapted from two studies of Ducheyne et al. (2013), and Papanikolaus and Adamakis (2020) to best suit the needs and possibilities of the project and of the target group. The track used playful methods to measure the determinants of basic cycling skills required in traffic as follows: 1) Cycling in a straight line while looking left, 2) cycling a slalom with the distance between cones becoming smaller as proceeding, 3) cycling in a straight line one-handed, 4) cycling in a straight line as looking over shoulder, 5) cycling a figure eight, the radius and width of the two circles being unequal, 6) cycling over obstacles, and 7) controlled braking within a box (1m wide, 2m long). Each element was scored according to set criteria. In between measurements children were divided into two study groups: one with and the other without training sessions in school time.

Neither children nor their parents received personal test results. Instead, children received a "Skills card of cycling" in which they would reflect on their perception of each measurement point on a "smiley face" scale after both tests. The skills card served simultaneously as 1) test feedback to parents on their child's perception of their ability to

cycle, 2) a means to help parents recognize the essential subskills of cycling, and 3) as a nudge to motivate the children to rehearse the subskills before the ex-post measurement.

After the ex-post measurement, children answered a short pseudonymized questionnaire, the objective of which was to determine e.g. the frequency of cycling, participation in cycling activities during school days, and the effect of the cycling track and skills card on cycling enthusiasm. Some of the parents also received a pseudonymized questionnaire, which included questions on the perception of the safety of letting their child cycle, at which age their child had learned to cycle, and how safe they perceived their living environment to be for cycling.

4 Results

Altogether 257 children participated once, either in ex-ante or ex-post testing, and a total of 194 children participated in both tests and answered the questionnaire. The share of age-groups was the following from preschool to 4th grade: 7,73%, 17,01%, 38,14%, 14,94%, and 22,16% respectively. The share of 5th and 6th graders was minor in participating in both tests and the questionnaire so they were left out of the analysis phase. A Likert scale from one to five was used in the questionnaires.

The cycling track had a very positive influence on 48,97% of all the children taking part in the ex-post measurement, and 37,62% considered it had had a positive influence. The track had least influence on pre-school-aged children and pupils in the 4th grade. 20% and 20,93% of them reported the skill track did not affect their enthusiasm towards cycling. Only one 2nd grader answered that the cycling track had a minor negative impact on the rate of enthusiasm.

The cycling skills card had a very positive influence on 30,93% of the participants and a positive influence on 48,97% when asked if the skills card encouraged them to cycle more or if it increased their enthusiasm towards cycling. 19,59% reported it having no effect. No negative effects were reported.

When comparing the skills development of 2nd graders (total points) between 1) the ones who reported the cycling track having no influence ($n = 6$) to 2) those who reported the track having a strong influence ($n = 27$), the difference was small. The average and median skill development for group 1 was 5,88 and 4,70 points, and for group 2 average and median were 1,73 and -1,82 points. Same results in the case of a skills card for group 1 were 4,66 and 2,46, for group 2 points were 6,00 and 1,56. The same comparison was made for the 4th graders with smaller changes between groups. Worth noting in the case of the 4th graders was that the group who got very motivated by the cycling track reached the skill level of those who didn´t (total score 60,81 and 59,80, respectively). Also the difference between the two age groups got smaller with ex-ante difference being 6,65 (avg) and 8,79 (median) points and ex-post difference being 3,93 (avg) and 4,36 (median).

5 Discussion of the Results and Conclusion

Attributing changes in travel behaviors to specific measures is challenging especially when it comes to nudges due to the complex nature of travel behavior. Children often may not be able to influence their choice of mode for school travel but are dependent

on practicalities, such as the distance of their home from the school and, even more importantly, the attitudes of their parents towards active mobility such as cycling. Those attitudes, on the other hand, may be influenced by the parents' perceptions of the safety of their living environment and their perception of the children's ability to cycle.

According to both survey results, which showed that the cycling skills track had a clear positive influence on the enthusiasm to cycle among the tested children, and informal feedback received from the cycling skills testing from parents, the children felt empowered by the testing and the testing inspired children to cycle. Based on these impact evaluation results there is thus indication that such a participatory data collection method can work as an activating measure in its own right. Informal feedback was received from the parents also on important subskills of cycling improving among the children during the activation model activities, and the parents had become more aware of the skills of their children. However, more research is needed to determine the full potential of participatory data collection methods in encouraging cycling among schoolchildren and in increasing the acceptance of cycling among parents who often decide the travel mode of their children. Another interesting avenue of further research is whether the children's desire to practice cycling with parents could increase the willingness to cycle among parents themselves too.

Improving intrinsic cycling skills increases traffic safety and it seems that by motivating and giving families tools to practice, skills also develop rather rapidly. When paired with infrastructural traffic safety improvements, skills-based nudges may prove to have positive impacts in active mobility promotion.

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Adaptive MaaS Planning via Demand Elasticity Scenario Analysis

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Abstract. Mobility-as-a-Service (MaaS) is one of the sustainable solutions proposed and implemented by transportation planners and policy-makers to cater for the rising issue of congestion and associated external social and environmental costs. However, it is seldom evaluated how a planned provision of the MaaS system can impact the transport network performance. This research is carried out as a part of the Green MaaS for Adaptive Urban Planning (GeTUP) Project. It aims to critically evaluate the road network structure of the city of Genova and skim out the network's most congested components (nodes and links), thus highlighting the much-needed places for an efficient MaaS provision based on adaptive planning that relies on various reliability measures quantified here. The network structure is analysed by using demand-based dynamic network centrality measures for its components (nodes and links). Whereas, the critical points of the network in each component cluster are skimmed out using a mixed-machine learning approach. Later, various demand elasticity scenarios are analysed for each cluster given adaptive green MaaS system presence and demand shift to that system. It is revealed from the analysis that in some parts of the road network the demand is as much as 78% higher than the provided capacity. Thus generating large travel times. However, when MaaS system is provided in terms of different demand elasticity scenarios the travel times are reduced improving the traffic network performance.

Keywords: Adaptive planning; MaaS · Criticality; Reliability; Machine learning

1 Introduction

In Italy, from 2000 to 2019 the total number of cars per 1000 people increased from 575 to 680 being used on urban road networks, whereas for the same period of 19 years, the total urban population in Italy increased only 3.3% [1]. Comparing it to the annual population growth rate it shows that the population growth rate decreased by 0.28% over the same period [2]. The increased usage of private means of mobility saturates the transportation supply system thus elevating the time spent on the roads during peak hours in the form of congestion. This congestion is accompanied by increased external costs (social, environmental and health) [3]. To address the issue of sustainable society and

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environment without compromising the mobility needs of the road network users; planners and policymakers came up with a range of potential sustainable transport solutions; Mobility as a Service (MaaS) is one of them.

The technology of MaaS has been in a boom recently, bringing about two key changes in the mobility paradigm; instant communication of commuters' needs to the journey providers and complementing operation of the shared mobility services with public transportation [4, 5]. This principally leads to customer-oriented comfort-tailored services offering a quality mobility product for the users.

Researchers [6–9] analysed the impacts of MaaS on the growth of the system, personalization of the interface of MaaS applications on users' adaptability, travel behaviour, vehicle kilometres travelled, vehicle ownership, parking requirements and social equity. Also, [10] revealed reduced public transport fare levels and land savings by including automated taxis in Lisbon. However, it is often overlooked how the provision and operation of MaaS services might impact a broader transportation network both private and public transportation in terms of travel times and network loads. This research aims to unpick the impacts of MaaS on traffic characteristics via various demand elasticity scenarios measuring the reliability of the whole transportation system thus facilitating an adaptive planning of a green MaaS system. The study was carried out under the project of GeTUP to validate the technological tools for effective urban mobility planning according to the MaaS concept.

2 Methodology

The approaches to assess the network performances for adaptive planning of Maas systems involve a detailed analysis of the private transportation network. It is assumed that:

1. A macroscopic model is developed with fixed and stable OD demand on a congested network.
2. Path choice for any generalised OD pair is carried out using a logit model with minimized variance parameters.
3. Assignment of demand to the network relies on the stochastic user equilibrium principle with no temporal dynamics.

2.1 Network Structure

The network is represented by a synchronic graph $SG = \{N, L\}$. A set of origin-destination pairs OD is considered which belong to the set of zones Z. i.e. $OD \in Z$. To reach the destination from origin; all the links are connected via a set of paths P which depicts that for any general origin-destination pair $ab \in OD$ a path $P_{ab} \in P$ is followed. An incidence matrix M involving all the possible paths connecting any generalized OD pair ab is set up. Initial OD demand is fixed for the base model and distributed over the entire network based on stochastic user equilibrium (SUE) principle. Each link in the network weighs on flow and time-dependent travel cost c_l.

Similarly to origin-based equilibrium methods, the assignment problem is partitioned by destinations in the LUCE procedure. The main idea is to seek at each network

component a user equilibrium for the local route choice of drivers directed toward the destination among the links of its next component. The travel alternatives that make up the local choice sets are the links that belong to the current path. The cost functions associated with these alternatives express the average impendence to reach the destination linearized at the current flow pattern. The network loading is then performed through such splitting rates, thus avoiding explicit path enumeration.

After a base network model is set up, the next task is to identify the clusters in the network based on centrality indicators. For this, state-of-the-art dynamic relations are formulated for the centrality of network components as mentioned here:

Dynamic Closeness. In the considered graph *SG*, for any pair of nodes, the number of links that occurred on the shortest path while traversing between these nodes shows the topological distance. In the present study, dynamic closeness relation $\mathrm{DYC_{n_1}}$ for any node n_1 is defined by incorporating the weight of links traversed in terms of flow-dependent travel time $ftr_{n_1n_2}$ as in [11], number of stops forced by pedestrians crossings and signals made $PASt_{n_1n_2}$ and number of vehicles traversing as in (1).

$$DYC_{n_1} = \left[\frac{1}{\sum_{n_2 \neq n_1} e_{n_1n_2} + ftr_{n_1n_2} + (\gamma * PASt_{n_1n_2})} \left\{ \frac{g_{n_1}}{N-1} \right\} \right] \tag{1}$$

where r_{n_1} is the number of reachable nodes from a node n_1 and Euclidean distance is represented by $e_{n_1n_2}$.

Dynamic Betweenness. In this study, the dynamic betweenness centrality DYB_l relation to the link l is formulated considering the weighted time series demand for any time interval $(t, t+1)$ in terms of flow $f_{ab}(t, t+1)$. Moreover, it is normalized by the stop centrality over a selected path based on path choice probability $PPr_v(p)$ as in (2).

$$DB_l = \frac{\sum_{n \in p} f_n}{\sum_{n \in P_{ab}} f_n} * \frac{\sum_{p \in P_{ab}} \left\{ \sum_{v \in f_{ab(t,t+1)}} PPr_v(p) \right\} * i(p,l)}{\left| f_{ab(t,t+1)} \right|} \tag{2}$$

2.2 Critical Components

Once dynamic centrality indicators are calculated and clusters in the network are revealed, a mixed machine-learning approach is used to identify the critical components in the network and the nearest vulnerable locations. Firstly, Taxonomy analysis is carried out based on topological centrality measures involving unsupervised learning. *The k-means* clustering method is used to draw inferences and hidden patterns in the evaluated centralities. A *city block* distance metric is used to compute the centroid in a *p-dimensional* space. It is a summation of the absolute difference between each cluster point and centroid location concerning the total number of data points. This results in a total number of clusters with the most vulnerable in each one of them.

Secondly, the nearest critical neighbours of that point are revealed using the *k-nearest-neighbor* algorithm. For efficient results a *kd-tree-searcher* object is first utilized to generate a searcher then two distance metrics are used in *knn* i.e. *Minkowski* and *Chebychev* for revealing the nearest critical components.

2.3 Demand Elasticity Scenarios

The demand elasticity scenarios are dependent upon the most critical components and the network load in the concerned zone skimmed from the machine learning approach previously. Given the nature of the analysis following scenarios are defined to identify the change in system performance reflecting the amount of improvement with and without the provision of the MaaS system.

S0 The base network scenario with no demand elasticity to analyse the network stress conditions both in terms of volume and travel times.

DES1 scenario for the 30% shift of demand from private transportation modes to the MaaS system for the zone that encompasses critical components of the network concerning the intrazonal trips only.

DES2 scenario for the 5% shift of demand for the interzonal trips. A buffer is adopted from the zone of critical components to the bordering zones.

DES3 scenario for the 3% shift of demand The demand shift is reduced keeping in view the distance of the trips where commuters may prioritize their vehicle instead of MaaS.

The change from a 30% to 3% shift of demand to MaaS is dependent upon the distance of the trips. Given the short distance of trips within a zone, a higher amount of demand is perceived to be using the MaaS system and vice versa.

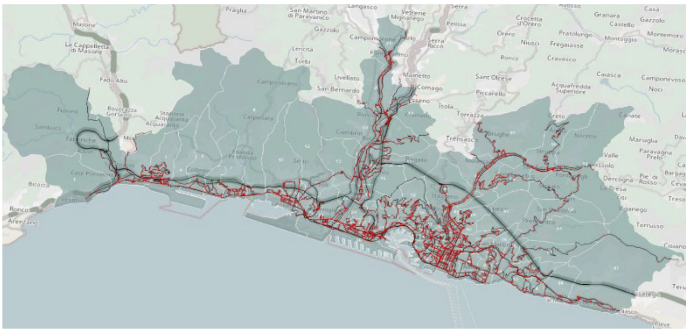

Fig. 1. Dynamic nodal centrality (Left) and link centrality (right) heat maps (Source: Heat maps exported from MATLAB R2022b)

3 Application on Real-World Network

For real network implementation of the methodology, the transportation network of the city of Genoa in northern Italy is used as can be seen in Fig. 2.

The transport network is modelled in PTV Visum and coded in MATLAB for the detailed analysis of the demand elasticity scenarios. The considered network consists of 71 zones with 4299 nodes and 7751 links covering an area of 240 km^2, home to almost 600,000 habitants. The demand is simulated for the morning peak hour (7:00 a.m.–9:00 a.m.). The results from the assignment of demand to the network in terms of

link attributes (volumes, free flow travel times, congested travel times, capacity of links) are passed to the coded network.

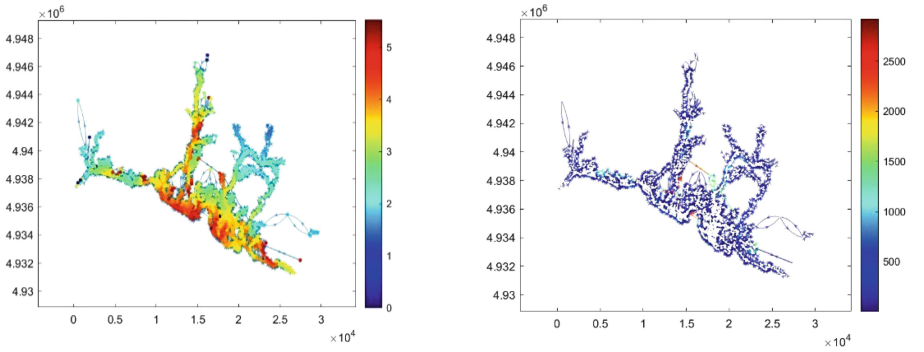

Fig. 2. Urban Transportation Network of Genova (Source: Macroscopic model developed in PTV Visum 2022)

For Genoa, the high-ranking centrality components are along major arterials towards the northern, east-central and western sides of the city. However, the two major northern arterials show moderate rankings of centrality even serving high demand of trips as can be visualized in Fig. 2 of nodal closeness. Looking into the dynamic betweenness of links, we can witness that the dynamic relation segregates high-ranking components of the transport network along the two busiest rail stations of the city (Piazza Principe and Brignole) as evident in Fig. 1.

The whole network is divided into 5 clusters (Eastern, Central Eastern, Northern, Central, and Western) based on the structural evaluation weighted by demand. Each cluster then reveals the most critical components in a total of 63 critical link segments across 5 clusters. The clustering process is not arbitrary instead it is dependent on the weights of nodes and links involved in the road network.

3.1 Demand Elasticity Analysis

For each scenario (S0, DES1, DES2, DES3), various reliability measures are compared as explained below to assess the network performance conditions as reported in Table 2. The free flow travel times (FTT), current travel time (CTT) in each cluster for the base scenario without any demand elasticity and the travel time under demand elasticity scenarios are reported in Table 1.

Travel Time Index (TTI). TTI represents the average additional time required for a trip during peak times in comparison with that trip duration in no-traffic conditions depicting the free flow conditions. The Free-Flow Travel Time is calculated by using a simple distance formula using the road link length and the maximum speed limit. TTI is given by the following equation:

$$TTI = \frac{Mean\ Travel\ time\ between\ an\ OD}{Free\ flow\ travel\ time\ between\ an\ OD} \tag{3}$$

Table 1. Travel time conditions with various demand elasticity scenarios

Cluster	Scenario	FTT (Sec)	CTT (Sec)	Travel Time Under DES (Sec)
Eastern	DES1	222	1320	752.4
	DES2	222	1320	607.2
	DES3	222	1320	462
Central Eastern	DES1	674	4474	3802.9
	DES2	674	4474	3579.2
	DES3	674	4474	3400.2
Northern	DES1	155	870	826.5
	DES2	155	870	774.5
	DES3	155	870	713.4
Central	DES1	653	3641	3422.5
	DES2	653	3641	3240.5
	DES3	653	3641	3058.4
Western	DES1	362	1527	1404.8
	DES2	362	1527	1160.5
	DES3	362	1527	885.6

Planning Time Index (PTI). PTI depicts the total time which is needed for an on-time arrival in 95% of all trips. It is the times of total travel time that must be considered for an on-time trip. PTI is given by the following equation:

$$PTI = \frac{Current\ Travel\ time\ between\ an\ OD(95th\ percentile)}{Free\ flow\ travel\ time\ between\ an\ OD} \tag{4}$$

A PTI value of 1.5 for a given period of travel for an OD pair suggests that travellers should spend 1.5 times as much time travelling as the free-flow travel time to reach their destination on-time 95% of the time. The planning time index is useful because it can be directly compared to the travel time index on similar numeric scales.

Buffer Time Index (BTI). It is defined as the additional time for unexpected delays that commuters should consider along with mean travel time to be on-time 95% of the time while travelling in the peak hours. BTI is calculated as follows:

$$BTI = \frac{Current\ Travel\ time\ between\ an\ OD(95th\ percentile) - Mean\ travel\ time\ for\ an\ OD}{Mean\ travel\ time\ between\ an\ OD} * 100 \tag{5}$$

BTI is expressed as a percentage. Since it is calculated by 95th percentile travel time, it represents almost all worst-case delay scenarios and assures travellers to be on-time 95% of all trips.

Table 2. Network reliability measures for various demand elasticity scenarios for all clusters

Reliability Measures	TTI	PTI	BTI
	S0	S0	S0
Central	7.4	10.2	3.4
Eastern	2.8	3.1	2.5
Central Eastern	7.9	6.8	1.7
Northern	2.5	2.8	2.5
Western	1.1	1.2	2.4

Demand Elasticity Scenarios									
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Central	5.1	5.1	5.1	10	10	10	3.3	3.3	3.3
Eastern	1.9	1.9	1.9	2	2	1.9	1.5	2	2.3
Central Eastern	5.5	5.3	5.2	6.6	5.9	5.9	1.6	1.4	1.4
Northern	1.7	1.7	1.6	2.8	2.7	2.7	2.5	2.5	2.5
Western	0.7	0.7	0.7	1.1	1.1	1.2	1.6	1.6	1.6

4 Results

Bearing in mind the excess demand of 70% in the Central Genova Cluster, the adaptive inclusion of the MaaS system resulting in a shift of 30% of the internal zonal demand within the cluster shows a decrement in all the reliability indices. TTI reduces from 7.3 to 5.1 bringing down the travel time up to 4.9%. PTI doesn't show an appreciable decrement giving us an insight that a traveler is spending 9.9 times the FTT as shown in Table 2 while going to its destination in peak hours. While BTI decreases from 3.4% to 3.38%. Whereas, if we consider the extra shift from bordering and next neighbouring zones in the same cluster, the BTI reduces from 3.4% to 3.3% respectively.

For the Eastern Genova cluster, the total demand on the network is 69% more than the actual supply to cater for the demand. Thus creating immense traffic delays on critical links. However 30% shift in the demand towards the MaaS system reduces the travel times up to 65% bringing down the TTI from 2.8 to 1.9. PTI comes down to 1.9 from a large value of 3.2 as can be witnessed in Table 2. BTI is reduced from 2.5% in the base scenario to 2% in scenario S3.

For Central Eastern Genova Cluster, the adaptive inclusion of the MaaS system reduces travel times by up to 15%. TTI is improved from 7.9 to 5.3 whereas PTI shows a minimal change from 6.8 to 5.9 showing that an average traveler spends 5.9 times of the free flow time in peak hours on critical links.

The northern and western clusters have an excess demand of 69% and 44% respectively. Albeit, the Green MaaS system attracts demand and reduces travel times up to 7.7% and 7.4% in Northern and Western clusters respectively as mentioned in Table 1. That also depicts an immense improvement in the reliability indices and consequently the network situation in peak hours with reduced burdens.

5 Conclusive Remarks

The centrality analysis revealed 5 major clusters in the network of Genoa namely eastern, central eastern, northern, central and western. Each cluster has its critical components. The eastern cluster has three critical links, Central Eastern has 18, northern has 6, central with the largest number of critical links i.e. 24 and Western has 12 critical links. The reason for the high criticality of the links in each cluster is their centrality values. Our in-depth analysis showed that the excess demand varies from 78% in the central-eastern cluster to 44% in the northern cluster. This answers the question of such high current travel times as compared to the free-flow travel times at the critical links in each cluster. However, the adaptive planning of a green MaaS system improves the situation in each of the analysed scenarios. For instance, in the central cluster, the difference reaches from 10.8 min in free-flow to a giant 60 min in a congested period. However, the presence of MaaS under various scenarios lowers the difference by 10 min. Yet, the reduction in travel times is not that appreciable specifically in central and central-eastern clusters which are particularly due to humungous differences in the capacity and demand of the links. Another factor is the number of trips that are less than 5 km in length, in contrast to the other three clusters the central-eastern and central Genova cluster has only 35% of trips that are less than or equal to 5km between an origin and destination. Also, it should be noted that the links connecting the eastern and western parts of the city are all going through the central clusters thus generating maximum demand for them and consequently imposing worst impacts on performance.

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Gender Gap in Cycling? Illuminating Gender-Specific Route Choices Preferences

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Abstract. The existing research evidence indicates that gender-specific travel behavior is poorly understood, and there is still a lack of knowledge about to what extent cycling route choice behavior of women varies significantly from that of men. This study is the first to reveal gender aspects in route choice of cyclists in the German context, based on revealed preference data. We employ a model which allows for a direct comparison of all preferences in terms of gender, and apply it on a well-balanced sample of bicycle route data collected through GPS tracking in a country with a gender-neutral cycling scenario. We include attributes such as surface type, elevation, bicycle infrastructure, or road type. We find, for example, that the sheer existence of bicycle infrastructure is more important to women than to men, but the type and quality of bicycle infrastructure has a higher importance for male cyclists. The route choice model indicates a high value of goodness-of-fit measure. Future research will encompass analysis on much bigger datasets and application of modelling approaches capturing unobserved heterogeneity.

Keywords: Gender · revealed preference · bicycle route choice

1 Introduction

There is evidence from research that gender-specific travel behavior is poorly understood. Gender issues have little impact on policymaking and traffic planning widely ignores women's needs [1]. However, mobility data indicate that women's travel behavior varies in comparison to that of men. Research reveals that women often have distinct preferences and needs concerning transportation systems [2]. This is also relevant in the field of cycling where safety and security, physical issues, trip distances and duration, speeds and other issues play a vital role [3]. However, there is still a lack of knowledge about to what extent cycling route choice behavior of women varies significantly from that of men.

Gender gap in cycling, referring to the disparity between male and female bicycle usage, has been a recurring issue in some countries and cities. Numerous studies have consistently shown that women are less likely to cycle compared to men (e.g., [4, 5]). Despite various studies focusing on cyclists' gender-related differences, a gap remains in the examination of route choices preferences of male and female cyclists. Although

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several studies on that topic exist (see Sect. 2), there is lack of knowledge for the German case and, thus, a need for research – especially on revealed preferences data – to gain insights into how cyclists choose their routes depending on gender aspects.

The proliferation of mobile apps for tracking individual cycling trips has led to the accumulation of vast amounts of geo-referenced bicycle data [6]. This data has enabled researchers to associate user characteristics, such as gender and age, with bicycle trip data. This study contributes to the field by illuminating the differences in route choice depending on gender aspects for the city of Dresden (Germany).

2 State of Research

There exist numerous studies on modelling cyclists' route choice behavior based on revealed preference data [7]. Moreover, efforts have been recently made to utilize large GPS datasets to understand cyclists' preferences in German context specifically [8]. Including socio-demographic information in bicycle route choice models allows for more personalized analysis and thus more specific policy implications. Studies based on stated preference data find, for example, that women have stronger preferences than men for greater separation from motorized traffic [9].

Some revealed preference studies on bicycle route choice behavior including information about cyclists' gender [10–12] indicated it to be insignificant or did not conclude on the influence of gender. A recent study from Switzerland [13] indicated a rather large gender effect on cyclists' route choice preferences considering type of bicycle infrastructure, car speed limit, and elevation. The study in [14] also showed differences between route choice behavior of female and male cyclists, for example in terms of the ease of use of the pathways and related choices. Although this study provides valuable indicators for differences in gender-specific route choices, it does not establish a full alternative-based choice model but compares the observed route to the shortest path instead.

The most consistent study comparing gender effects on bicycle route choice preferences can be found in [15]. They found that coefficients for certain variables, which negatively affect route choice (e.g., AADT, speed, slope), are consistently higher for women. However, this study was performed in the US-context, where the community of cyclists is male-dominated.

Our study contributes to the existing line of research by estimating a consistent bicycle route choice model on a well-balanced sample, collected in a country with a gender-neutral cycling scenario. The model is estimated as joint multinomial logit (MNL) model, which allows for a direct comparison of all preferences in terms of gender and accounts for the heteroscedasticity of error terms for both groups.

3 Data and Methods

3.1 Route Data

The used bicycle route data was collected through GPS tracking during a field study in of the RadVerS research project conducted by the University of Technical of Dresden (Germany). The dataset contains route data from 187 volunteer cyclists representing

the city's demographic diversity in the city of Dresden. Participants were selected from a pool of 10,000 respondents to an online survey on cycling habits and includes 80 female and 100 male cyclists aged 16 to 88. Data collection, which was implemented using the Cyface smartphone app, took place in June/July 2018. Participants tracked their rides within a two-week period. Initially, over 5,000 GPS tracks were collected, but after extensive data processing, around 4,000 trips remained. Further information on data collection and processing can be found in [16]. For route choice analysis in this paper, utilitarian trips have been chosen to fulfill the utility-maximization assumption, which resulted in 2,342 trips from 160 individuals (71 female and 89 male cyclists).

3.2 Transport Supply Data

To determine route characteristics for modeling purposes, essential transport supply data was gathered, considering a range of factors influencing bicycle route choice. These factors encompass distance, slope, existence of cycling infrastructure, path width, surface quality, car parking and speed limits, motorized traffic (mt) volume, number of lanes for mt, presence of other cyclists, pedestrian density, types of intersections, accident risk, perceived safety, and land use.

Data originates from various sources, such as the City of Dresden's open data platform or OpenStreetMap. When the required information was unavailable or incomplete, data was collected by using satellite images, Google Street View, and on-site inspections.

All collected data was then integrated into a transport supply network model, covering over 350 km of the city's road network. This network represents approximately 25% of the total road infrastructure (1,400 km) in Dresden. It encompasses the primary road network and crucial bicycle routes and corridors within the city, forming a comprehensive dataset for analysis and modeling purposes.

3.3 Choice Set Generation

To analyze bicycle route choice, route alternatives were generated using an extended penalty tube approach (as in [8]). First, a buffer with a diameter d is created around the chosen route, and edges within it are added to a penalty tubes list. The cost (e.g., travel time) of all edges in the penalty tubes list is scaled up by a penalty factor pf. Next, a shortest path routing (Dijkstra's algorithm) is applied between the start and end points of the chosen route, considering the scaled costs to find the least-cost path. The found alternative is added to the set of potential alternatives. Steps one to four are repeated until k alternatives (here: two) have been generated. The optimal parameters ($d = 100$ m, $pf = 2$, $k = 2$) were determined using a test dataset to ensure spatially distinct alternatives to address the Independence of Irrelevant Alternatives (IIA) problem in model analysis.

3.4 Route Choice Model

We employ a joint multinomial logit model [17] to jointly model cyclists' route choice behavior for both gender groups.

Let S_1 and S_2 denote two groups being the subject of comparison, and ε_{S_1} and ε_{S_2} the respective random errors (iid, EV1-distributed). Then, the utility expressions associated with alternative i in choice situation t are defined as follows

$$U_{it}^{S_1} = \beta_L\left(x_L + \beta^{S_1} X_{it}\right) + \epsilon_{it}^{S_1} \tag{1}$$

$$U_{it}^{S_2} = \theta\left[\beta_L\left(x_L + \beta^{S_2} X_{it}\right) + \epsilon_{it}^{S_2}\right] \tag{2}$$

where x^L denotes the length attribute with the respective parameter β_L, β^{S_1} and β^{S_2} denote the preference parameters for groups S_1 and S_2, respectively, X_{it} corresponds to the set of model attributes, and θ defines the *scale factor,* accounting for the ratio of standard deviations of the error terms $\epsilon_{it}^{S_1}$ and $\epsilon_{it}^{S_2}$. θ is estimated in the estimation process, together with other parameters β_L, β^{S_1}, and β^{S_2} and describes the variance of unobserved factors in group S_2, relative to S_1.

To ease the interpretation of the results, we additionally define the parameters in value-of-distance (VoD) space, which corresponds to the willingness-to-pay (WTP) space [18]. In this way, model scale is incorporated in the distance coefficient (β_L), enabling a direct interpretation and comparison of the scale-free WTP parameters (β^{S_1} and β^{S_2}), expressing the marginal rates of substitution for the respective attributes.

4 Results and Discussion

The results of the joint model (Table 1) indicate heteroscedastic random utilities (different variances of the error terms) across the observations for male and female cyclists. The distance coefficient is dominating and negative, which is in line with the expectation that cyclists on utilitarian trips aim to minimize distance. Generally, asphalt routes are preferred to routes with other surface type, as also found in studies from Denmark [7, 19].

The existence of bicycle infrastructure is more important to women than to men – an observation previously made in, e.g., [13] and [14]. Our model indicates that women are willing to ride 67% extra distance to reach a road with bicycle infrastructure; this willingness is less for men and amounts to 36% (the coefficients in VoD space are estimated as -0.668 and -0.361 for women and men, respectively). On the other hand, the results indicate that type and quality of bicycle infrastructure has a higher importance for male cyclists – they are willing to detour more to reach bicycle infrastructure with separation from motorized traffic and wide lanes. The latter is found to have no additional utility for women. These results suggest that women prioritize safety over comfort more than men do.

Streets with a maximum permitted speed of 30 km/h for the motorized traffic are found to be insignificant for both segments (men and women). A question arises if this attribute gains more importance if combined with the bicycle infrastructure type or other factors, describing the cycling environment. Surprisingly, slope is also found to be an insignificant parameter, which is probably affected by the choice of research area that shows limited topographic variety. Previous research indicates that cyclists clearly disprefer steep route segments (e.g., [7, 11, 12, 15, 19]).

Table 1. Bicycle route choice models. Symbol 'X' indicates group S2 from Sect. 3.4. Parameters in bold are statistically different between the groups at the 5% level (according to the statistical test from [20]. Parameters in bold are not statistically significant at the 5% level.

	Generic		*Female*		*Male*	
	Coeff.	z-val.	Coeff.	z-val.	Coeff.	z-val.
Scale factor θ	0.558	5.191			X	
Distance	−3.501	−7.639				
Parameters in VoD space						
Asphalt surface			−0.195	−2.976	−0.343	−5.175
Steep elevation			0.134	0.961	0.142	0.777
Bike infrastructure			**−0.668**	−6.301	**−0.361**	−4.271
Safety separator			**−0.466**	−6.311	**−0.922**	−9.847
Wide lane			−0.076	−0.877	−0.271	−3.013
Streets with more than one car lane			−0.184	−2.261	−0.155	−1.771
Main paths			−0.057	−1.135	−0.153	−2.444
Zone 30			−0.038	−0.669	0.082	1.013
High ADT			0.272	4.314	0.409	4.432
Low pedestrian density			0.426	2.503	0.426	2.503
Model evaluation						
Number of observations	2,342					
Number of parameters	22					
Final log likelihood	−1,154.5					
McFadden's pseudo-R2	0.89					

The route choice model in this study indicates that cyclists are also willing to take a detour to ride in areas with high density of pedestrians. There is also a slight but significant difference in route choice of men and women. Female cyclist tend to prefer route with higher pedestrian density somewhat stronger than male cyclist do. (see Table 1). Similar strength of influence was found for roads with a high average daily traffic (ADT) on route choice of both gender. These results contradict with some findings from other studies (e.g., [7, 15, 19]), which find that interaction with other modes of transport, both motorized and non-motorized, acts as a deterrent for cycling route choice. However, in our data set, high pedestrian density and high traffic volume levels proxy for locations

within the city with a high livability, and another model attributes might be needed to separate the effect of area livability and the actual interaction.

The model indicates a goodness-of-fit measure (McFadden's pseudo-R^2) of 0.89, which is high compared to the existing bicycle literature where values of the McFadden's pseudo-R^2 typically range between 0.3 and 0.5.

5 Outlook

This study is the first to reveal gender aspects in route choice of cyclists in the German context, based on revealed preference data. Although our study applies a solid approach to modelling cyclists' route choice behavior and provides several insights into gender-related differences in route choice, further research directions appear.

Next steps will encompass analysis on much bigger data sets with dozens of thousands of trips. Such data are currently gathered within a research project of the Dresden University of Technology where rides from whole Germany are recorded. The utilization of such data would result in higher model accuracy and would enable an application of both in-sample and out-of-sample validation frameworks. The list of network attributes used for the utility function specification can also be extended and enriched with, for instance, land-use attributes or modern bicycle infrastructure concepts, such as cycle superhighways or bicycle paths in low-speed zones.

Methodologically, further approaches to the choice set generation procedure will be tested and the generated alternatives will be assessed w.r.t. the overlap-distinctiveness trade-off or heterogeneity of the attributes. Finally, since cyclists' behavior for certain attributes is heterogeneous [7, 19], another modelling approaches capturing unobserved heterogeneity will be applied.

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Gender and Age Gap in Waiting Times at Signalized Intersections – Are Groups of Cyclists Structurally Disadvantaged?

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Abstract. This paper addresses whether traffic lights in German cities exhibit systematic discrimination against potentially slower cyclists. Recent literature indicates that female and elderly riders tend to cycle at notably lower speeds compared to other demographic groups. Hence, our analysis centres on waiting times at intersections in six German cities, specifically focusing on these particular groups. GPS trajectories were collected via smartphone apps as part of the CITY CYCLING campaign in 2022. Statistical analysis revealed only minor differences in waiting times between genders at traffic lights. Similar observations were made concerning age groups, except for two categories. Unexpectedly, individuals in age brackets where discrimination was anticipated (<16 and >64 years) experienced shorter waiting times at traffic lights compared to others. When examining waiting events per kilometre, a slightly different scenario emerged: women encountered significantly more waiting instances at traffic lights than men. This, coupled with a marginal disparity in average waiting time, hints at potential avoidance strategies.

Keywords: Cycling · Gender · Waiting time

1 Introduction

In many nations, increasing the percentage of female cyclists shows substantial potential for growth in cycling [1]. One strategy to encourage more cycling involves minimising travel time by synchronising consecutive traffic lights. A reduction in travel duration could position cycling as a viable alternative to individual motorised transport. A critical factor influencing traffic light coordination is the travel speed of road users – in this case, cyclists. Considering that cyclists' speeds, despite the rise of pedelecs, rely on physical conditions, disparities in these conditions significantly impact the success of traffic light coordination and subsequently affect travel times. Pre-existing signal schedules, whether coordinated or not, may favour individuals capable of higher speeds, potentially discriminating against those unable or unwilling to maintain such speeds.

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2 State of Literature

Differences in cycling behaviour can be assessed through various methodologies, including online surveys [2, 3], capturing stated preferences, naturalistic cycling [4], or simulator studies [5]. Another method involves analysing GPS trajectories of cyclists to acquire transportation demand data. These data can be gathered via smartphone apps [6, 7] or specialised devices such as the Hövding cycling airbag [8]. Numerous studies have highlighted differences in cycling behaviour between male and female cyclists as well as across different age groups [9–11]. These differences manifest notably in higher speeds on open roads [6] and greater acceleration among male cyclists [9, 12] or younger age groups [9]. Flügel et al. highlight that on average, male cyclists are 13% faster than female cyclists [6]. However, among female cyclists, there is a high variety in speed – the fastest 25% of female riders outpace the median speed of male riders [6]. Further differences relate to route choice [11] or the perception of infrastructure and subjective safety [10]. Differences in speed and acceleration, particularly among cyclists without electric assistance, inevitably result in varied arrival times at signalized junctions during everyday cycling, potentially leading to significantly distinct waiting times. Following the German Manual for the Design of Road Traffic Facilities (HBS), the waiting times experienced at intersections play a pivotal role in shaping the overall cycling experience for users [13]. Given the documented disparities in cycling speeds based on gender and age, there exists a possibility of discrimination in the utilization of cycling infrastructure.

3 Methods

In our study, we analysed the varying time losses experienced by women, men, and different age groups based on waiting times, drawing from a comprehensive Germany-wide GPS dataset encompassing over 7 million trips involving more than 200,000 cyclists. To manage the data effectively, we selected six cities of varying sizes - Dresden, Munich, Darmstadt, Freiburg, Darmstadt, and Weimar - from this dataset. This dataset was originally collected in 2022 as part of the CITY CYCLING campaign, a three-week cycling initiative undertaken across 2,400 German cities, ensuring a gender-balanced sample. The chosen cities are diverse in terms of population size and density. Population numbers range from 62,000 individuals in Offenburg to 1.47 million in Munich. Moreover, these cities present slightly varying proportions of cycling as a mode of transportation, varying from 16% (Offenburg) to 34% (Freiburg). The topography across all cities can be described as generally flat to hilly.

The trip data underwent initial processing to rectify outliers and eliminate other modes of transport and activities. The data processing involved categorising cycling activities into four states: riding, accelerating, decelerating, and waiting, determined by speed and acceleration values [14]. Subsequently, GPS trajectories were aligned with the road network using OpenStreetMap (OSM), which included traffic lights at intersections and pedestrian crossings. Instead of using a map-matching algorithm, we expanded the OSM network around intersections and pedestrian crossings by 30m. This allowed direct matching of GPS points into these extended zones, enabling the incorporation of intersection details into the pre-processed trips. Following this, various statistics were

computed for each track, encompassing gender, age, duration, distance, median speed, average waiting time at intersections, total waiting time, the number of waiting events at intersections and overall, as well as the total number of crossed intersections. The resulting dataset for the study area comprises 267,401 trips (48% undertaken by female riders) involving 15,192 distinct users.

Statistical analysis was conducted using RStudio. In addition to descriptive statistics, non-parametric tests were employed to scrutinize variations in waiting times concerning age and gender, acknowledging the non-normal distribution of waiting times. To explore potential gender discrepancies in waiting times, the Mann-Whitney-U-test was utilised. For evaluating differences in waiting times across age groups, the Kruskal-Wallis test with Bonferroni correction was applied in the pairwise comparisons. The effect size was calculated using the Wilcoxon test.

4 Results

Descriptive statistics reveal differences in both speed and waiting times across the various cities, shown in Figs. 1 and 2. Although variations in speed between these cities appear marginal, significant differences emerge in waiting times at traffic lights, particularly showing higher waiting times in larger cities. This observation seems intuitive, considering that the number of traffic lights likely increases with the city's size and the frequency of intersections. Conversely, the seemingly consistent median speed across cities appears somewhat counterintuitive. This discrepancy arises from the methodology employed in data processing: the calculation of median speed relied solely on GPS points categorised as "riding" excluding instances of acceleration and deceleration processes.

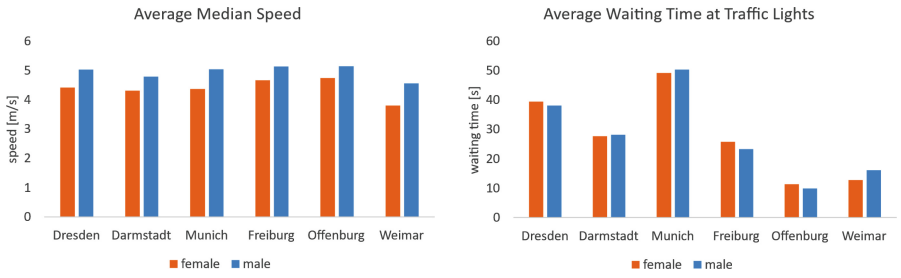

Fig. 1. Average median speed (a) and average waiting time (b) for cities and gender.

Concerning differences between genders, the average waiting time at intersections shows minimal disparity between male and female riders, indicating a marginal distinction in both directions (Fig. 2b). Multivariate statistics support this observation, demonstrating significant differences between genders in Dresden, Freiburg, Offenburg, Weimar ($p = 0.000$), and Munich ($p = 0.042$). However, the effect size remains relatively small (ranging from 0.02 to 0.07). When consolidating all city datasets and accounting for gender differences in waiting time at traffic lights, significant differences emerge ($p = 0.000$) with a small effect size ($d = 0.008$) as well.

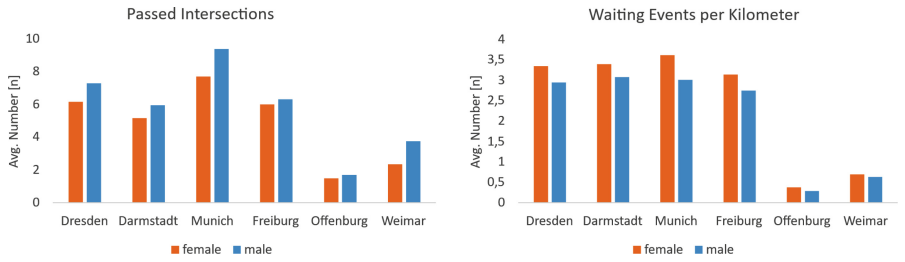

Fig. 2. Average passed intersections (a) and average waiting events (b) for cities and gender.

Differences between male and female riders become apparent in the average number of signalized intersections crossed (Fig. 2a), indicating that male riders tend to use the primary street network more frequently than female riders. Conversely, females encounter a higher frequency of waiting events per kilometre at traffic lights on average compared to male riders (Fig. 2b). The number of waiting events at intersections per kilometre differs significantly between male and female riders ($p = 0.00$ across all cities), albeit with a small effect size (ranging from $d = 0.06$ to 0.156). Examining the influence of age reveals that younger individuals (<16 years) tend to experience shorter average waiting times at intersections compared to those aged between 16 and 64 years, with the age group 16–29 exhibiting the longest waiting times. In nearly every city (excluding Freiburg and Weimar), waiting times decrease from the age of 30 years onwards. Notably, smaller cities like Weimar and Offenburg consistently exhibit significantly lower waiting times and waiting events across all age groups (Figs. 3a and 3b).

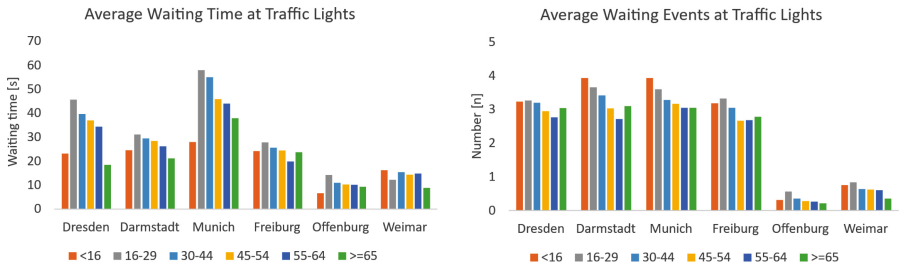

Fig. 3. Average waiting time at traffic lights (a) and average waiting events (b) for cities and age groups.

A Kruskal Wallis test shows significant differences in waiting time between the age groups across all cities ($p = 0.000$) with small effect sizes using the Dunn post-hoc test ($r = 0.02$ to 0.14).

5 Discussion

The analysis of GPS data from six diverse German cities reveals significant differences in waiting times between male and female riders, albeit with a small or very small effect size. Furthermore, the effect does not consistently indicate the same trend. Across some cities,

male riders generally experience slightly shorter waiting times than their female counterparts. Nonetheless, there are exceptions (such as Darmstadt, Munich, Weimar) where the effect shows an opposite trend. In contrast, the frequency of waiting occurrences per kilometre of a journey demonstrates a distinct trend. Women cyclists encountered more instances of waiting at traffic lights than their male counterparts, although the duration of their waits was not notably longer. One potential explanation could be the adjustment in cycling behaviour among female riders: it's possible that they significantly adapt their speed and deceleration when approaching a red light. Another explanation might lie in their route choice: female riders often opt for less hazardous paths, diverging from the primary cycling network (arterial routes) [5, 10, 11]. Junctions within the subnetwork tend to be less complex and feature shorter durations of red light phases. As for the 'age' variable, the outcomes are even more varied: the primary observation indicates that individuals under 16 years old and over 64 years old wait significantly shorter periods on average compared to others. Both groups exhibit notably lower waiting times than all other age brackets, aligning with existing literature findings on differences in speed and acceleration among various age groups [6, 9, 10]. To some extent, this suggests that traffic lights are more likely to favour slower cyclists. This phenomenon might also be attributable to the route preferences of elderly or young individuals. The former tend to alter destinations, favouring shorter routes within residential neighbourhoods or leisurely rides on the outskirts of cities, a parallel that aligns with findings in Goodman et al. [15]. Finally, the initial hypothesis of this paper must be reconsidered. While there exists notable yet slight differences in waiting times among male and female riders or various age brackets, the more pronounced contrast lies in the dissimilarities between cities. It remains ambiguous whether this discrepancy arises from distinct behavioural adaptations or if there is an absence of discrimination against slower cyclists.

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Transport Equity – Exploring Gender-Inclusive Infrastructure in the Context of Rural and Inter-urban Cycling in Ireland

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Abstract. The results from this research will inform how cycling infrastructure is designed and planned to mitigate barriers that prevent women accessing and utilising cycling as a form of travel. It will support the Irish Government's strategic objectives within the Climate Action Plan (2023), which sets a target of net-zero carbon emissions by 2050, by providing evidence to support a shift from carbon-based transport to higher uptake of cycling among women in Ireland. In addition, it will provide evidence on how to best meet objectives within the trans-European transport network to increase the benefits for its users by ensuring accessibility for all users is fair and meets their mobility and transport needs.

The research project has to date included a literature review of current cycling patterns in Ireland and internationally, and qualitive and quantitative data collection from women living in Ireland. This paper outlines the results from those initial phases. The literature review was used to inform the follow on qualitative and quantitative research phases. The first phase consisted of a survey to collect data from women in Ireland, the second phase involved recording travel diary data followed by depth interviews.

Keywords: Gender · Equality · Behaviour Change · Cycling · Active Travel · Net Zero

1 Introduction

Gender mainstreaming is not a new paradigm, but its application is not yet widely accepted particularly in traditional transport management and planning. Traditional transport delivery typically assumes that users are a homogenous group i.e., the transport needs of different genders are not explored or disaggregated. In Ireland, significantly more men than women use cycling as their main mode of transport and their typical trip purposes also differ. Men complete more working trips while women carryout more accompanying trips than men. Furthermore, findings from recent Irish research, *Travelling in a Woman's Shoes,* found that car-dependency, especially outside Dublin, is

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particularly high among women, and women's main reason for travelling was to accompany children or family members [1]. To achieve desired modal shift targets, to reducing carbon emissions, the factors that impact women's lack of uptake of cycling should be better understood. This study seeks to address the knowledge gap by gaining a better understanding of the factors relating to roads and cycling network infrastructure, weaknesses or barriers, that impact cycling uptake among women in Ireland. The research project is still in progress and has to date included a literature review of current cycling patterns in Ireland and internationally, qualitive and quantitative data collection. This will be followed by a workshop with stakeholders examining systems effecting levels of cycling for women in Ireland.

2 Literature Review

The literature review identified several infrastructure factors that encourage people to cycle more such as "safer cycling routes", "better health" and "more specific cycling routes". Commuter journeys in Ireland has a far lower uptake by women than men, 1.6% versus 3.9%, although the results are low for both genders. Commuter cycling rates also dropped between 1986 and 2002 before rising again from 2006 to levels in 2016 which were close to the 1986 levels but which by this time made up only 3% of commuters overall as opposed to 6% in 1986 [2]. Across all travel modes women in Ireland make considerably more companion/accompanying journeys than men, 26.1% versus 15.3% [3]. This reflects the established evidence that women in Ireland complete a greater proportion of caring duties and with most women not perceiving cycling as a safe option for transport of dependents [1]. Cycling to education and work rates are typically higher in urban settings than rural settings.

Personal safety concerns, such as fear of attacks and harassment, is another significantly greater concern for women than men. More women than men (34% v 24%) cite "feelings of insecurity" which have deterred women from travelling occasionally, across all modes of travel [1]. Even in the Netherlands, where women cycle (29% of all journeys) at least as often as men (27%) [4], personal safety concerns for cycling at night were stronger among women than men. In Ireland there is often negative views of cyclists using road space and greater risk of aggressive/hostile interaction with drivers than other countries where cycling is a more established norm; this experience is not unique to women although potentially more off putting than for men [5]. Personal appearance also factors into women and girls' decision to cycle. Higgins and Ahern's research [6] showed that there was a significant difference in the average responses between boys and girls on how cycling affects their appearance, with girls more negatively affected. In interviews conducted in Bristol and Cardiff on commuter cycling, themes emerged of cycling not being conducive to dressing smartly for women and that women who cycle are perceived as "tomboys" [7].

Factors that would encourage more women to cycle were found to be Safer Cycling Routes, Better Health (i.e., the possibility to improve health through exercise), and more cycling specific routes [3]. Although women are more likely to feel unsafe in traffic and prefer segregated cycle infrastructure than men with some evidence to suggest that women are more concerned than men about near misses [8], even if there is little evidence to suggest that vehicles actually travel closer to women than men [9].

3 Methodology

The literature review was used to develop the questionnaire in the first phase of the research. This phase administered an online survey to more than 1,000 women aged 18 and over who live in Ireland to gather data about their attitudes to cycling and current cycling behaviour. The ethnographic study provided insight into the experiences, perspectives and everyday practices of women who cycle; this was conducted using a smartphone app where participants record their cycling journeys in a travel diary over a two-week period. Although the sample size of the ethnographic study was small it was possible to ensure that participants from different ethnicities, age groups, disabilities or long-term health conditions, and rural/urban locations were represented.

4 Quantitative Survey Results

The respondents were recruited via the Dynata panel with the aim of securing a spread of responses from all age groups over 18 and with representation from urban, suburban and rural areas. 1,047 adult women living in Ireland completed the survey.

Cycling ability and confidence *(overall sample)* Most (over two thirds) of respondents say they are confident and able to ride a cycle. Very few respondents (3%) report that they have never learnt to ride a cycle, so this is unlikely to be a major barrier to cycling. A greater barrier is confidence and ability; just under a third (29%) are not confident or able to ride a cycle at the moment. Of those who are not able to currently ride a cycle, there is a clear appetite for improving skills and confidence. Almost a half (47%) indicated that they were interested in learning to ride or refresh their skills.

Current cycling habits and motivations to cycle *(those who are able to cycle and own/have access to a cycle only – 55% of overall sample)* most who are able to cycle (and own/have access to a cycle) do so for leisure or functional journeys at least occasionally; only 5% reported that they never cycle. Women cycle more often for leisure, recreation or exercise than functional journeys; 20% do not do any functional cycling (journeys with a purpose other than purely for leisure or fitness). Almost half (47%) of respondents cycled for leisure or recreation at least a few times a month; 21% at least once a week. Similarly, almost two-thirds (58%) cycled for exercise at least a few times a month; 27% at least once a week. Almost 1 in 5 (19%) ride for training or with a club at least a few times a month. Looking at the most frequent type of cycling (once a week or more), commuting to work is the most common journey type (19% of respondents) followed by running errands (18%) and going shopping/visiting family and friends (both 14%).

Urban/rural differences The survey revealed many significant differences in the frequency of journeys between people from different locations. In urban (26%) or suburban (20%) locations were more likely to commute to work by cycle once a week or more than those in a rural location (10%). In suburban (48%) or rural locations (58%) were more likely to say they never cycled to go shopping compared to those in urban locations (34% answered never). In rural locations women are more likely to say they never visit family and friends, travel to entertainment or leisure venues or run personal errands by cycle compared to people who live in urban or suburban locations. Those living in an urban location are less likely to be motivated to do journeys by cycle to keeping fit and healthy than those in suburban or rural locations.

Barriers and motivators to cycling (*overall sample*) The most reported barriers to cycling were the weather (53%) unsafe roads (49%), and traffic volume/speed (39%). The least commonly reported barriers were unpleasant environment/scenery (4%), barriers/gates/other infrastructure on route (6%) and lack of knowledge of bike maintenance/repairs (8%). Over 55s are more likely to report traffic volume and speed, and unsafe roads, as barriers. Those who never cycle were more likely than those who regularly cycle to agree that cycling is dangerous. The **most reported factors that would encourage starting/more cycling were safer roads (54%)**, better cycling routes (37%) and shorter journey distances (32%). The top five factors generally mirror the top five barriers of the previous question, aside from the weather. When asked specifically to consider infrastructure that might encourage people to cycle, there was a stronger focus from respondents on **the availability and quality of cycle routes** than the facilities on these routes. The most reported desirable infrastructure factors were segregated cycle lanes on roads (29%), well-lit cycle routes (27%) and well-connected cycle routes (25%).

Attitudes to cycling (*Overall sample*) Encouragingly, over three quarters of respondents (76%) agreed that cycling is enjoyable. And while almost half reported they saw people like them cycling for transport (47%), less than quarter (22%) reported doing journeys by cycling were the norm where they live. Nearly half (47%) agreed that cycling is dangerous, and a similar proportion (49%) did not think children can cycle safely where they live. There is some indication of generational differences in attitudes to cycling, with people in the youngest age group (18–34) more likely to disagree that cyclists have a negative image compared to those aged over 55.

5 Ethnographic Research Results

A sample of 30 women was invited to take part in ethnographic research which involved using a smartphone app (through the Sago Qualmobile platform) to keep a travel diary of all journeys made over a two-week period. Of the 30 invited to take part, 22 completed a diary for at least one journey, with most (19) completing diaries for at least three journeys. A total 73 journeys were recorded across the sample with 33 journeys being made by cycle, 20 by car, 6 on public transport and 14 by walking. All participants were contacted and asked if they would be willing to take part in a follow-up interview: 18 were interviewed.

The women who participated in the ethnographic research cycled regularly. Most cycling journeys were for 'functional' reasons, such as commuting, running errands, and visiting family and friends. However, some of the women did cycle for leisure, particularly with their families on weekends or during holidays. The women who commuted by cycle had either done this for a long time or had started doing it when they returned to their workplace after the COVID-19 pandemic. The time of this cycle commute was up to half an hour. Lack of time is a barrier to engaging in exercise, particularly for women who often combine work and caring for children and/or other dependents. **The opportunity to integrate exercise into their everyday lives by undertaking functional journeys by cycle is a key motivator for many of the women in our sample.** Leisure cycling (often done with family at weekends) - usually involved transporting bikes to a destination by car, rather than cycling from the doorstep. Locations for leisure

cycling included canal paths, local forests, lakes and parks, or for those who live close enough, the beach. Not having to worry about cars was noted as a particular benefit by one user of these types of routes.

The women interviewed were asked whether they would describe themselves as 'a cyclist' and despite cycling regularly, most answered 'no' to this question. **The women perceived a 'cyclist' as someone who cycles fast, often and for long distances, wears Lycra, and cycles for fitness** rather than function. Women generally did not associate themselves with this image and don't think of themselves as 'proper' cyclists. Group cycling was perceived to be a 'male activity', and no women could recall seeing female cycling clubs or groups cycling in their local area. **There is clearly a gendered image of cycling, particularly cycling for leisure.**

Participants of all ages had fond memories about cycling when they were younger, generally up to their teenage years. For those growing up in rural areas, **cycling gave them the freedom** to travel to different places, and a functional way of getting to school or to **meet up with friends.** Learning to drive and a preference for travelling by car was the most common reason for stopping cycling, along with moving away to college or for work. Having children impacts both positively and negatively on women's cycling habits. These participants enjoyed cycling as a family and perceived it to be an important skill for their children to develop.

Travel diary barriers: route preference by the women in the study echoed the survey results. The diaries revealed more detail, for example women reported that the types of vehicles using busy roads was an issue (road safety), lack of cycle lane continuity was described as frustrating (connected routes), and vehicles parking in cycle lanes, poor cycling surface or lack of maintenance of cycle lanes were also seen as a deterrent (quality routes). Women noted that junctions, particularly those with no cycle lane, were unsafe for cyclists and that it caused them to dismount or negotiate junctions on foot and that temporary road works hindered their visibility (better routes).

6 Discussion and Conclusion

This research demonstrates the need for gender specific planning and design. The results from the first phase provide strong evidence that cyclists and non-cyclists have different viewpoints when asked about various aspects of cycling infrastructure or routes and what they required to either begin cycling or cycle more frequently. Further differences exist between urban and rural cyclists and age impacts the degree to which women are concerned with certain factors such as road safety and how cycling/cyclists are perceived. Interestingly, non-infrastructural interventions may be more influential for women who do not currently cycle. The ethnographic study provided detail about daily infrastructural barriers from parked cars to unsafe junctions and surface quality. Many of these aspects relate to poor design and maintenance of cycling infrastructure. The result from this study suggests that cohesion, safety and comfort in particular hinder cycling among women in Ireland and are likely to be issues for all cyclists. Women in the study who did cycle regularly did not see themselves as a 'cyclist', the term was associated with sport cycling. Both pieces of research highlight the need to cater for travelling with others and accompanied trips. This research will support the Government's strategic

objectives within the Climate Action Plan (2023) to ensure maximum move away from carbon-based transport to higher uptake of cycling among women in Ireland.

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Equity Issues in Achieving Sustainable Mobility Patterns of Workers of a Factory of an Industrial Area

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Abstract. In recent decades, there has been increased regulation of industrial activities, resulting in their concentration in industrial areas located at a considerable distance from major urban areas. This approach aimed to mitigate the environmental impacts of these activities on the health and overall quality of life of the entire population. However, these industrial areas often present a deficit in transport supply, resulting in the promotion of car use as the main mode of transport for workers' home-workplace commuting, giving rise to issues of equity and accessibility to employment in these areas. A survey of the factory's characteristics and a diagnosis of worker mobility were carried out through a questionnaire to 363 of a total of 505 workers, and issues of equity were studied concerning gender, income, and the distance between their homes and workplaces. The results showed that 85% of workers live less than 20 km from the factory, which is in an industrial area with a lack of supply of bus services, especially during the 2 (of 3) production shifts, resulting in high use of cars to meet their commuting needs. It was also observed that certain worker groups face substantial difficulties in accessing their workplace due to a lack of or inadequate public transport options to access industrial areas, highlighting disparities in access to different modes of transport among the workers.

Keywords: commuting · worker's mobility · equity · sustainable mobility

1 Introduction

In recent decades, there has been greater regulation of industrial activity with the consequent concentration of industries in dedicated industrial areas far from the main urban areas, to reduce the environmental impact of these activities on the health and quality of life of the population, i.e., in residential areas. This planning practice increases the need for workers to travel greater distances to work in industries. Furthermore, combining this with inadequate public transport services has led to the forced use of cars by families to meet their commuting needs to work [1, 2]. Both the location of the workplace and

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the place of residence of people influence access to basic health, education, or leisure services, causing negative effects on mobility, and may even lead to spatial exclusion, which leads to spatial inequality [3]. Although companies do not control the way their workers travel to work, they can have a great capacity to stimulate and promote more sustainable mobility of their workers through supporting measures to reduce car use in home-work commuting [4]. Most peripheral territories, where many industrial areas are located, compared to other urban more central areas often have problems with transport supply, e.g. bus services, generating difficulty and inequality issues in access to employment, since there are no alternatives to the private car for traveling to work. In this context, an analysis of a case study of the Continental factory, located in an industrial area in Vila Real, north of Portugal, will be presented, showing that, among other results, 94% of workers use a car when traveling between home and work, due to the inadequate bus service that limits the access to the industrial area, namely in terms of bus schedules and spatial bus network coverage. Therefore, equity in terms of access opportunities to work can be related to mobility issues, since the location of industrial areas (home/work distance), combined with levels of public transport provision, income classes, and gender, can be important factors that can influence in promoting equity among workers, as well as more sustainable mobility patterns for commuting purposes.

1.1 Literature Review

One of the basic needs of populations is mobility, since it is fundamental to community participation in society, providing access to different geographic spaces [5], activities, services, and opportunities [6]. Access to public transport impacts people's social and economic well-being and can compromise employment opportunities, or access to basic health and education needs. Studies show that low-income families, the elderly, people with disabilities, women, and ethnic minorities suffer disproportionately from disadvantages in transportation, presenting difficulties in traveling due to costs and even lack of security, increasing socio-spatial inequalities [7].

Employment is the main source of income for people and the main responsible for increasing the economic power of families, representing, in this way, a key factor in facilitating the carrying out of other activities [8] and, consequently, minimizing some problems of lack of equity. Income inequality leads to inequality in access to mobility, which is reflected in the modal choice process and consequently in the travel times and distances that can be travelled by users. One of the ways to overcome this issue is the adoption of positive discrimination policies in the transport sector, with the allocation of public transport ticket subsidies for different income or socio-professional groups, which can reduce inequalities in terms of mobility and potential social and spatial segregation of populations, as a phenomenon of socio-spatial exclusion [9].

On the other hand, there are phenomena of lack of supply of certain modes of transport in certain neighborhoods or regions with disadvantaged populations, which is often identified as one of the main difficulties in accessing work for them. This fact is even more penalizing when these areas are not covered by reliable public transport, forcing workers to have a single modal option, which is the car to go to work [10].

According to the United Nations (UN), the goals of sustainable development include the promotion of social, economic, and political inclusion for all. The Portuguese Charter for Diversity, arising from the European Commission, aims to develop policies to promote diversity in all public, private, and non-profit sectors through concrete measures to promote diversity and equal opportunities at work, regardless of origin, ethnicity, sexual orientation, nationality, ancestry, age, marital status, religion, among others, which should include the mobility of workers in industrial areas.

2 Methodology

Firstly, research was carried out on current publications and bibliographical references, through scientific articles published in indexed scientific journals in Scopus, Web, and Science bases, covering topics such as equity in public transport, worker mobility, and sustainable mobility [11]. After the theoretical contextualization, a survey was applied to characterize the mobility patterns of the Continental factory employees through a revealed preference survey with 25 questions. The questionnaire was structured into 4 blocks of questions: B1 - Socioeconomic characteristics: 1) Gender; 2) Age; 3) Professional category; 4) Education; 5) Residence; 6) production shift. B2 - Home-to-work commuting: 1) the main mode of transport; 2) If the car was the main mode: fuel, place of parking, and the reasons for opting for cars; 3) distance and approx. Time on a home-to-work trip; 4) reasons for using public transport; 5) travel costs (monthly). B3 - Company support to promote more sustainable home-to-work commuting: 1) what sustainable modes of transport are/ should be encouraged; 2) the type of financial and other support by the company or other entities; 3) factory responsibility for providing a more sustainable mode of transport for its workers; 4) possibility of working remotely (teleworking). B4 – Promoting Modal Shift for home-to-work commuting: 1) interest in switching to a more sustainable mode; 2) reasons to start using public transport; 3) conditions to opt for a bicycle.

The survey was administered and answered, in person, at the factory on March 30, 2022. The survey was applied to the factory's employee population, that is, to the 505 workers, with 73% of employees responding, resulting in 354 valid surveys, which is statistically significant for a 95% confidence interval and a 5% margin of error.

According to Amorim [8], for a better analysis of accessibility, four main components are used: land use, transport, temporal, and individual components. For equity performance, were used: accessibility to employment, income, travel time/distance, and environmental factors. Thus, in this study, the equity analysis will focus on a correlation study among age, gender, distance between home and work, and income classes.

3 Results

This study was conducted in a factory located in an Industrial Zone, approximately 5 km from the city centre of Vila Real, in the north of Portugal. The city's main manufacturing units are concentrated in this area. Cars and buses are the main modes to connect this area with the surrounding territory. There are no cycling infrastructures or formal pedestrian networks for this purpose, i.e., cyclists must use the roads and pedestrians do not have footways but must travel on the road shoulders.

The industry operates 24 h a day and shifts are distributed across 3 production shifts (06:00–15:00/15:00–00:00/00:00–06:00), in addition to the "normal" (08:00–18:00) and "flexible" shifts. The current urban public transport network only offers 8 timetables originating in the city centre and stopping at the factory and does not cover the factory entry or exit times in the 3 production shifts.

From the survey, it was found that 94% of workers travel to the factory by car as a driver or passenger. Furthermore, 60% of the cars are diesel. More than half (54.5%) of workers spend more than 30 min commuting and 80.2% of workers live between 1km and 15km away from the factory.

From the information on gender and mode of transport used by workers for commuting to the factory, it was found that 60% of total carpooling (car sharing) is carried out by women. In a total population of 56% women in the factory, only 47% use cars as drivers. Of the 35% of men who work in the factory, 32% use the car as a driver.

The factory's work categories are based on the base salary of each category, to this end, positions and functions were segmented according to the worker's income (salary class). The distribution of income categories is mapped with gender, age, and commuting distance, as shown in Table 1.

Table 1. Categories (income classes) vs gender, age, and commuting distance

Categories		€̶	€̶€̶	€̶€̶€̶	€̶€̶€̶€̶	€̶€̶€̶€̶€̶	# Total
Gender	Male	94	4	1	15	1	115
	Female	154	12	2	10	1	179
Age (years)	18 to 30	89	6	1	6	1	103
	31 to 45	120	9	2	13	0	144
	46 to 60	64	1	0	5	1	72
	over 61	2	0	0	1	0	3
Commuting distance to work (km)	1 to 15	179	10	2	11	1	203
	16 to 30	25	3	0	5	0	33
	31 to 45	6	0	0	1	0	7
	over 46	1	0	1	7	1	10

€̶ - Operational (Production workers)
€̶€̶ - Administrative and technical
€̶€̶€̶ - Specialized technicians
€̶€̶€̶€̶ - Engineering positions
€̶€̶€̶€̶€̶ - Managers

4 Discussion and Conclusion

By crossing gender with salary class, it was possible to observe that, in general, there is a high incidence of workers in the lowest salary class (€̶), as would be expected since it is a production unit and electronic components. Within this group (€̶ and €̶€̶) the largest

percentage are women. On the other hand, women tend to make fewer trips alone and shorter trips than men, in addition to making more diversified trips, i.e., multi-purpose trips (e.g., schools, stores, health units, among other destinations) [12], which could result in greater difficulty in accessing mobility, given that this factory is almost entirely car-centric, which could immediately highlight some lack of gender equality.

By crossing the age of workers with their salary class, it was possible to conclude that around 34.2% of employees are between 26 and 35 years old. The lowest salary class (€) represents 86.5% of the total working population. From 50 to 60 years old, all (100%) workers are in the lowest salary class (€), since financial capacity combined with older age contributes to reduced access to opportunities and [8, 9], it is possible to identify a potential group with inequity in mobility, where a change to more sustainable modes of transport may be more difficult and dependence on cars greater.

The location of the company is often a limiting factor when recruiting new workers as they do not have affordable access to these locations, which can be somewhat segregating/restrictive [13], especially in situations like this case study, where accessibility is practically centered on the car, creating phenomena of social exclusion in access to employment and an obvious issue of lack of equity for the population in general.

It was also possible to observe that workers with lower salaries live closer to the factory and those with higher salaries in more distant locations (above 50km), since salaries are associated with the level of education, training, and responsibility in the factory, which may not be synonymous with a lack of equity in access to mobility, but only with issues of competitiveness in the labor markets. However, since salary is a strong factor of segregation between social groups, where the accessibility of each worker is related to their salary [14], deserving to be evaluated in future works.

Most workers who are on production shifts, are in the lowest salary class and live within a radius of approximately 10 km. However, the accessibility by bus is compromised due to bus schedule issues that encourage car use for commuting.

Walking and cycling to the factory could also be a possibility, especially for workers who live at 1.5 km. Yet, due to the absence of cycle paths and the hilly terrain, it was possible to verify that 64% of employees stated that "nothing would make them opt for cycling", neither cycle paths nor financial incentives, despite 30% of all workers stating that they would make a modal shift to more sustainable modes for "environmental reasons", that is, indicating that the path to sustainability could pass for improving bus service, implementing carpooling and switching to electric cars.

In a broader context, mobility shapes individuals' capacity for movement, while accessibility is closely tied to the availability of opportunities, whether they pertain to employment, healthcare, education, or various other aspects of life. Another critical factor to consider is the financial capacity and availability required for mobility, as financial restrictions can effectively limit mobility and lead to social exclusion. In this case study, 86% of all workers fall into the lowest salary class, which is considered the highest risk group in terms of equity, where greater inequalities are observed with other groups, particularly to factors such as gender, age, and distance between home and work. In this case study where workers' mobility is very dependent on the car, the public transport service is the most viable solution for more sustainable mobility, which would also allow a significant contribution to reducing inequalities between workers.

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Using the Logsum to Explore Transport Equity in Public Transport Planning in Ireland

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Abstract. Transport planning decisions can have large and diverse equity impacts and evaluating these can be challenging but this is an important element as equity is considered as a major policy goal in transport policy (Litman, 2022). Whilst there are various ways to measure the impacts of equity, use of logsum has not been widely discussed yet. The logsum is a disaggregate measure that can capture the impact of land-use, transport, individual characteristics and their interactions on accessibility. It is capable of capturing accessibility benefits from changes in the distribution of activities as it accounts for both changes in generalised transport costs and destination utility. Therefore, this paper explores the use of logsum method to evaluate the impacts of transport projects on accessibility. It also reviews the literature on measuring transport equity and using logsum as an assessment tool for transport infrastructure. The case study, using Regional Modelling System (RMS) developed by the National Transport Authority (NTA), will show where logsums are computed in several transport scenarios to assess the distributional impact across social groups and geographic locations.

Keywords: Logsum · Accessibility · Transport Equity · Distributional Impact · Regional Modelling System (RMS)

1 Introduction

A core element in recent changes in transport policy and planning is the increasing move to replace the traditional mobility focus with an accessibility-based perspective (ITF, 2020). The logsum accessibility measure can provide a convenient solution to measure the direct accessibility benefits from land-use and/or transport policies when a travel-demand model is available that already produces logsums (Geurs et al., 2010).

This paper explores the use of logsum method to evaluate distributional impacts of transport projects on accessibility within the Regional Modelling System (RMS) developed by the National Transport Authority (NTA) across social groups and geographic locations. The paper also aims to demonstrate how the logsum measure can be applied within an existing modelling system, and to explore the implications of the results for transport equity analysis.

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2 Literature Review

Accessibility refers to people's ability to reach desired services and activities (Litman, 2022) It is a crucial component of transport equity, which ensures that transport systems are accessible, affordable and fair for all social groups. Accessibility is a wider concept than mobility though conventional planning tends to evaluate transport system quality primarily based on mobility, which focuses on the physical act of moving from place to place and the factors that enable or hinder that movement (Litman, 2022).

Research shows existing land use and transport system has a distributional impact on population groups, especially the low income earners and car-less households (Rock et al., 2016). There is a high level of car dependency and forced car ownership for people in living rural areas. It shows how accessibility differs between drivers and non-drivers, and therefore non-drivers' relative disadvantage (Carroll et al., 2020; Litman, 2022).

Most of the measures for computing accessibility focus are either infrastructure-based or place-based, e.g., distance/time to the closet location or cumulative opportunity measures. However, they might overestimate or underestimate an individual's functional accessibility because they do not consider the individual's unique travel behaviour or the temporal variation of transport services (Kim, 2018; Geurs, 2018; Miller, 2019). Compared to other common approaches, the logsum measure has advantages of being sensitive to multiple modes of travel and to individual-level factors such as travel times and costs, automobile availability, and individual travel preferences (De Jong et al., 2005; Dixit and Sivakumar, 2020). It can also account for long term land use change, such as trip production effect and destination utility effect (Geurs et al., 2010). Bill et al. (2022) forecasted equity benefits by using a logsum accessibility calculated from a regional travel demand model. The result shows that the accessibility gains would be slightly higher for lower income communities and transit-dependent households.

The logsum measure has also been applied in many researches to measure the user benefits in transport appraisal. The rule-of-half is in widespread use for measuring user benefits in transport appraisal. It is commensurate with the assumption that the benefit of switching between alternatives is related only to the (generalised) cost changes associated with the alternatives, and therefore can ignore the underlying attractiveness of the alternatives, e.g., large generalised cost changes, introduction of new modes and new generation of trips (Geurs et al., 2010). The use of logsum measure is also able to include consistency between simulated behavioural changes in the travel model and quantification of benefits, which cannot be achieved using typical measures of benefits such as travel time savings. However, it also suffers issues related to the form and creation of alternatives in the mode choice model, and the difficulty in explaining the concept and changes to non-technical audiences (Villanueva et al., 2018).

3 Methodology

In econometric choice theory often used in mode choice and destination choice models, the probability of choosing one alternative among several options is a percentage incorporating the various utility of each alternative. The logarithm of the denominator

of this ratio is called the logsum, which can be used directly as an accessibility measure. Mathematically, this is represented as

$$A_i = \log(\sum_{j \in J} \exp(V_{ij})) \tag{1}$$

where:

A_i is the accessibility in zone i; J is the set of all destination zones; V_{ij} is the utility of selecting destination j.

The logsums presented in this paper are derived from the NTA's RMS - East Regional Model (ERM). These logsums are computed for at demand segment level and it shows the utility from a choice set of travel alternatives including both mode (car, public transport, park and ride, walk and cycle) and destination (1953 zones in the east regional model). The utility function for a mode and destination choice is specified as:

$$V_{dm} = \beta_{GenTime} * (GT_{dm}) + \beta_{IZ} IZ_d + ASC_m + \ln(A_d) \tag{2}$$

where:

$\beta_{GenTime}$ is an all-mode generalised time parameter; GT_{dm} is the generalised time to destination d by mode m; β_{IZ} is an intrazonal constant; ASC_m is the mode specific constant; IZ_d is an intrazonal destination flag which takes a value of 0 or 1; A_d is the attraction variable for destination d.

The logsum for zone is computed as:

$$\log(\sum_{j \in J} \exp(\mu_d * \frac{1}{\mu_m} (\ln \sum_{m \in M} \exp(\mu_m * V_{dm}))) \tag{3}$$

where μ_d and μ_m are the spreading parameters as the mode and destination model here uses the architecture of a nested logit model.

This study compares accessibility changes between current (or equivalent) transport provision and future transport provision within the County Dublin area in Ireland. To see distributional impacts between different social groups, this study considers individual characteristics (e.g. blue-collar, white collar) and trip characteristics such as trip purpose and car availability.

A total of 33 demand segments are modelled in RMS model (NTA, 2016). In this paper, only the logsums for the following demand segments are calculated:

(1) Blue Collar with Car Availabililty (Commute)
(2) Blue Collar Car without car Availabilility (Commute)
(3) White Collar with Car Availabilility (Commute)
(4) White Collar without Car Availability (Commute)
(5) Other Employed with Car Availablility (Other purposes of the trip, e.g. medical visit, leisure or social trips etc.)
(6) Other Employed without Car Not Availability (Other purposes of the trip)
(7) Other Not Employed with Car Availability (Other purposes of the trip)
(8) Other Not Employed without Car Availability (Other purposes of the trip)

The case study uses the following three scenarios for logsum computation and results comparison:

- 2016 Scenario: RMS 2016 ERM calibrated base year scenario.
- 2035 Scenario A: a hypothetical project scenario that includes transport schemes within the National Development Plan[1] that are likely to open before 2035 such as bus network improvement and light rail project. Most of the schemes included in this scenario are public transport schemes and active travel schemes.
- 2035 Scenario B: In addition to the transport schemes included in the A scenario above, light rail extension project is also included in this scenario.

4 Result Discussion

Accessibility computed using the logsum measure is compared spatially between 2016 scenario and 2035 scenario B for all the demand segments.

The comparison is undertaken at the ERM modelling zone level for the County Dublin area. It is important to note that 1) the logsum measure considers both land-use changes and generalised cost savings, which includes travel time cost, wait time, transfer time, parking charge, productions/attractions change etc., and 2) the logsums are not comparable across demand segments as they were estimated separately (NTA, 2016).

The accessibility change trend is different across demand segments when comparing 2016 and 2035 B scenarios. Commute demand segments with car availability are likely to experience disbenefits in the future year in general as the congestion experienced on the road traffic is incorporated in the logsum measure. On the contrary, commute demand segments without car availability show increases in accessibility in most of the areas. There is no significant change for 'Other' demand segments on the county level regardless of their geographic location and car availability status.

Figure 1 shows the output for the demand segment (4) white collar without car availability, which shows noticeable changes between two scenarios. The accessibility is found to be highest in the city centre area (inside of the black line) for both 2016 and 2035 Scenario B scenarios. 2016 scenario shows poorer accessibility for areas such as Portmarnock, Baldoyle and Howth areas (inside of the purple line) though they are in the vicinity of the DART[2] line, which. With more public transport schemes introduced across the County Dublin in 2035, there is significant increase in accessibility within the areas surrounding the city centre and Swords (indicated by dark blue box) areas.

Accessibility change on a particular scheme (e.g. the light rail extension project) is also evaluated by comparing the results between 2035 scenario A and B, to see the accessibility change brought by a specific transport infrastructure scheme only. Figure 2 shows that areas close to light rail show significant increase of accessibility for demand segment (4) white collar car not available. Though there are some areas experiencing disbenefit (red areas), the negative impact is minimal. This observation is seen in both 'Commute' and 'Other' for the groups without car availability. While the public transport

[1] The National Development Plan sets out the Government's over-arching investment strategy and budget for the period 2021–2030. Please see details at: https://www.gov.ie/en/publication/774e2-national-development-plan-2021-2030/.

[2] Dublin Area Rapid Transit, https://www.irishrail.ie/en-ie/about-us/iarnrod-eireann-services/dart-commuter.

project could bring out disbenefits (red areas) in some areas, the results show that the group which would rely on the public transport could gain accessibility benefits from this scheme.

The analysis of this case study shows that: 1. The logsum measure shows a person's underlying perception of accessibility and this varies between social groups and geographic locations. 2. Improvement on public transport system might not provide the same level of accessbility benefits for everyone, and these benefits could be localised.

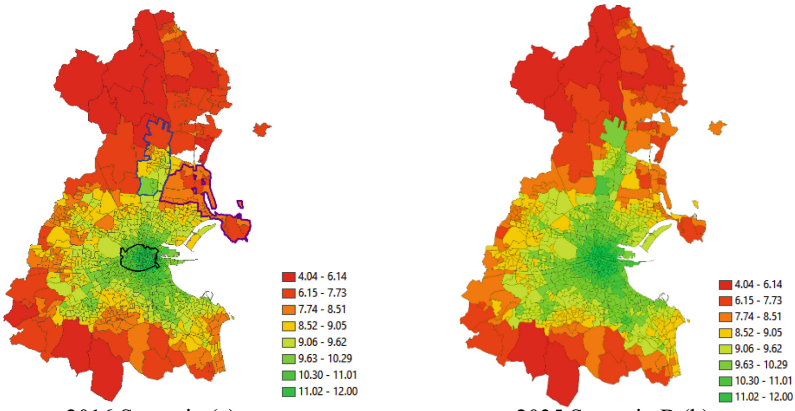

Fig. 1. Accessibility computed from 2016 and 2035 B scenario for demand segment (4) white collar without car availability. Source: ArcGIS 10.4

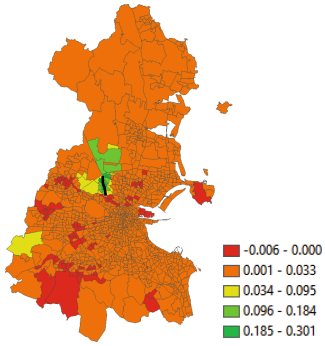

Fig. 2. Accessibility change before and after the opening of the light rail project for demand segment (4) white collar without car availability (the light rail alignment in black color is indicative only). Source: ArcGIS 10.4

5 Conclusion

This paper explores the application of computing the logsum measure using NTA's RMS for transport equity analysis. The results show distributional impacts that accessibility varies across different social groups and geographic locations.

There are limitations associated with the assumptions within this analysis. In terms of the model specifications, most of the variables considered in the utility function are still related to the concept of mobility, which might not be applicable to those trips who don't have time constraint. The current values of accessibility (utility) are ordinal and can only be compared between the same demand segments. It would be useful that the benefits are quantified and presented in a universal unit (e.g. minute or euros) to be compared across demand segments. The magnitude of the accessibility benefits can also be calculated which take the level of trip makings of each demand segment into account.

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‘Mobile Without Fear’: How to Foster Inclusive Urban Public Transportation for People with Anxiety Disorders

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Abstract. Mobility is a crucial aspect of everyday life and facilitates social participation. Nevertheless, for groups of people enduring psychological burdens such as clinically significant or daily anxiety, being mobile can pose a significant obstacle and lead to exclusion from social activities. In the process of developing infrastructure, mobility offers and information-and-communication technologies, such as apps, route planners and assistance systems, little attention is typically given to psychologically accessible mobility. The aim of the ‘Mobile Without Fear’ project is to address this deficiency and tackle the psychological barriers inherent in current urban public transportation to suit the unique needs of individuals suffering from anxiety disorders. In this manner, suggestions for offering information, communication assistance and enhanced mobility services for individuals experiencing psychological stress are devised, integrated into existing infrastructure and considered for future planning.

Keywords: urban public transportation · mental illness · anxiety disorders · inclusion · vulnerable groups

1 Inclusion in Public Transport for People with Anxiety Disorders: Raising Awareness

Urban public transportation, such as trains, buses, subways and their associated stations, can pose an almost insurmountable problem for people with psychological illnesses, effectively excluding them from societal engagement. Studies on mental illness and passenger anxiety [1], also in the context of digital planning tools [2], have shown that mobility situations are generally overwhelming for people with anxiety disorders. Surprisingly, scant attention has been given to anxiety disorders within the context of

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urban public transportation. To address this research gap, the interdisciplinary 'Mobile Without Fear' project team (project duration: 2020–2022), which was comprised of transport planners from Wiener Linien,[1] psychologists and communication scientists embarked on an investigation of psychological barriers impeding mobility in urban public transportation. Employing a sensitive-method mix [3], which included semi-structured interviews, mobility walks, expert interviews and expert workshops, the team aimed to develop measures that transportation providers can employ to facilitate the use of urban public transportation for people with anxiety disorders. The strength of this study lies in its focus on including individuals who experience acute psychological distress, with the ultimate goal of enhancing their personal mobility through the utilisation of urban public transportation.

Anxiety disorders encompass phobias and other forms of anxiety disorder, which often co-occur [4]. As a result, individuals with anxiety disorders encounter challenges in urban public transportation arising from the environment itself (e.g., fear of crowds, fear of tunnels), as well as unrelated factors (e.g., panic attacks). Unfortunately, mental illness receives limited attention in public transportation planning, which leaves affected passengers to rely on makeshift strategies to navigate an environment that is not tailored to their needs.

1.1 Research with Vulnerable Audiences

Qualitative sensitive interviews and positive mobility walks with 12 affected individuals were conducted. The participants were strategically recruited with the assistance of self-help groups and an active search by the research team (i.e., as many different types and afflictions as possible, such as anxiety disorders, different motives for use, places of residence, travel times and routes in public transport in the city of Vienna). The dense descriptions of routes and sensitivities, including visual documentation, provided deep insights into the needs of the psychologically burdened group of people in urban public mobility situations. Survey instruments, information and recruitment materials, as well as data collection, storage and analysis strategies - which included privacy protection and the participants' right of withdrawal - were developed under the strict supervision of the Ethics Committee of the University at Vienna.

1.2 Key Findings

For individuals with anxiety disorders, each stage of an urban public transportation journey should strive for maximum predictability and adhere to the principles of user-centred design with a focus on usability [5]. Access to information is crucial, particularly in the pre-trip phase, as precise trip planning alleviates anxiety. While on the trip, individuals with anxiety disorders encounter significant challenges; implementing structural solutions that provide safe spaces can help these individuals escape overwhelming situations. While communicative solutions such as *information and communication technologies* (ICTs) in the form of digital applications (apps) can enhance predictability during the

[1] Wiener Linien is part of Wiener Stadtwerke and is Vienna's urban public transport operator.

trip (e.g., departure times) and offer emotional support (e.g., distractions). Some individuals perceive technical solutions to be problematic and challenging to use, however, so *human support* plays a crucial role for those affected. Moreover, individuals with anxiety disorders often feel that their difficulties are not understood by fellow passengers or transportation staff. Enabling public mobility for people with anxiety disorders not only requires the creation of customised solutions, but also the promotion of awareness among both society and transportation personnel.

Finally, the key findings of the present study were discussed in expert workshops and interviews, and further interdepartmental working groups were organised with the companies of Wiener Stadtwerke (i.e., Wiener Linien, Wiener Lokalbahnen and WIPARK parking), in which the psychological accessibility of the mobility offer - in addition to the physical accessibility - was evaluated with regard to implementation strategies.

2 Lessons from Wiener Linien Implementation

Given the range of topics raised and the brief project timeline, the project partners needed to identify additional focal points and coordinate for a comprehensive evaluation. Structural measures in the current infrastructure or vehicle fleet are expensive and offer limited quick-acting implementation possibilities. For that reason, Wiener Linien prioritised *communication solutions* and *human support* in urban public transport for future developments and projects. The following presents the respective measures taken, as well as the further consideration thereof in future projects.

2.1 Providing Information and Communication Solutions

As previously described, access to information is a fundamental prerequisite to enable urban public mobility for people with anxiety disorders, including ICTs and other solutions. Accordingly, Wiener Linien prioritised enhancing the accessibility of their information.

How to Foster Information Accessibility. To foster accessibility, existing documents and support materials such as videos, information pages, folders, etc. were collected and checked for their accessibility. The gathering of readily available information should be interpreted as a transparent collation. Companies have adopted a myriad of approaches to promote accessibility. To gain an overview as a data subject and easily locate pertinent information, the data should be collated centrally, clearly displayed and communicated in an unrestricted, accessible manner for those without an account. Existing information products should therefore be reviewed in collaboration with data subjects.

Going forward, providing access to existing material is of utmost importance. It is crucial to improve the accessibility of information related to the measures and implementations by Wiener Linien and the municipal utility companies (i.e., Wiener Stadtwerke). The options for accessing the corresponding channels or website could be explained at the stations and on the vehicles. A separate platform should provide a comprehensive presentation that includes route planning, real-time information on the public transport network, direct connections to supporting staff and social media channels.

In addition to offering general information, it is essential to provide information tailored to specific target groups. Organising this information into categories allows for a structured, targeted presentation that better addresses the diverse needs of vulnerable groups. As one example among many, for those impacted by anxiety disorders, knowledge regarding toilet availability at the stations holds significance for several reasons, particularly because these areas can be used as safe spaces, for instance, to recover from a panic attack. Providing such information can be achieved by developing and promoting a comprehensive scheme for the toilets in subway stations.

According to Katharina, a passenger with anxiety disorders, *'One major reason I often avoided public transport was that I didn't know where to find the nearest restroom'*.

How to Support Usage. Besides excellent usability, competence and media literacy are essential prerequisites for the successful use of apps and other ICTs; solutions will be addressed in upcoming projects. Consulting with various experts allowed for valuable experiences to be gained from this project regarding young people facing psychological stress or language barriers. Although many believe they are able to use digital media, these individuals may face difficulty in developing this ability without restrictions and are more likely to develop deficits therein. Navigating public transport from one place to another with the use of technical aids not only poses challenges for young people with and without impairments, but also for older individuals, and may lead to further burdens that can have an impact on their psyche and health, including exclusion based on a lack of mobility competence.

Nicole, a passenger with anxiety disorders, admitted, *'But it just confuses me. I simply can't do it. I'm more accustomed to reading printed maps and can orient myself better than with a cell phone'*.

2.2 Human Support

Psychologically barrier-free urban public mobility must not solely rely on information accessibility, but must also offer human support. The aim of the measures outlined below is to simplify the process for affected individuals to reach out and receive the assistance they require. To address this, the staff's understanding of mental illnesses was enhanced and their visibility was elevated. Additionally, the public was educated on the subject.

How to Enhance the Staff's Knowledge. Existing trainings were adapted by Wiener Linien in collaboration with relevant departments and tested in a trial workshop attended by social workers from the Help U Team.[2] In addition to anxiety disorders and other forms of psychosocial disabilities, the workshop also focussed on people with mobility impairments, as well as those with cognitive impairments. The workshop participants responded positively and expressed a desire to try these exercises for other topics to improve their understanding, especially the sensitisation exercises designed to increase

[2] Mobile Social Work at Help U provides services to all urban public transportation users with the aim of promoting social cohesion. Help U's target group consists of all users in the operational area and primarily focusses on marginalised people, but also includes business people, residents and others.

awareness. Implementing these exercises in existing trainings can raise awareness and emphasise the importance of giving special attention to vulnerable passengers.

Paula, a young passenger with panic disorder, stated, *'It would be very helpful if the staff had a basic understanding of what anxiety disorders are. Because if I were to have a panic attack, for example, it wouldn't be helpful to immediately call for emergency services, as this would likely escalate the stressful situation. […] During a longer bus ride, when the next stop is 10 min away, I could be offered the option to get off at the next safe spot to prevent the situation from escalating'.*

How to Improve the Staff's Visibility. A generally increased presence of employees, especially at complex stations, would be beneficial for those affected with anxiety disorders. It is therefore important to ensure contact persons are easily identifiable and readily available when needed. Raffael, a young passenger with anxiety disorders, asserted, 'One of the most important things is to have a contact person in the public transport system, someone with a waistcoat, where you know you can go if something happens. […] It would be important that they know the transport network well and of course that they are a very social person, etc.'.

While affected individuals often deliberately refrain from direct contact, announcements in case of an emergency, especially when made by a real person, can be reassuring and helpful to them. Wiener Linien therefore began showcasing the stories of the people behind the announcement on social media.

Renate, a passenger with anxiety disorders, agreed: *'The fact that the driver does it directly gives you more of a sense of security than with the recorded announcements, because it comes from someone who more or less has an eye on everything.'*

Going forward, support can be extended to other staff members such as control personnel to aid public-transportation passengers in easily relating to them. Contacting a telephone service or a contact station at subway stations for assistance with orientation can provide this support. During emergencies, it is crucial to take conscious action to calm down and accompany the person to their destination and to distract them while contacting their caregivers.

Inge, a passenger with anxiety disorder, suggested, *'That you can, for example make a phone call and say, "I'm here and there now, how do I get there and there?"; or, "Where is the next park?"; or, "How do I get to an exit?"'.*

How to Foster Public Awareness. In situations like panic attacks, fellow passengers can assist, provided they are informed about the issue. Wiener Linien's social media posts on the "Mobile Without Fear" project sparked significant interest. Going forward, social-media campaigns can be used to provide information in simple language on how to offer first aid in case of anxiety disorders when using public transportation.

Christoph, a passenger with anxiety disorder, observed, *'I believe there's a general lack of understanding regarding anxiety disorders. Numerous times, I've been put in situations where I've had to explain myself, even when I'd rather not.'*

3 Challenges for the Future

The aim of this research, combined with the measures taken and those proposed, is to foster inclusion in urban public mobility for people with anxiety disorders in Vienna by focussing on communication solutions and human support. While structural changes remain unresolved, people with anxiety disorders turn to stopgap solutions, such as using restrooms as safe spaces. In the long run, projects should focus on the design of stations and vehicles to reduce anxiety during travel.

Moreover, additional forms of mental disorders that are currently overlooked should become part of mobility research [1]; particular attention should be given to groups of people who rely heavily on urban public transportation. For this reason, a follow-up project is currently being planned to address these challenges, with a specific focus on urban public mobility of young people 14–24 years of age in relation to technology usage, vulnerability and climate change.

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Can Individuals with Visual Field Loss Drive Safely?

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Abstract. In Sweden, individuals with detected visual field loss (VFL) will have their driver's license withdrawn based on perimetry results. In a previous study, a simulator-based method was used to test VFL individuals driving performance. Over 200 VFL individuals passed the simulator test and regained their driver's licenses. **Method:** Seventy of the VFL individuals who had their driver's license withdrawn due to VFL but then regained it after passing the simulator test and still had a valid driver's license in February 2022 took part in a regular on-road driving test study. In addition, one age matched, and one younger control group (both groups matched on driving experience as well as area of living) also participated in this on-road study. Traffic inspectors, blind to group affiliation assessed the participants in cars provided by the exam office. **Results:** Just over 67% of the VFL participants passed the on-road test while almost 66% of the age- matched and just over 81% of the young controls passed the test. No statistical differences exist between the three groups. **Discussion:** The process used in Sweden for withdrawing driver's licenses due to VFL seems to be unfair as all results indicate that participants with a detected VFL passed the on-road driving test to the same extent as did their matched controls. Second, a comparative study is needed to clarify if a simulator-based method or on-road testing is to prefer. **Conclusion:** Perimetry alone cannot predict driving performance on a driving test in a simulator nor on an on-road driving test assessed by traffic inspectors.

Keywords: visual field loss · driving performance · driving tests

1 Visual Field Loss and Driving Abilities

Having a driver's license has proven to be very important for individuals with visual field loss (VFL). The process for withdrawing the driving license due to VFL has even shown to reduce 50 percents of the VFL individuals trust in the democratic society (Nyberg, Andersson and Strandberg, 2023) and the frustration and anger over the withdrawal process leads all the way to court. One problem is that the VFL individuals experience that their driving ability is intact even after the VFL is detected. The requirements that apply to holding a driver's license in the event of VFL are regulated in the European Parliament and the Council Directive 2006/126/EC of 20 December 2006 on driving

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licenses, Annex III, Sect. 6 (Driving License Directive). A directive sets out which goals the member states must achieve but leaves it to the national authorities to determine the form and approach for implementation, which opens up for differences in the member states' regulations. The requirements in the directive on physical and mental fitness to drive motor vehicles are so-called minimum requirements, which means that the member states must observe the directive's rules but have the right to establish stricter requirements for issuing or renewing driving licenses. A short description of the EU directive: According to the directive the horizontal field of view should be at least 120 degrees, which should be expandable by at least 50 degrees to the right and left and 20 degrees up and down. In addition, there must be no defects within the central twenty-degree radius.

In Sweden, medical doctors are obligated to notify the Transport Agency if a VFL is detected. Based, mainly on perimetry results, the Transport Agency withdraw the license. This situation opened for an alternative method of assessment, i.e., a driving test in a simulator was developed and implemented at the Swedish National Road and Transport Research Institute (VTI). During August 2016 to June 2018, VTI offered people that have had their driver's license withdrawn due to VFL to complete the driving test in the simulator in Linköping at cost of 1700 euro. A total of 314 people completed the simulator test of which 215 passed (Andersson and Peters, 2019). Together with another 11 people, who passed the test during the development phase, a total 226 people with VFL passed the driving test in the simulator (see Table 6). Of these 226 people, approximately 200 individuals regained their driver's license after using their results of the simulator test to apply for an exemption. Only the individual applicants and the Swedish Transport Agency know why not all 226 regained their driver's license.

Using the national driver's license register, it was established that 157 VFL individuals still had a valid driver's license in February 2022. This is approximately 40 individuals less than those previously regaining their driver's license after passing the simulator test. Out of these 40 individuals, 10 individuals had died while 30 had not renewed their authorization after receiving the dispensation.

Purpose: The aim of the study is to assess to what extent VFL individuals who regained their driver's license, after passing the simulator test, also pass the regular on-road driving test. In addition, another aim is to investigate if ordinary traffic inspectors are suitable for assessing individuals with VFL.

2 Method

Participants: Using the contact information from the simulator test a letter was sent to the 157 VFL individuals who have had their driver's license withdrawn due to VFL but then regained it after passing the driving test in the simulator and still had a valid driver's license in February 2022. The letter stated the purpose of the study and the consequences of participation. If the VFL individuals wanted to participate in the study, they replied with an agreement to participate as well as information about where they lived. It was very clearly stated that the participation in the study would not affect their driver's license in any respect. As soon as an agreement to participate was obtained the

search for matching individuals, to two control groups, begun (see Andersson et al., 2022 for details). In Control group 1 the individuals were matched on age, gender, number of years with a driver's license, yearly driving experience, and area of living. In Control group 2 (young) all individuals were matched on the same criteria but were young and had recently received their driver's license. All matched individuals received the same letter as the VFL individuals and had to return the same agreement to participate. When a constellation was obtained (3 participants, one from each group) the Swedish Transport Administration's (TRL's) exam offices were contacted, and time slots were booked. A total of 216 individuals participated in the study with 72 participants in each group. Table 1. Shows the number, age and driving experience for the three groups.

Table 1. The number, age and driving experience for the participants in each of the three groups.

Group	Number	Women	Mean age	Years holding a driver's license	Yearly driving experience
VFL	72	11	66.6	Varied	15000
Control 1 (same age)	72	11	66.4	Depending on unique VFL	15000
Control 2 (young)	72	11	26,4	Between 1–9 years	17000

On-Road Driving Test: The on-road driving test was the same as for all driver's license applicants in Sweden. The traffic inspectors had their ordinary protocol based on the 5 criteria used in Sweden for examination (freely translated from Swedish; Vehicle understanding, Maneuvering, Eco driving, Traffic rules and Traffic safe behaviour). The basic idea was to keep everything as ordinary as possible. Each drive took approximately 45 min. The test route was different for different locations but should contain several standard situations and actions to be taken by the driver. Even though the locations largely varied all 3 participants in a constellation did their on-road driving test at the same location and with the same traffic inspector.

Procedure:
When the time slots were booked the participants went to the exam office, met the traffic inspector, completed the on-road driving test, received the results of the test, was thanked for their participation and were thereafter free to leave. All participants completed the driving test with a car provided by the Swedish Transport Administration (TRV). This was partly done to make sure that all participants had similar conditions and partly to ensure the traffic inspector's safety. All three participants in a matched constellation were always assessed by the same traffic inspector, who did not know which of the groups the participants belonged to. The instruction to the traffic inspector was to control the identity (that the participant to be tested had a valid driver's license) and send the results to the responsible person at TRV in writing. The responsible person at TRV then sent all results to VTI.

The traffic inspectors used a paper protocol to record the results. The on-road driving test should, as far as possible, be carried out under the same conditions for all three participants in each constellation (same route, time of day, time of year). This detailed planning was done by Swedish National Road and Transport Research Institute (VTI) together with the TRV exam offices. Both the traffic inspectors and the participants were instructed not to speak about the participants visual abilities. The theory exam test was not included. The visual abilities of the participants with normal sight were based on their self-reports, and not verified with any objective vision tests.

3 Results

Seventy participants from each of the three groups completed the on-road driving test with a traffic inspector at 39 different locations in Sweden during April to October 2022. It should be noted that all participants had a valid driver's license and should, theoretically, have passed the test.

Table 2 shows that just over 67% of the participants in the VFL group passed the on-road driving test while almost 66% of the participants in the age-matched Control group 1 passed. Furthermore, just over 81% of the participants in the young Control group 2 passed. No significant difference was found between the VFL group and the age-matched Control group 1, nor between the VFL group and the young Control group 2 (Fisher's exact test: $p > 0.05$). This means that participants with VFL passed as often as did the participants with normal vision.

Table 2. Participants passing (out of 72) the on-road driving test in the VFL, Control group 1 (same age and Control group 2 (young), respectively.

Group	Participants passing the on-road driving test	
	Number	Percentage
VFL	47	67.1
Control 1 (same age)	46	65.7
Control 2 (young)	57	81.4

4 Discussion

The first aim of this study was to assess to what extent VFL individuals who regained their driver's license, after passing the simulator test, also pass the regular on-road driving test. Neither all participants in the VFL group nor in any of the two control groups passed the on-road driving test. The results did however unequivocally reveal that individuals with established VFL perform as well as individuals with normal vision on the regular on-road driving test. This means that the process for withdrawal of driver's licenses that Sweden currently applies is unfair as many of those who have their licenses withdrawn due to VFL would pass a regular test.

The second aim of this study was to investigate if ordinary traffic inspectors are suitable for assessing individuals with VFL. A given reservation is that the on-road driving test was a regular driving test and not adapted according to the visual impairment studied here. Secondly, the traffic inspector was not trained for the assessment of VFL individuals. This study cannot clearly state that traffic inspectors need a special education for testing this unique group. However, it cannot be ruled out either. The results also indicate that the on-road driving test works as an assessment instrument of individuals with VFL because they perform as well as individuals with normal vision. This is of course given the understanding that on-road test are the "golden standard" and can be used to discriminate between safe and unsafe drivers' ability to drive safely. If on-road testing can discriminate, or not, has not been studied here.

However, the results also suggest that the simulator test was valid in the sense that it works as an assessment method as well. The success rate for the control group (normal vision) in the previous simulator-based study was only 50% but 70% for VFL participants. This difference (Andersson et al. (2022) was interpreted as an effect of how important the simulator-based test results were. The VFL participants knew that an approved test could result in a regained driver license, i.e., VFL participants were extremely highly motivated in the simulator-based study. The conclusion was not that VFL participants were better drivers than participants with normal vision. To clearly investigate the methods to be used for evaluation of driving ability a comparative study is required where the participants with normal vision and VFL are tested with the simulator test as well as the on-road driving test as in the Ungewiss et al. 2018, study. The authors showed that the overall overlap was approximately 77%.

The results suggests that Sweden need to develop a more functional process for assessing driving performance (Bro and Andersson, 2021; Bowers, 2016; Wood, 2022) However, it remains to be investigated which of the two methods that is most suitable VFL individuals. Second, it is also not clear if traffic inspectors need more training to become sufficient assessors. As the on-road test validity is a clear strength many important hazards is impossible to arrange and test in a normal setting. The strengths with the simulator test is that these hazards can be tested.

Further analyzes of the exam protocols completed by the traffic inspectors would bring additional knowledge about why certain individuals, regardless of group affiliation, failed the on-road driving test. In these protocols, it was usually clear (variants of protocols occurred) on which criteria the participant failed. Another aspect that could be further analyzed is whether the etiology (the root cause of VFL is of importance. Were there any differences in on-road driving test performance between individuals with progressive impairments and those with static impairments or between individuals with central lapses and those with peripheral lapses?

It should be noted that one limitation of this study is that those who failed the previous simulator test, or by any other reason did not regain their driver's license, were not allowed to participate in this study. Another limitation is that we do not know how well the on-road driving test identifies unfit drivers. It could be hypotheses that certain scenarios, where VFL might impair the driver, is not included in the on-road test. To combat this limitation a larger number of on-road driving tests, including further analyses of the exam protocols, as well as follow-up studies on accident involvement,

is needed. The follow up test on the 216 VFL participants who regained their driving license revealed that 2 participants have been involved in traffic accidents as drivers. The estimation is that 2 accidents of this kind was within normal distribution. However, a word of caution, the yearly driving distance was not possible to include in the analysis.

5 Conclusion

The results unequivocally revealed that individuals with established VFL perform as well as individuals with normal vision on the regular on-road driving test (Andersson et al. (2022). The processes and criteria used in Sweden for withdrawal of driver's licenses due to VFL need to be changed (Andersson et al., 2022; Nyberg, Andersson and Strandberg, 2023). Future studies are needed to investigate which assessment method to use, and the necessary competences needed for evaluation of performance.

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Social Responsible City Logistics Development on the Basis of Parcel Locker Example

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Abstract. The dynamic development of cities and thus increasing demands of their users imply steadily escalating need to increase the scope and quality of transport and logistics services, both with respect to the carriage of passengers, and freight. Their fulfilment is a serious challenge for the city managers, both at the macro level, i.e., complex management of the entire urban structure, as well as at the micro level, in which the attention is focused only on selected aspects related to, e.g., the execution of tasks by the operator on a specific area (Chwesiuk et al., 2007). The sustainable development of transport systems, including urban freight transport, is mainly focused on environmental issues. However, due to demographic changes, social issues and needs seems to be better consider. The objective of the paper is to discuss the a better understanding of the expectations and transport needs of the elderly and disabled people, which help to reduce the transport problems and, thanks to that, make it possible to avoid the transport exclusion and hence the social exclusion increasing in terms of the lack of or less possibilities of realizing transport needs of different groups of users.

Keywords: city logistics · sustainable development · aging · social exclusion · disabled people · sustainability

1 Introduction

The major challenge for city authorities is to understand the behaviour and societal factors (especially needs and barriers) that influence transport supply and demand. It shapes the transport policies, research, and innovation, in which the values, needs, and expectations of the society are met. It is critical to establish clear and realistic directions for the development of transport systems considering limitations on the ability, skill, and willingness to use transport services arising from physical and psychological barriers of transport users as well as to reduce the problem of transport exclusion in terms of lack of or less possibilities of using transport systems and mobility. The mentioned barriers are determined by health status of present and future society (resulting among others from the aging and information society development), transport accessibility of urban infrastructure and the development of technical solutions and innovations, which on the

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one hand can help to meet the needs for mobility, but on the other hand have a negative impact on the ability to efficiently move (e.g. due to the difficulties in handling them or psychological barriers in this respect). The health status of the population must be considered in different dimensions, like age, gender, economic status, cultural environment. All these aspects may influence it and, consequently, on possibilities of achieving transport needs.

The complexity of the urban transport system and often conflicting objectives of the parties involved in its operation force situation in which the transport system plays a particularly important role in the discussion on quality of life in cities. It affects many key aspects of well-being factors of city users, in particular related to (OECD 2003):

- transport availability (mainly related to the infrastructure of the city and restrictions on movement of vehicles) and congestion
- environment
- security
- energy consumption.

These issues are mostly considered in the context of passenger transport. However, the complexity of the processes that take place in urban freight transport (especially related to last mile delivery), as well as the diversity of its direct users, contribute to the generation of multiple functional dependencies. It significantly influences quality of life (Witkowski & Kiba-Janiak, 2012). The lack of the fulfilment of the above mentioned needs is directly related to the problem of social exclusion, which becomes a crucial problem for the aging society and, after that, for the city authorities, as well as business stakeholders of urban freight transport. The concept of social exclusion is used as a term to describe several problems that may arise individually or accumulate. Social exclusion connected with transport can be considered by considering transport supply (including the quality of transport services, access to public transport, spatial gap in supply transport, etc.) and demand (travel models, attitudes, and needs of specific social groups, etc.) (Xia et al., 2016).

This paper focuses on the analysis of the chosen barriers and challenges of city logistics measures in the context of aging society and disabled people. The basis of the work is the identification and systematization of the key factors influencing the less or lack possibilities in the use of last mile delivery services (like courier delivery, parcel lockers, pick-up points etc.), including the physical and psychological barriers. Next the analysis of chosen last mile delivery measure – parcel lockers – have been introduced. These topics will cover the correlation with social needs, expectations, and barriers of present and future users, as well as their impact on the transport exclusion problem.

2 The Key Factors Influencing the Lack or Less Possibilities in the Use of Transport and Mobility Services

The dynamic development of cities, and thus increasing demands of their users, imply a steadily increasing need to increase the scope and quality of transport services, both with respect to the carriage of passengers and freight. These requirements manifest themselves above all in the growing need to ensure well-being factors for residents,

companies, and visitors (Chwesiuk et al., 2007). Their fulfilment is a serious challenge for the city managers, both at the macro level, i.e., complex management of the entire urban structure, as well as at the micro level, in which the attention is focused only on selected aspects related to, e.g., the execution of tasks by the operator on a specific area (Chwesiuk et al., 2007). The complexity of the urban transport system and often conflicting objectives of the parties involved in its operation force situation in which the transport system plays a particularly important role in the discussion on quality of life in cities. It affects many key aspects of factors related to the well-being of city users, in particular related to (see OECD 2003) transportation availability (mainly related to the infrastructure of the city and restrictions on movement of vehicles) and congestion, environment, security, and energy consumption.

The complexity of the processes taking place in urban transport (both in terms of passenger and freight transport), as well as the diversity of its direct users, primarily including customers (not only residents, but also those visiting the city in connection with work or tourism), suppliers, recipients, carriers, and entities involved in the indirect implementation of transport services (such as local authorities and regions), contribute to the generation of multiple dependencies both of a functional, as well as economic nature. One of the key issues related to meeting the needs of stakeholders of the urban transport system is to meet the expectations of the city residents and visitors (those, who work there, do shopping, spend leisure time or do sightseeing, etc.). Ensuring well-being factors for this group is difficult as, on the one hand, it requires to fulfil expectations in terms of quality and living conditions, and, on the other hand, to provide adequate quality of services for the smooth movement, as well as a good supply to stores and fast deliveries of goods ordered directly to the home (e.g., in e-commerce) (Witkowski & Kiba-Janiak, 2012).

A vital role for the effective realization of transport and the quality of well-being factors is played by transport accessibility, understood as the main 'product' of the transport system, determining whether the location of the area (region, city or route) is beneficial compared to other similar areas (Spiekermann & Neubauer, 2002). Transport accessibility is determined mainly by two components: spatial, including the development of urban space, and transport, showing the ability to travel between specified points of the transport network (Sierpinski, 2010). Inducers, which have a direct or indirect impact on these factors, primarily include:

- in social terms:
  - the aging of the population,
  - issues related to the role of men and women in communities,
  - cultural factors
- in socioeconomic terms:
  - economic growth,
  - impact on the environment and the challenges of sustainable development,
  - globalization

- in technological and social terms:
  - The development of the information society,
  - development of innovative technologies and solutions that support directly the operation of transport systems, or affect them indirectly,
  - urbanization.

3 Transport Services' Accessibility as the Key Determinant of Social Exclusion

The concept of social exclusion is used as a term to describe problems that may occur individually or that may accumulate. When analysing the references relating to the issues in question, it can be concluded that the issues of transport and social exclusion were described by scientists in the 1990s and the beginning of 2000. This resulted from an increased interest in this issue primarily by researchers from the United Kingdom (UK). In 2003 the UK Social Exclusion Unit (SEU) published the report, in which the phenomenon of the lack of access to transport infrastructure that contributes to the emergence of the phenomenon of social exclusion among the population impaired due to economic and social factors is emphasized. The outlined issues were then incorporated into the development plans prepared by the transport authorities of England. In a short time, these issues have been described in many other countries. The authors dealing with the issues of transport and social exclusion mainly include A. Hurni (Hurni, 2005), J. McDonagh (McDonagh, 2006), G. and J. Stanley Currie (Currie et al., 2007), À. Cebollada (Cebollada, 2009), E. Rose, K. Witten, and T. McCreanor (Rose et al., 2009) and K. Lucas (Lucas, 2010). They emphasized the role of the governing bodies in making decisions on the development of the transport system, zoning, and creating services available to the whole society, including the poor. In this way, the necessity of levelling social differences was shown.

The efficiency of each system is measured with the limits of its weakest element. This approach also applies to the transport system, the weakest link of which is a consumer of transport services. Thus, usability of transport systems is manifested in the ability to meet well-being factors of their users, such as the provision of conditions for work, recreation, and living, and the resulting needs for movement, acquiring goods, etc. Often, the human factor is highlighted as the key factor mainly regarding the passenger transport (in particular, public transport). However, in practice, any form of transport activity is realized, both within urban areas and beyond, to satisfy human needs. In an era of constant growth in the dynamics of life and thus increasing transport needs, these aspects are becoming increasingly important.

The main problem for efficient functioning of the transport system are numerous barriers, leading to a wide range of disabilities, resulting from both physical and mental limitations of its users, which make it difficult or impossible to use transport services (Fig. 1). These barriers lead to transport exclusion, understood as the inability or failure to meet one's own needs for transport and mobility, which in turn can lead to social exclusion. Disability in this sense is a long-term condition of the occurrence of certain restrictions on the proper functioning of the human body.

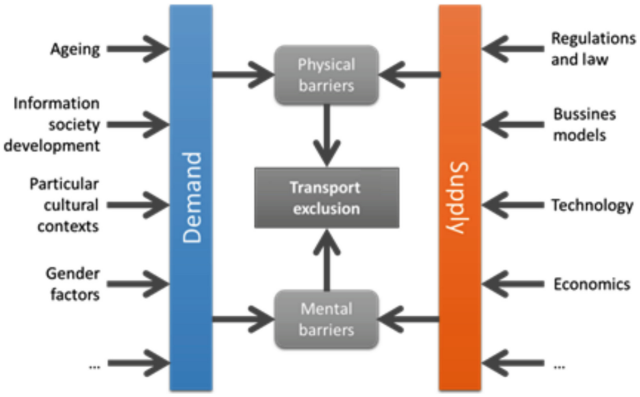

Fig. 1. The influences between transport demand/supply and transport exclusion. Source: own work.

These restrictions may be due to physical, psychological or mental impairment, but also the total, partial, permanent or temporary, congenital or acquired, stable or progressive loss or mental, physiological and anatomical defect of the body. Therefore, these barriers can be divided into two main categories (Fig. 2):

- physical barriers related to health factors directly affecting the difficulty or inability to meet the transport needs or making it difficult to meet these requirements in an indirect way (this applies for example to people with congenital or acquired reduced mobility, people who are overweight or obese and those with sensory impairment, i.e., the lack of, damage to, or dysfunction of sensory analyzers (those, who are blind, visually impaired, deaf, with impaired hearing or impaired visual and auditory perception), and those with e.g. impaired psycho-physical fitness due to somatic diseases, e.g. cancer, diabetes, hypertension, degenerative diseases of the musculoskeletal system, and all disorders and diseases that prevent the exercise of fundamental and complex activities of everyday life);
- psychological barriers, leading to a wide range of disabilities, which relate to the inability or unwillingness to use transport services (this applies, for example, to people with reduced mental performance due to intellectual or mental disabilities or dementia, people with reduced social functioning characterized by impaired nerve, emotional and mental health balance);
- availability barriers related to the situation when transport system customer can (there are no physical or economical obstacles) and wants (there are no psychological obstacles) to use chosen transport service, but this service is not available for him;
- Economic barriers when the customer can (there are no availability or economical obstacles) and wants (there are no psychological obstacles) but does not have the money to use it.

Physical and psychological barriers in the use of transport systems are the result of the impact of various factors, among which the dominant role is played by the availability of transport (mainly related to the infrastructure of the city and manifested in restrictions

on the movement of vehicles and congestion), the health status of the transport system users and their behaviours.

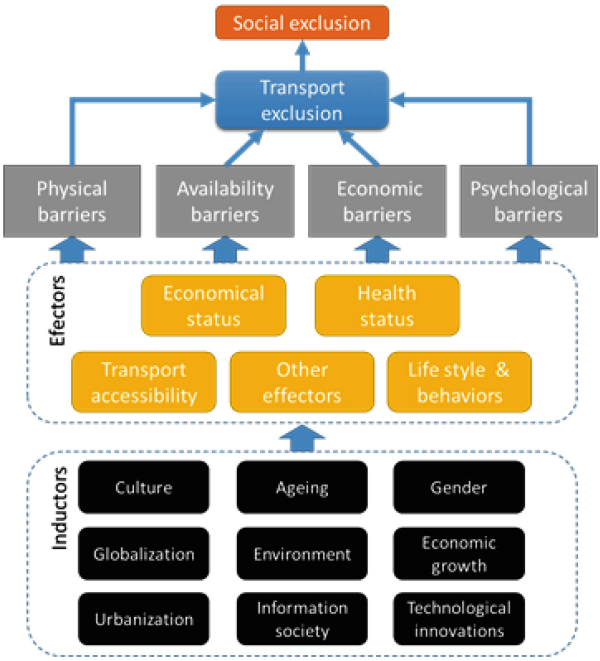

Fig. 2. The main barriers in the utilization of transport systems. Source: own work.

The problems intensifying the occurrence of social exclusion connected with transport include unemployment, lack of appropriate qualifications (knowledge, skills, and education) and, consequently, achievement of low income, poor housing conditions, the existence of physical barriers, and the poor state of public health. The occurrence of the identified problems prevents people's full participation in society. Social exclusion can become a cause of transport exclusion. On the other hand, transport exclusion can exacerbate social exclusion of the population. Moreover, the European Union has noticed the need to deal with the problem of poverty and social exclusion in the member states. For this reason, these issues were at the heart of the strategy developed by the European Commission in Brussels in March 2010. This document was entitled "Europe 2020 Strategy for smart, sustainable and inclusive growth". One of the priorities of the "Europe 2020" strategy is to strive for inclusive growth by fostering a high level of employment and ensuring economic and territorial cohesion (Europe, 2010).

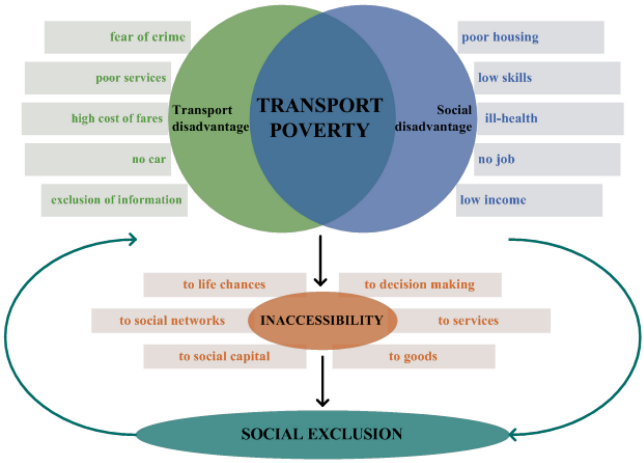

Fig. 3. The concept of social exclusion associated with transport. Source: (Lucas, 2011).

Among the European projects focusing the social exclusion in transport, the project entitled TRANSENDANC - Transport and Social Exclusion: New directions and National Comparisons was implemented in 2012–2015 in the UK, which aims to:

- develop concepts and definitions of social exclusion related with transport;
- develop indicators of interaction between defects of the transport system, social exclusion, and social capital;
- conduct a case study based on three cities, i.e. Ghent (Belgium), Los Angeles (Chile), and Merseyside (United Kingdom) in order to better understand the mechanisms of social exclusion connected with transport at a given time and space;
- determine the effect of social capital and social networks on the phenomenon of social exclusion connected with transport.

It should be emphasized that the problem of social exclusion associated with transport is a major problem not only for the member states of the European Union. This is a problem that affects countries around the world, both developed and developing ones (Fig. 3).

The lack of access to transport services may be due to the transport disadvantages of the society. The main cause of this phenomenon is the limited availability of public transport. This phenomenon may be due to the lack of availability of the network infrastructure and transport services in relation to passenger services, satisfying the needs of society resulting from its increased mobility. It can be argued that this situation is associated with the transport policy. This applies, in particular, to areas characterized by low population density and consequently low demand for transport services. It should be stressed that the desire to ensure the profitability of companies providing communication services with an excessively low number of passengers using the services of transport results in an increase in prices. Transport disadvantages caused by low availability to public transport relate primarily to residents of small towns, and in particular those who are not in possession of the individual means of transport (e.g., a car).

In the near future, the phenomenon of exclusion of transport of the elderly is expected to intensify because of the aging of the population. The analysis and study proposed by demographers suggest that in addition to the systematic reduction in population, the increase in life expectancy and low fertility rates, it is expected that adverse changes in the age structure of the population will occur. The most dynamic changes expected in the coming years include, inter alia: the reduction in the number and share of the group in the working age in the general population, the aging of the labour force, the progressive aging of the entire population and increase in the demographic burden rate. According to the report World Population Aging 1950–2050, the world's aging population is one of the most characteristic phenomena of the twenty-first century. However, the direction of the aging process is not the same for all countries. Currently, on a global scale, the growth rate of the elderly population is considerably higher compared to the growth rate of the total population. It is estimated that in the near future the differences between these two indicators will get worse, given the fact that in some parts of the world the baby boom generation will be in post-working age. Demographic projections also indicate that between 2025 and 2030 the population of people over 60 years will increase 3.5 times. Around 2050, on a global scale, there will be more than one person at the age of 60 per five people, and almost one person aged at least 65 years per six people. However, these proportions are not identical in all regions of the world.

4 The Social Responsibility in City Logistics

The problems mentioned above as well as the EU regulations and city authorities' activities are mostly focused on passenger transport. The needs and problems in this area are well known and usually discussed. However, the problem of transport services' exclusion is also related to the city logistics. Especially in regards to the last mile delivery systems. In recent years many innovative measures in city logistics have been implemented. Among the administrative, financial or organizational solutions as well as the alternative fuels utilization, significant group of measures covers the technological systems, including information on freight routes, intelligent route guidance in freight transport, integrated logistical tools or alternative delivery systems. The concept of Social Responsible City Logistics arises from the Corporate Social Responsibility (CSR) idea. This idea for few years is adopted to the specificity of logistics services as a Logistics Social Responsibility (Carter, Jennings 2002, Ciliberti et al. 2008, Piecyk, Björklund 2015). The LSR measures consider six topics elements, like environment, ethics, diversity, working conditions and human rights, safety, philanthropy and community involvement (Carter, Jennings 2002).

Considering the specificity of city logistics, especially last mile deliveries, the proper transport management seems to be the basis of development social responsibility in this area. From the perspective of accessibility issues and barriers, as well as the specificity of city users' needs, the most important category is the organisation of delivery systems, including development of van sharing, parcel lockers, cargo-bikes as well as the delivery points (micro urban depots, city hubs etc.). Table 1 shows the Hierarchization of accessibility barriers in chosen delivery systems.

Table 1. Hierarchization of accessibility barriers in chosen delivery systems. Source: own work.

Measures category	Hierarchization of accessibility barriers
van-sharing	economic barriers physical barriers psychological barriers availability barriers
cycle-logistics	physical barriers psychological barriers availability barriers economic barriers
parcel lockers	availability barriers physical barriers psychological barriers economic barriers
delivery points (micro urban depots, city hubs etc.)	psychological barriers physical barriers availability barriers economic barriers

5 The Analysis of the Parcel Lockers Accessibility

In recent years one of the most popular delivery system become utilization of parcel lockers. Many implementation of this kind are realized in many cities not only in Europe, but also Brazil, Australia, Chine. Nevertheless, nowadays, the best experienced country at the world considering utilization of parcel lockers is Poland. The first successful implementation has been realized by InPost Company in 2009. Until now, the parcel lockers are utilized by InPost, DPD, Poczta Polska, DHL, Allegro, Orlen, Alibaba. It is very hard to count the total number of parcel lockers in Poland. Approximately, the total number of the machines equal close to 40 000.

Based on many experiences of utilization of parcel lockers in Poland, it was possible to analyse them in the context of accessibility for the elderly and disabled people. Under the experiments made by Authors with utilization of parcel lockers, the barriers mentioned availability, physical, psychological, and economic barriers were analysed. The analysis showed, that three of them play the most significant role:

- availability barriers related to the localization of the parcel locker and the infrastructural elements of the close environment;
- physical barriers – in what manner elderly and disabled people are able to use the parcel locker, considering both technological expectations (utilization of mobile or touchscreen. This applies for example to people with congenital or acquired reduced mobility, people who are overweight or obese and those with sensory impairment i.e. the lack of, damage to or dysfunction of sensory analysers (those, who are blind, visually impaired, deaf, with impaired hearing or impaired visual and auditory perception), and those with e.g. impaired psycho-physical fitness due to somatic diseases, e.g.

cancer, diabetes, hypertension, degenerative diseases of the musculoskeletal system and all disorders and diseases that prevent the exercise of fundamental and complex activities of everyday life);

- psychological barriers, leading to a wide range of disabilities, which relate to the inability or unwillingness to use parcel lockers (this applies for example to people with reduced mental performance due to intellectual or mental disabilities or dementia, people with reduced social functioning characterized by impaired nerve, emotional and mental health balance).

Economic barriers were assessed as the less important in the context of social exclusion. It is due to the fact, that utilization of parcel lockers in Poland is usually less costly than utilization of other delivery systems.

The most important barrier of parcel lockers utilization in the context of accessibility for disabled people or elderly seems to be the localization of the chosen machine. Except the fact, that it should be placed as close to the user home or work as it is possible, the machine give the user possibility of easy access. It covers the pathways, as well as the area for comfortable use of the machine. The Fig. 4 shows the example of less accessible location of parcel lockers. The physical barrier at the front of the parcel locker influence on the accessibility of it for disabled people, using the wheelchairs. Very narrow area between fence and the machine make it impossible to manoeuvre the wheelchair.

Fig. 4. The example of the parcel locker's low accessibility. Source: own work.

The Fig. 5 shows the other example of accessibility problem. The posts at the front of the machine separate it from the car parking area. However, the way of their implementation made less possible for elderly and people on wheelchairs the access to some parcel slots as well as to the touchscreen.

In the next step of the analysis, the accessibility of parcel slots for disabled people and elderly were analysed. It must be mentioned that the biggest parcel lockers operator in Poland – InPost, implemented in recent months the special option – Easy Access Zone (https://inpost.pl/aktualnosci-wprowadzamy-strefe-ulatwionego-dostepu-paczkomaty-sa-przeciez-dla-wszystkich). Using this option, the parcel will be putted by courier to the slot located on the height between 30–150 cm (Fig. 6).

Fig. 5. The example of the parcel locker's low accessibility. Source: own work.

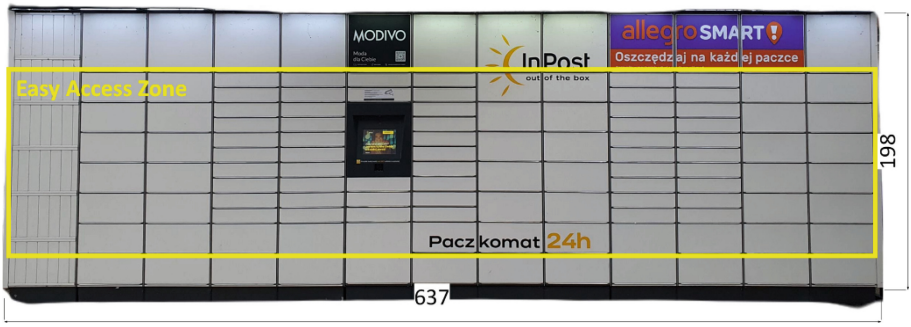

Fig. 6. Easy Access Zone in InPost parcel locker. Source: own work.

This approach seems to be very good step to improve the accessibility of this system. However, based on the analysis made by authors, it must be mentioned that the structure of the slots is not enough appropriate. The InPost parcel lockers offer four types of parcel slots: letter (vertically oriented with 9 cm width), small (horizontally oriented with 11 cm height), medium (horizontally oriented with 22 cm height), and big (horizontally oriented with 44 cm height). According to the results of analysis of 10 parcel lockers, only first three types of slots are available in the Easy Access Zone. Moreover, the lowest and the highest slots are not comfortable available for elderly and people using wheelchairs. It must be underlined that depth of the each slot equal 77 cm. It means that in the case of small parcel, it's very hard to take it from the slot.

6 Conclusions

According to the resolution Health 21 - Health for all in the 21st century, the European Region of WHO set a goal for itself and for the Member States – a healthy and safe physical environment. The consolidated Resolution No. 2001/3 of the European

Conference of Transport Ministers regarding transport services accessible to elderly and disabled people emphasizes that the overriding principle for all initiatives or projects in transport and spatial planning is that they should be assessed in terms of their safety and accessibility to the elderly and the disabled, while all the links of the transport chain should ensure improved accessibility to the environment, and efforts should be made to combine different kinds of transport into an integrated, safe, and accessible transport system.

An important inducer of the mobility needs contributing to the occurrence of barriers is urbanization, which is one of the most important and the most dynamic processes taking place in the socioeconomic space of Europe and the world. The development of urban areas contributes to the increasing number of vehicles. Also urban areas, especially in the first phase of their settlement, often lack institutions that can meet the needs of a growing population as well as the demographic changes. They also have inefficient transport systems, forcing residents to use their own transport. In addition, the growing demand for all kinds of goods increases the demand for freight delivery. Therefore, initiatives aimed at social aspects of the transport system operation should be considered from the perspective of residents living in modern cities. In practice, this aspect should be viewed primarily from the perspective of urban residents. In this context, residents is understood not only as a resident of the area, but also as anyone visiting this area, while realizing his or her needs in terms of work, shopping, tourism, etc. With regard to the inhabitants of nonurban areas, a crucial aspect is their mobility associated with urban areas; it is also a major inducer of difficulties in ensuring the quality of transport services.

Social exclusion related to last mile deliveries results from the existence of physical and mental barriers in individual population groups. These are mainly the elderly and people with disabilities. These groups are more vulnerable to exclusion of transport. According to that the development of city logistics measures must be more related to the needs of these groups. The solutions should be analysed and discussed with the representatives of them in the context of better addressing their needs and expectations.

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The Effect of the Pandemic on the Mobility of Persons with Disabilities

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Abstract. Still, little is known about the impact of the COVID-19 pandemic on the mobility habits of persons with disabilities. The paper focuses on the research question how people with disabilities assessed the effects of the pandemic on their mobility behaviour. An online survey assessed data of a total of 745 people with disabilities from 21 European countries. Data was collected at two points in time: winter of 2020/2021 (n = 553) and summer 2022 (n = 181). Survey respondents were asked whether the pandemic affected their mobility behaviour in terms of six aspects: 1) willingness to travel, 2) difficulty of traveling, 3) comfort, 4) dependency on others, 5) length of journeys and 6) safety. Nearly 60% strongly agreed that the pandemic made them less willing to travel. Almost half stated that the pandemic made their journeys more difficult, less safe and less comfortable. The effect of the pandemic on users' mobility behaviour was assessed to be greater in winter 2020/2021 than in summer 2022. The analysis revealed some interesting variations between the various kinds of disabilities in the way in which they assessed mobility changes. It was shown that female respondents tended to feel less safe, more dependent on others and less willing to travel compared to men.

Keywords: Inclusive Design · Disability Research · COVID-19 pandemic

1 Introduction

Since the beginning of the COVID-19 pandemic, a considerable number of empirical studies examined the effect of the pandemic on the mobility of people in general [1–4]. These studies revealed a substantial decline of mobility, in particular by means of public transport, as a cause of the pandemic and the related measures to prevent the spread of the virus [2–4]. Giving regard to the fact that persons with disabilities heavily depend on public transport [4], it is reasonable to argue that persons with disabilities experienced even more drastic consequences in their daily mobility. However, little is known about the impact of the pandemic on the mobility of persons with disabilities. Studies from Canada [5] and California [6] showed that in the early months of the pandemic persons with disabilities experienced increased difficulties when using public transport. However,

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empirical findings are missing that give regard to the subjective assessment of changes in travel behaviour due to the pandemic by persons with disabilities. Furthermore, it is still an open question whether there are interpersonal differences of perceived effects with regard to kind of disability and gender.

To close the research gap, the paper focuses on the research question: "How did persons with disabilities experience the effects of the pandemic on their mobility behaviour?".

2 Methods

2.1 Study Design and Material

The online survey was conducted within the scope of the European research project TRIPS (http://trips-project.eu), and yielded data of 745 persons with disabilities from 21 European countries collected from different individuals at two points in time: winter of 2020/2021(n = 553) and summer of 2022 (n = 181). Survey respondents were asked whether the pandemic affected their mobility behaviour in terms of six aspects: 1) making them less willing to travel, 2) making their journeys more difficult, 3) making journeys less nice, 4) making journeys more dependent on others, 5) making journeys longer and 6) making them feel unsafe. The aspects were based on the multi-dimensional mobility divide index (MDI) that has been developed within the scope of the TRIPS project [5].

2.2 Study Participants

Respondents from 21 European countries took part in the survey with Italy (20.8%, n = 155) and Germany (16.6%, n = 119) being represented most often. Gender was nearly equally distributed with 49.5% referring to themselves as female (n = 369) and 48.5% as male (n = 359, n = 17 for "other" or "prefer not to say"). Mean age of respondents was 51.9 years (SD = 18.9 years). The study sample was heterogenous in terms of types of disabilities. The majority of respondents stated to have a mobility disability (53.7%, n = 400). Another 15.6% (n = 116) reported having a visual disability, 13.6% multiple disabilities (n = 101), 7.4% hearing disability (n = 55), 4.6% other forms of disabilities (n = 34, e.g. cardiovascular disease), 3.1% intellectual disabilities (n = 23) and 2.3% mental health issues (n = 16).

3 Results

3.1 Effects of the Pandemic on Mobility Behaviour

Respondents assessed the impacts of the pandemic on their travel behaviour to be strong overall. Nearly 60% of the respondents strongly agreed with the statement that the pandemic made them less willing to travel (56.8%, n = 417, Fig. 1). Almost half of the respondents stated that the pandemic made their journeys more difficult (45.2%, n = 332), less safe (47.1%, n = 346) and less nice (46.6%, n = 342). For the dimensions of duration of travel and dependency on other people, the effects were less severe. Approximately one fifth of all respondents stated that the pandemic made their journeys longer (22.9%, n = 168). One third (n = 32.8%, n = 241) fully agreed that the pandemic made them more dependent on others when traveling.

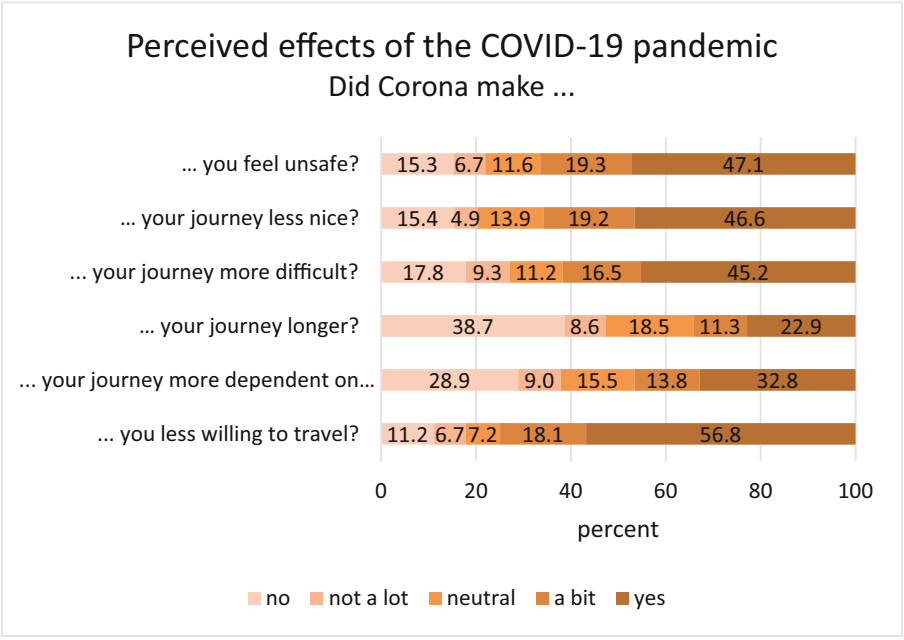

Fig. 1. Perceived effects of the pandemic with regard to six aspects (n = 734, rest missing)

3.2 Interpersonal Comparison

The analysis revealed some differences in the perceived effects of the pandemic between the various types of disabilities. It was shown that especially persons with intellectual disabilities experienced their journeys to be longer due to the pandemic ($M = 3.64$, $SD = 1.56$). Compared to other groups, especially persons with physical impairments ($M = 3.91$, $SD = 1.43$) or disabilities classified as others ($M = 4.12$, $SD = 1.24$) tended to feel less safe than before. When comparing to other types of disabilities, persons with visual or hearing impairments experienced less severe barriers with regard to length of journey and dependency (Fig. 2).

With regard to gender, it was shown that female respondents tend to feel significantly less safe, more dependent on others and less willing to travel compared to men, as displayed in Table 1. With regard to the other aspects, no significant differences were shown between men and women.

3.3 Time-Related Comparison

The effect of the pandemic on users' mobility behaviour was greater in winter 2020/2021 than in summer 2022. People were significantly less willing to travel in winter 2020/2021 compared to summer 2022 ($t\ (732) = 2.169$, $p = .031$). Furthermore, a marginal significant difference was found with regard to length of journey: People reported that the effect of the pandemic on the length of journey was stronger in summer 2022 ($M = 2.91$, $SD = 1.59$) than in winter 2020/21 ($M = 2.65$, $SD = 1.61$). No differences were found between the two points in time with regards to other aspects (Table 2).

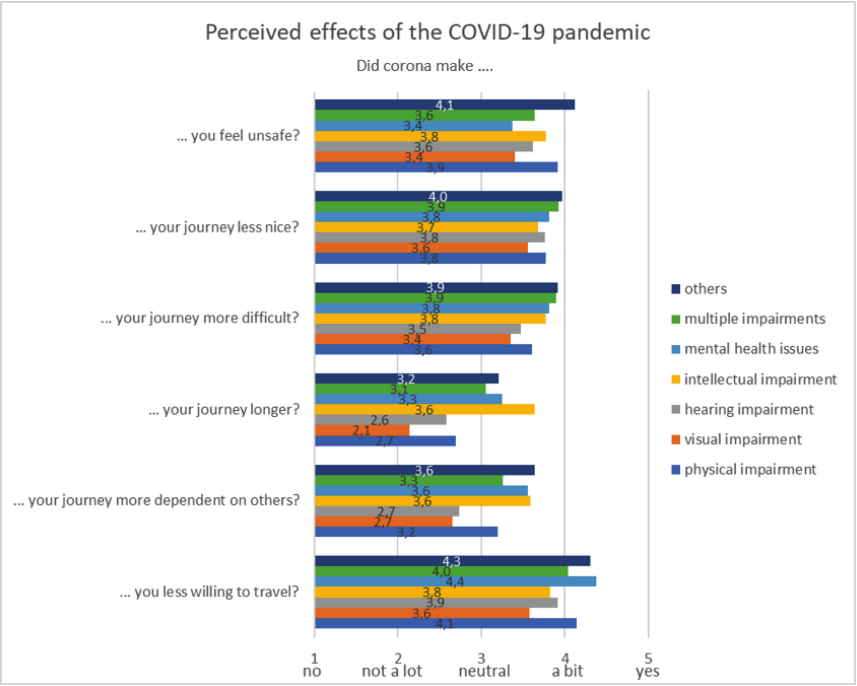

Fig. 2. Perceived effects to the COVID-19 pandemic with regard to kind of disability

Table 1. Comparison of agreement with six aspects of COVID-19 effects on mobility with regard to gender based on t-tests.

Aspects of Mobility Divide Index (MDI)	Male respondents (n = 359) Mean (SD)	Female respondents (n = 369) Mean (SD)	*T* (p)
Willingness to travel	3.92 (1.39)	4.13 (1.38)	2.022 (.044)*
Difficulty of traveling	3.61 (1.51)	3.64 (1.60)	.267 (.789)
Comfort	3.67 (1.48)	3.86 (1.47)	1.748 (.081)
Dependency on others	2.98 (1.61)	3.29 (1.66)	2.542 (.011)*
Length of journeys	2.67 (1.61)	2.78 (1.62)	.900 (.369)
Safety	3.59 (1.46)	3.94 (1.48)	3.163 (002)*

Note. SD = standard deviation, significant findings are marked with an asterisk

Table 2. Comparison of agreement with six aspects of COVID-19 effects on mobility with regard to time based on t-tests.

Aspects of Mobility Divide Index (MDI)	Winter 2020/2021 (n = 553)	Summer 2022 (n = 181)	*T* (p)
Willingness to travel	4.09 (1.34)	3.82 (1.49)	2.169 (.031)*
Difficulty of traveling	3.64 (1.56)	3.57 (1.53)	0.514 (.608)
Comfort	3.78 (1.47)	3.73 (1.44)	0.405 (.689)
Dependency on others	3.12 (1.63)	3.16 (1.66)	−0.314 (.754)
Length of journeys	2.65 (1.61)	2.91 (1.59)	−1.894 (.059)
Safety	3.78 (1.48)	3.72 (1.46)	0.428 (.669)

Note. SD = standard deviation, significant findings are marked with an asterisk

4 Discussion

The results highlight the drastic effect of the pandemic on the mobility of persons with disabilities. It was shown that the pandemic made persons with disabilities less willing to travel and made their travelling more difficult, less safe and less comfortable in their view. Giving regard to the already unequal and inaccessible conditions for persons with disabilities when traveling, the pandemic made their journeys even longer and more dependent on other people.

Interestingly, the analysis revealed only small differences between the assessment of mobility changes when comparing the data from the early beginning of the pandemic and the later phase. A possible explanation is that persons with disabilities feel severely affected by the pandemic in the long term. Surprisingly, the perceived effect of the pandemic on the length of journey was stronger in summer 2022 than in winter 2020/21. It is conceivable that people tend to make longer and more frequent journeys in summer 2022 when travel restrictions were largely lifted and thus they experienced their journeys to be longer.

With regard to differences between the various kinds of disabilities, the analysis revealed some interesting variations in the way in which respondents assessed mobility changes. The findings suggest that especially persons with physical impairments and persons with other forms of disabilities, mostly long-term health issues, such as cardiovascular diseases, felt less safe when travelling due to the pandemic.

It was further revealed, that female gender was linked to the perception of stronger effects of the pandemic on their mobility behaviour. Thus, the study findings suggest that pandemic-related supporting measures should address women in particular.

For interpretation of the results, it should be emphasized that persons with mental health issues and or intellectual disabilities were underrepresented in this study. Further research should pay particular attention to these groups as findings suggest that they experience drastic effects of the pandemic on their mobility behaviour.

Keeping in mind that persons with disabilities are facing various barriers while using different types of transport, it needs to take extra effort to ensure that travelling for

passengers with disabilities is not only accessible but also safe and comfortable even in the unexpected circumstances, such as a pandemic situation.

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Impact of Slope Upon Pedestrian Flow

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Abstract. Numerous studies have explored the relationship between walkability and various factors such as neighbourhood planning, quality of life, health, sustainability, tourist attractions, housing affordability, crime rates, and safety. However, there seems to be a research gap in understanding how slope affects walkability. In hilly regions, walking serves as an important mode of transportation due to challenges related to right-of-way (ROW) limitations and turning radius constraints that make it difficult to provide a robust public transport system. The Indian codes do not address the influence of slope on walking. The aim of this study was to analyse how slope impacts walkability while focusing on midblock sections in both flat and hilly terrain. One significant finding from the study involved benchmarking the flow of pedestrians along sloped footpaths and carriageways, comparing the upward and downward slopes based on the pedestrian speed-density relationship. It also illustrates the variation in service levels on a footpath corresponding to changes in its width. To validate these findings, a pedestrian simulation was conducted using PTV VISSIM.

Keywords: Slope · Speed · Density

1 Background

Walking plays a fundamental role in every journey, whether it's a brief stroll to a nearby destination or a means to connect with other modes of transportation [1]. The concept of walkability pertains to a neighbourhood or city's capacity to support walking as a viable mode of transportation [2]. In hilly regions, pedestrians face distinct challenges due to the steep slopes and changes in elevation [3].

2 Literature Study

In 2008, the Indian Ministry of Urban Development conducted a study on urban traffic and transportation policies and strategies in India. It was found that walking constituted 28% of all trips taken in the country. Hill cities like Gangtok and Shimla, had the maximum number of walk trips. The study also calculated a Walkability Index for 30 cities, considering factors such as the presence of footpaths along major roads and the satisfaction rating of pedestrian facilities by the pedestrians themselves. The overall average walkability Index for all cities was 0.52. Notably, cities situated in hilly terrain

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exhibited low pedestrian indices. The walkability score for hill cities considered for the study was 0.29 [4]. The Indian Road Congress guidelines for pedestrian facilities define the required width of footpath based on the abutting land use. The guidelines also specify the minimum width of footpath: 1.8 m (m) in roads of ROW 10 m and above, 1.5 m in roads of ROW of less than 10 m and pedestrian speed-flow-density relations for carriageway, sidewalks, wide-sidewalk, and precincts but it seems to be silent on slopes [5]. Based on the literature review, there were a few research questions formulated for the study:

- What is the impact of slope on pedestrian speed?
- How are pedestrian speed flow related on footpaths and on carriageways for different slopes?
- How does the walk level of service get affected with the change in the width of the footpath?

3 Site Study

The study site selection was based on two main criteria: availability of relevant secondary data and ease of conducting drone-based videographic surveys. The study focused on walking in both hilly and flat terrains to highlight differences in parameters influencing walking. Bankura in West Bengal was chosen for the flat terrain, while the three hill sites selected were Darjeeling in West Bengal, Shimla, and Solan in Himachal Pradesh. Majority of land use in the selected stretches was commercial with few exceptions of public/semi-public land use in Darjeeling. The stretches selected had varied slopes ranging from 0 to 14 degrees. The stretches were categorized based on their slopes: plain stretches (slope $< 2\%$), mild slopes (2% to 8%, although no data was collected in this category), moderate slopes (8% to 18%), and steep slopes (18% to 25%).

4 Data Analysis

Each video was decoded for an initial 5 min, with the recorded data being decoded in one-minute segments. Parameters such as pedestrian speed, flow and density were determined as follows: Pedestrian speed (meter per second or m/sec) was calculated by dividing the stretch into 3 m * 3 m grids, noting the time from the video, and then dividing the distance covered by the pedestrian during that time.Flow (persons per second or person/sec) was determined by counting the number of pedestrians walking on the stretch in a minute and dividing it by 60. To calculate pedestrian density (person per square meter or person/sq.m), screenshots were captured from the video every 10 s, the number of pedestrians in each frame was counted, and the resulting count was divided by 6 to obtain the average density on the stretch in a minute. The data was computed separately for each direction and for carriageway and the footpath.

5 Findings and Results

Slope of terrain impacts the walking speed of individuals. It was observed that the average speed for downhill direction in steep slopes was more than the average speed in plains. This proved that it is easy to walk in a downhill direction on a steep slope. The mean

speed for uphill direction in steep slopes was the minimum of all, showing that it is difficult to walk in an uphill direction. Table 1 summarises the observations.

Table 1. Pedestrian Speed on Different Slopes

	Plain (With flow of vehicles)	Plain (against flow of vehicles)	Moderate uphill	Moderate downhill	Steep uphill	Steep downhill
Minimum	0.6	0.5	0.4	0.8	0.5	0.7
Maximum	2	2	1.6	0.8	1	1.7
Mean	1.1	1.1	0.9	0.8	0.7	1.2

Pedestrian speed flow relations were analysed on carriageway and footpath in all three categories of slope for both directions. Figure 1 shows the results of the speed flow relation on the carriageway. The red trendline in the graph represents the speed-flow relationship on a moderate slope in the downhill direction. The graph clearly indicates that walking on a road with a steep slope in an uphill direction is the most challenging. To simplify the analysis, data from flat terrain and moderate slopes in the downhill direction, which exhibit similar speeds, were combined into a new equation referred to as "downward slope" Data from steep slope in uphill direction was formulated into a separate equation known as the "upward slope" The free mean speed was set at 2 m/s. The speed flow equations for upward and downward slope on the carriageway are shown below.

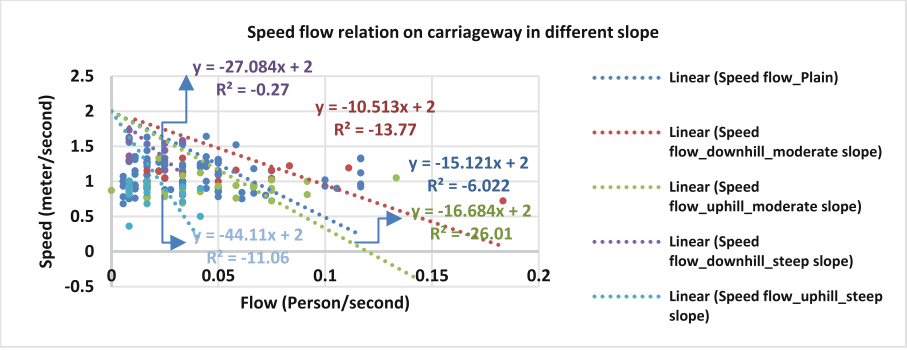

Fig. 1. Speed Flow Relation on Carriageway on Different Slopes

$$\text{Downward slope} - \ y = -11.279\ x + 2 \tag{1}$$

$$\text{Upward slope} - \ y = -38.694\ x + 2 \tag{2}$$

A similar method was followed using speed flow relations on footpaths for different slopes. Figure 2 depicts the relation. The equations formed for upward and downward slope for speed flow relations on footpaths are shown below.

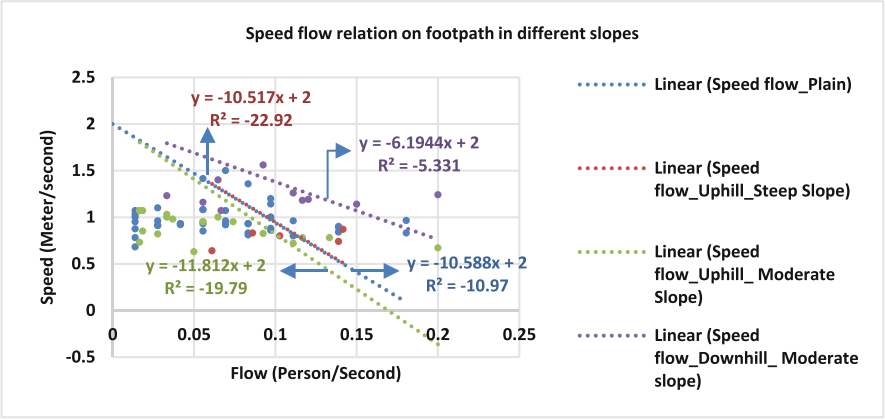

Fig. 2. Speed Flow Relation on Footpath on Different Slope

$$\text{Downward slope} - \ y = -4.468\ x + 2 \tag{3}$$

$$\text{Upward slope} - \ y = -18\ x + 2 \tag{4}$$

The above equations are used to calculate the densities for upward and downward slope on carriageway and footpath. In the above equations y stands for pedestrian speed and x stands for pedestrian flow. Density is determined by dividing pedestrian flow with pedestrian speed [6]. Pedestrian speed and pedestrian density were examined both on footpaths and carriageways, with a further breakdown into upward and downward slopes. The theoretical expectation was a linear relationship between speed and density [6]. Nevertheless, when the data was graphed, the relationship was curvilinear. Figure 3 depicts that it is easiest to walk on a footpath in a downward slope followed by carriageway in a downward slope. It is most difficult to walk on the carriageway in an upward slope.

The flow difference between upward slope and downward slope on both footpaths and carriageways is evident from Table 2 for example, the value of 2.44 indicates that, for an equal footpath width, flow on downward slope is 2.44 times the flow on upward slope. To validate these findings, pedestrian simulations were conducted using PTV VISSIM. The simulations used input values of speeds (m/sec) for upward slope on footpath paired with corresponding flow (person/sec) on a 1 m-wide ramp. The inclination angle for the ram was set at 14 degrees. Speed values in m/sec were converted to kilometers per hour. Flow values in person/sec were converted to person/hr for software input. The resulting density was converted to person/ sq. m and compared with observed data. Simulated

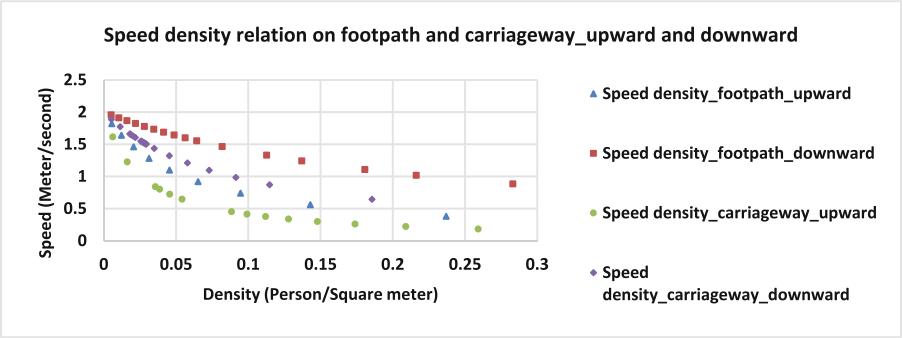

Fig. 3. Speed Density Relation on Footpath and carriageway on Different Slopes

Table 2. Ratio of Flow on Footpath and Carriageway on Upward and Downward Slope

Ratio of Flow	
Footpath upward/carriageway upward	1.65
Footpath downward/carriageway downward	1.45
Footpath downward/footpath upward	2.44
Carriageway downward/carriageway upward	2.52

density was then calculated in (person/sq.m). The same process was applied to simulate pedestrian density for downward slope. Figure 4 displays the observed and simulated densities for both upward and downward slopes on the footpath.

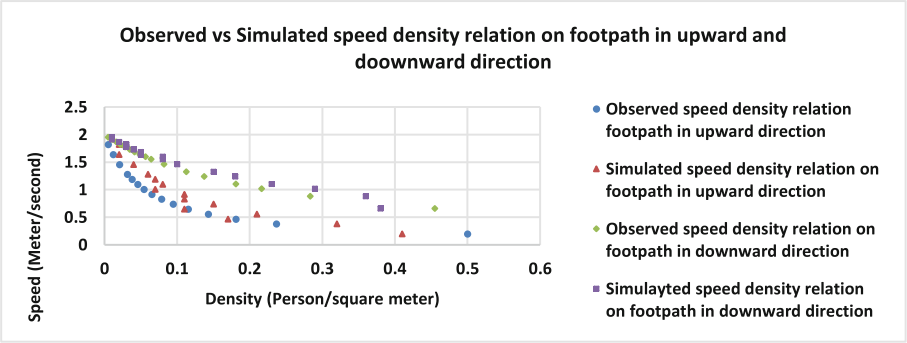

Fig. 4. Observed vs Simulated speed density relation on footpath and carriageway.

Figure 4 shows that the observed results closely matched the simulated data, affirming the accuracy of the data analysis regarding pedestrian speed, flow, and density for both upward and downward slopes. To assess changes in service levels for different widths of footpath, speed and flow data for upward movement were used as input for various

widths: 1 m, 2 m, 2.5 m, and 3 m, generating simulated density plotted against flow. Figure 5 illustrates a noticeable change in service quality as the footpath width shifts from 1 m to 2 m. This change remains prominent as the width increases from 2 m to 2.5 m. However, when the footpath widens to 3 m, the shift in service quality is less significant compared to the 2.5 m width. Figure 5 serves as evidence that the standard width specified by the IRC guidelines [5] may not be suitable for areas with steep slopes, as it would result in a decrease in the level of service. Instead, an appropriate width of either 2.5 m or 3 m should be considered, depending on the slope of the area.

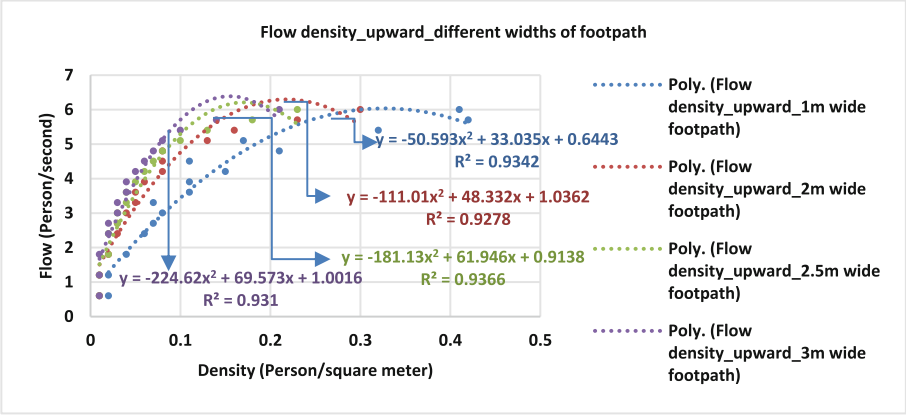

Fig. 5. Observed vs Simulated speed density relation on footpath and carriageway.

6 Recommendations and Future Scope of Work

Before discussing ways to improve pedestrian facilities in hilly areas, it's crucial to acknowledge two main challenges. First, limited space in hilly regions complicates pedestrian infrastructure design and execution. Second, the absence of separate footpaths for two-way pedestrian traffic results in congestion, reducing speed and increasing footpath density. The issues can be solved by providing wider footpaths in steep terrain, providing a wide enough footpath on one side of the road, providing cantilever footpath in areas with limited ROW and avoiding slope (cut fill) while constructing footpaths. Future studies may focus on, considering other factors influencing walking behaviour, such as footpath quality, lighting, and proximity to public transit stops.

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Time-Based Airport Accessibility: Examining the Role Played by Time of Travel on Surface Access Travel Time at Dublin Airport

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Abstract. The surface accessibility of an airport is described by how easily potential passengers can reach it using their preferred mode of transport. Air travel often requires trips at irregular times, making it difficult to find available public transportation services and forcing the use of alternative modes such as ride-hailing or taxi services. Flight schedules are significantly impacted by time zones, aircraft bases, and crew hours, resulting in flights not corresponding with local bus or rail operating hours. This study focuses on Dublin Airport as a case study to explore how the availability of transportation options varies depending on the desired arrival time. The study utilises data such as flight schedules, public transport timetables, and spatial data to demonstrate how travel times to and from the airport vary greatly depending on the time of day. The findings highlight gaps in public transport and their impact on transportation choices. This paper presents a method that can be applied at an airport to analyse time-based accessibility using readily available data. The results aid airport operators in predicting passenger dwell times as they encourage a shift towards sustainable modes for access.

Keywords: Airport surface access · GTFS · Public transport

1 Introduction

The aviation industry operates globally with flights operating 24 h a day. Although local noise regulations may restrict some flight movements [1], airports remain open beyond typical business hours for reasons such as long-haul flight arrivals, aircraft positioning, and crew schedules. To avoid potential delays, travellers are encouraged by airport operators to arrive at the airport early, even if it means travelling during off-peak hours when public transport may not be readily accessible. This research explores the relationship between public transport availability and passenger surface access mode choice. Dublin Airport in Ireland is presented as a case study. Analysing passenger mode share survey data, flight schedules and public transport schedules, the aim is to determine whether the availability of public transport affects passenger's dwell time at the airport. This question is essential for airport operators and transport agencies, as restrictions on parking necessitate increased public transport usage, aligning with sustainability goals

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[2]. If passengers' travel habits change to grow the use of public transport, it may warrant re-evaluating existing services, such as expanded lounge areas for earlier arriving passengers and increased demand for 24-h bus routes.

The following section presents a review of relevant academic literature. The method used is outlined in Sect. 3, with results in Sect. 4. The paper concludes with limitations, conclusions, and recommendations for further study presented in Sect. 5.

2 Literature Review

Surface access to airports is a well-researched topic. Factors such as travel cost, distance, group size, weather, baggage, and public transport frequency affect mode choice [3–5]. Time of day is also important [6, 7]. Passengers with early flights prioritise travel time and reliability [8] and tend to be more cautious due to the risk of missing their flight [9]. Policymakers typically prefer public transport due to its ability to move large numbers efficiently [2], but the location of airports away from built-up areas can mean longer travel times than when using a private car [10].

In their analysis of past research, Pasha and Hickman [11] pointed out that determining the mode of transportation used to access an airport is not as simple as conventional demand models, due to the unique requirements of airport surface access. Popular methods for identifying such behaviour include passenger surveys [3–6]. Other methods include surveys based on revealed and/or stated preferences [7, 9]. Several studies have employed traffic counts and modelling techniques to analyse transportation systems [5]. Among these studies, the method Rothfeld et al. [10] used is particularly noteworthy; they employed the Distance Matrix API function of Google Maps [12] to calculate travel times between an airport and various origin points within its catchment area.

Travel time estimates are a common method of measuring accessibility, and the availability of GTFS data [13] is increasingly used to produce such estimates in a wide range of applications, such as accessibility and planning [14, 15]. However, the shortcomings of using GTFS schedules have been highlighted when compared with actual operations due to incidents of traffic delays and service cancellations [16]. Further examination has revealed that airport surface access literature has not yet used some of these methods for time and place-based transit accessibility that are common for other land use and planning applications, e.g. the spatial statistical models used by Handley et al. [17] could be adapted for use to identify gaps in surface accessibility for an airport. This research evaluates the time-based airport accessibility utilising these methods.

2.1 Case Study: Dublin Airport

Dublin Airport served 28.1 million passengers and almost 200,000 flights in 2022. The airport is well connected by road, with convenient access for private cars, taxi and buses. A departing passengers' surface access mode survey for 2022 showed that 24.8% used public transport, 29.5% used taxis, and 44.8% used private cars. The mode share for public transport is comparable to peer airports such as Manchester with 15.5% using public modes, Heathrow at 33.9% and Luton at 35.3%, but falls short of airports such as Oslo with a 71% share. Table 1 interrogates the Dublin Airport data further and reveals

how mode share changes depending on the time of day. For instance, between 05:00 and 07:00, only 16.9% of passengers used the bus, while between 11:00 and 13:00, this figure is 34.7%. A higher mode share is observed for buses before 03:00 and after 08:00, although the sample size at these times is small.

To promote sustainable access, airports need to address apparent drawbacks to using the bus. Private cars and taxis are perceived to offer reliable travel times, especially at night. This paper will examine how bus service availability affects travel time.

3 Method

This case study examines how spatial accessibility at Dublin Airport changes depending on the time of day and the mode of transport chosen by departing passengers. The schedule for commercial flights on the 21st of August 2023 is consulted, to assess the surface access demand at Dublin Airport. On that day, there were 384 commercial departing flights over a 24-h period. Figure 1 shows that there was reduced traffic during the night-time hours, with no passenger flights departing prior to 05:55.

Passengers departing from Dublin Airport are advised to arrive at least 2 h before short-haul flights and 3.5 h before long-haul flights to allow time for check-in, security and to reach gates which close 30–40 min prior to the scheduled departure time. While not accounting for the spread in arrival times, it serves as a helpful guideline in determining when to expect passengers at the airport. There are 51 departing flights in the "First Wave" before 07:00, and passengers come to the airport as early as 03:30. Figure 1 shows scheduled departure times overlayed with advised presentation times, showing a pattern of arrivals to the airport. GTFS schedules of all operators in the Republic of Ireland are used to check public transportation availability at the airport. Table 2 shows services every hour serving the airport. Buses operate 24 h a day, but there are fewer services in the early morning.

Open Trip Planner software [18] is used with OpenStreetMap spatial data to calculate travel time, originating from national statistical boundaries. Journey times factor in the total duration of a trip from its origin point, including time spent travelling and at the airport before the recommended presentation time. Trip origins are weighted by area population, allowing the calculation of a national average trip time for each hour, and other metrics such as the variance of trip times from different origins and a measure of the time spent at the airport before the recommended presentation time.

4 Results and Discussion

The data presented in Fig. 1 illustrates a surge in passenger demand during the "first wave" of travel between 04:00 and 05:00. Figure 2 displays the travel time combined with the period spent waiting at the airport to ensure arrival by 04:00 for the "first wave" of flight departures. Figure 3 depicts the equivalent for the "evening peak" between 17:00 and 18:00. During the "first wave," the share of bus travel is 16.9%, while it increases to 30.2% during the "evening peak." This disparity is primarily due to a greater percentage of taxi travel during the "first wave," when road travel is significantly faster than public transport, as depicted in Fig. 4.

Table 1. Surface Access Mode Share at Dublin Airport

Mode	<03:00	03:00–05:00	05:00–07:00	07:00–09:00	09:00–11:00	11:00–13:00	13:00–15:00	15:00–17:00	17:00–19:00	19:00–20:00	>20:00
Public (%)	40.4	19.2	16.9	17.9	25.8	34.7	31.7	26.0	30.2	25.8	38.8
Private (%)	59.6	80.8	83.1	82.1	74.2	65.3	68.3	74.0	69.8	74.2	61.2
Sample size	99	1146	1328	985	931	991	952	830	401	128	98

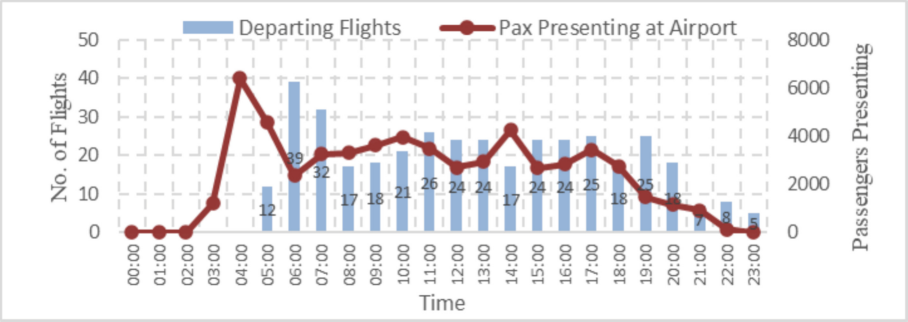

Fig. 1. Dublin Airport Departing Flights Passenger Presentation 21/08/2023

Table 2 illustrates the 24-h bus services available at Dublin Airport, but they are not accessible from all places. As a result, there can be large differences in journey times between areas with and without these services (Table 3). The lack of round-the-clock services is noticeable in the 10-100km range, with significant disparities in travel times to arrive by 04:00, though these have evened out by 17:00. Of note is how travel at 08:00 can vary more than travel at 04:00 for trips greater than 150km, (Table 3). At 04:00, the bus service at the trip origin is still operational as it occurred the previous evening and allows connection with a 24-h airport service. However, to arrive by 08:00 requires beginning the journey after local bus services have ceased.

Table 4 displays the fluctuation in passenger dwell times throughout the day, showing two to three-hour waits at 04:00 for passengers over 30km distant. The effect is that while passengers within a short distance of Dublin Airport favour taxis to public transport during early hours, outside of where taxi fares are feasible, passengers without access to a private car need to arrive at the airport significantly in advance of recommended presentation times. As passengers shift to sustainable transport modes, airports may need to accommodate longer dwell times and increase waiting area capacity.

This paper highlights the benefits of travel times to the airport along corridors where 24-h services exist compared to origins on other corridors that are equally distant. This disparity demonstrates the success of the routes. It is recommended that additional services be considered along other significant corridors, whether directly serving Dublin Airport or connecting with 24-h bus services in Dublin city centre.

Table 2. Public Transport Services at Dublin Airport

TIME	<03:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	>20:00
TERMINATING	7	3	17	13	20	23	30	33	39	31	33	33	31	30	28	28	26	29	93
ORIGINATING	16	3	6	12	30	24	31	28	30	31	33	31	32	33	32	32	30	25	87
EN ROUTE	36	9	14	9	17	16	18	22	19	18	18	17	19	19	21	19	20	18	57

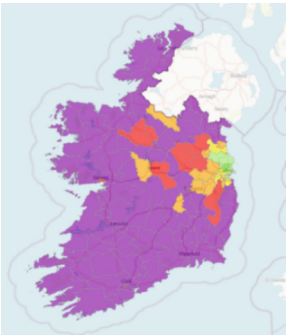

Fig. 2. Public Transp at 04:00. Source: Esri (2023), ArcGIS Pro version 3.1. https://www.esri.com

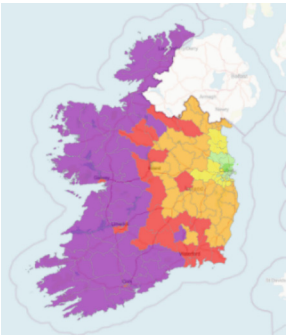

Fig. 3. Public Transp at 17:00. Source: Esri (2023), ArcGIS Pro version 3.1. https://www.esri.com

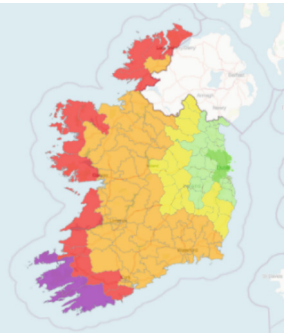

Fig. 4. Driving at 04:00. Source: Esri (2023), ArcGIS Pro version 3.1. https://www.esri.com

Table 3. Public Transport Travel Time Variance

Distance	04:00	08:00	13:00	17:00
<10	616	254	272	235
10 < 30	1368	211	196	146
30 < 100	23183	806	1301	961
100 < 150	18631	7266	1359	1043
150 < 250	15997	44222	1826	2169
>250	14519	39493	5182	3956

Table 4. Minutes arrived before the target

Distance	04:00	08:00	13:00	17:00
<10	12.7	3.3	2.7	0.7
10 < 30	9.1	3.6	4.5	3.4
30 < 100	125.6	11.7	7.2	10.3
100 < 150	212.7	16.3	18.2	10.8
150 < 250	102.4	44.1	15.2	24.2
>250	116.4	99.1	15.2	24.3

5 Conclusion

This study explored the link between airport surface access mode choice and public transport availability. In Dublin Airport, public transport takes longer during early morning hours, leading to lower mode share and increased use of taxis and private cars. This

highlights the importance of service availability in passenger mode choice. Although there are 24-h airport-serving bus services currently available, the study notes that access to the airport still depends on the operating hours of other bus services that connect with the airport bus. This is particularly challenging during mid-morning hours when passengers from distant areas that make taxi fares unaffordable are compelled to spend the night at the terminal to arrive by public transport, significantly before recommended presentation times. Otherwise, their journey would commence when local bus services are closed for the night.

The study suggests that in this instance, transport agencies should consider increasing the number of 24-h bus routes available to population centres within the 0 to 150km range, either directly serving or connecting with existing airport bus services. Generally, as airport operators promoting sustainable modes of surface access experience more travellers arriving by bus, they should consider expanding the waiting areas of terminal buildings as passengers need to come earlier for their flights due to public transport schedules and trip reliability.

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Pedestrian Tracks Crossing: How to Conceive Safety Systems Based on Human Cognitive and Biomechanical Understanding?

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Abstract. The paper presents the methodology developed in a collaborative project between academic and industrial partners set-up to develop and test new safety systems at pedestrian tracks crossing installed in little French train stations. While these installation benefit from a safety system installation indicating approaching trains, they still lead to frequent accidents, mainly due to travelers' inattention, misunderstanding or environmental factors that impact traveler perception. Few research has been conducted on this specific situation, resulting on a lack of knowledge on human behavior when crossing this installation. Moreover, when developed, safety systems are rarely objectively tested in terms of efficiency on behavior leading to currently few perspectives to reduce the number of accidents. Thus, to fill this gap, the research project exposed in this paper propose a new approach based on cognitive and biomechanical analyses to develop and test in real-like situation, using a virtual reality environment completed to a scale 1:1 physical train station mock-up, various new safety systems. These analyses completed with technical and economic ones will help to produce better well-sourced data to ground decision-makers choice concerning more effective future safety system to implement.

Keywords: Biomechanics · Human Behavior · Neurosciences · Safety

1 Introduction

In train stations, in the absence of a footbridge or an underpass, a passage can be directly installed on the tracks, to enable travelers to go from one platform to another. This installation, called Pedestrian Tracks Crossing (PTC, see Fig. 1), is relatively common all around the world, especially in Europe and America. In France alone, there are approximatively 1000 train stations equipped with PTC. To ensure travelers' safety

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during crossing, various type of "safety systems" are installed before or on the PTC to alter and/or explain the risks to travelers, such as lights, signage, ringing alarms or barriers. However, a constant number of accidents are observed every year. One assumption to explain the lack of efficacy of safety systems on travelers' behavior is that the safety systems were not developed considering human cognitive and physical activity when moving through train stations and PTC. This can be explained by the past poor practices that do not include human factor and cognitive science in industrial and technological development, but also by the lack of methodologies to objectively measure the effectiveness of a product before its release.

Fig. 1. Photograph of a train station (Belloy Saint Martin, France) equipped with pedestrian tracks crossing.

However, this past decade, both cognitive sciences and methodologies to measure human behavior and movement precisely have been developed. Therefore, it can be assumed that moving and safely crossing tracks involve many high-level cognitive processes to [1–3]:

- acquire information (schedules, weather, presence of a train),
- form a global representation of the situation and the crossing track situation,
- evaluate the risks (collision, fall, delay), and
- make a decision (to cross or not).

All these steps necessary for safely crossing tracks might be disrupted by other factors [4]. These factors can be related to travelers themselves such as heuristics to minimize cognitive effort (habits) or distractions (music, smartphone, talking). They can also be linked to the environment [5] such as the visibility or the behavior of other travelers.

Research on biomechanical aspect also have helped to better define this activity. The locomotive task primarily involves walking, considered a complex activity from a biomechanical point of view. Walking requires moving the body along an anteroposterior axis through a sequence of unipodal and bipodal supports [6]. This complexity requires the coordination of multiple body systems and cognitive functions, including sensory perception and motor planning [7–9].

Track crossings is a challenging locomotive task, where walking is intersected by the potential dangers of oncoming trains. Understanding the biomechanics of this locomotive task during track crossings is mandatory to improve safety. Historically, motion

analysis has been used to understand the effect of surroundings infrastructures, including markings, tactical pavements on crossing behavior, by quantifying reaction-time, head rotations, walking velocity, crossing onset and duration, and analyzing crossing initiation [10–13]. The previous research methods are heavily criticized [14, 15]. For example, several studies have used uncontrolled data from surveillance cameras, which might impact the results due the unknown participants conditions [15]. Moreover, other methods rely on questionnaires [16] or decision measurement using a keyboard/joystick [14]. The ecological validity and objectivity of these methods are limited as they force participants to imagine how they would act or feel.

Thus, using virtual reality combined with various physiological sensors is now possible to track human behavior (gaze, head movement, acceleration) in real-like situations. For example, two safety systems at PTC have been recently evaluated considering their effects on human behavior using virtual reality combined with physiological as well as behavioral measures [17].

Thus, the aim of the project presented in this paper is to conceive new safety systems based on human behavior understanding to improve safety at PTC. To this end a collaborative project has been launched between the French National Railway Company (SNCF), SNCF Réseau, the Technological Research Institute specialized in railway transport (IRT Railenium), a French company specialized in rail signage (SCLE SFE), and the haut-De-France Polytechnical University. Together, partners will develop an approach combining both cognitive and biomechanical research with industrial developpement. In this paper, the authors propose to describe the methodology developed in the project to highlight the value of combining all these competencies from the early stages of conceptualization to the final stages of development of safety systems.

In the early stages of the project, literature on cognitive and biomechanical aspects will be analyzed to propose a human model of a safe PTC. Based on that model, new safety concepts will be developed and tested through a close-to-reality experimental set-up combining virtual reality, a scale 1 mock-up PTC and various behavioral, physiological, and biomechanical measures. These experimental studies will help to precisely understand the effect of safety concepts on human behavior, and to improve, validate or reject them. Economical as well as technical evaluations of systems will be then conducted to select which concept is most suitable for industrial developpement.

2 Method

2.1 Testing Platform

To fulfil the objectives set for the project, it was deemed necessary to equip ourselves with a test platform of our own. This will allow for the participants of the study to progress in a virtual reality environment aiming at reproducing real-life conditions of a situation, but with limited biases compared to what a real situation usually implies. The test platform consists of two distinct environments. The first one is the physical platform, which recreates parts of a train station true to scale (1:1) – this includes a station platform, a portion of a double-track railway and a pedestrian tracks crossing (see Fig. 2 for a 3D modeling of the 1:1 platform).

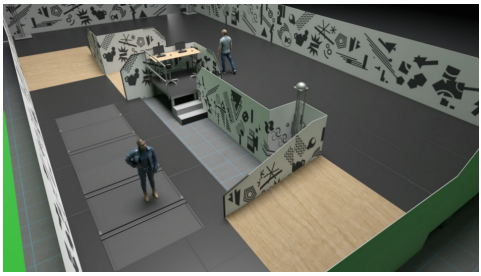

Fig. 2. 3D modeling of the 1:1 scale platform. Participants will be allowed to move through a 11 × 20 m platform including a PTC and height difference between the PTC and train station platform. Image created by Movida Production with HARFANG®3D.

The second one, the virtual environment, synchronized to the physical environment, reproduces in detail all the elements of a train station cited previously as well as various scenarios depending on the weather or the aim of participants (see Fig. 3 for a virtual environment view). Sensors are set up to collect behavioral and physiological data, such as eye tracking data, kinetics and kinematics data relative to walking, muscle activation data. The combination of these methodologies (mixed reality, sensors) allows for a detailed understanding of train passenger behaviors in interaction with contextual factors (weather, station layout, station footpath location, potential presence of running/stationary trains), as well as the quantification of behaviors.

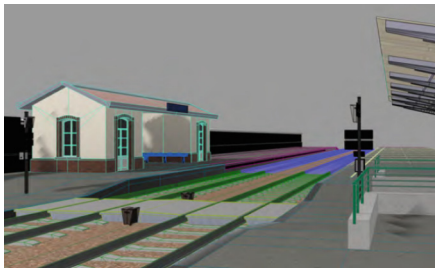

Fig. 3. Screenshot of the virtual train station in development. The station includes two little buildings, two platforms and one PTC. Image created by Movida Production with HARFANG®3D.

2.2 Principles of Behavioral Studies

Transport Research Arena

In order to observe participants behavior as naturally as possible and avoid any expectancy effect, participants won't be informed at first of the purpose of the study, but they will be explained that their participation in the study will help SNCF to improve its services in train station. This explanation will give objective for participants to travel in the virtual environment as they will have to move through it to evaluate different services. During these moving, they will or not cross the PTC.

We will vary the condition of the PTC crossing, taking a special attention to traveler's personal factors such as distraction or age, but also to environmental factors such as visibility (night or day), social influence (other people crossing the PTC), and the approaching of train. To appear as natural as possible, all induced factors will be fully integrated in the scenario. For example, if we are interested by the impact of crossing the PTC with luggage, participants will have to test a service that justify the fact they have to carry a luggage (such as a new luggage room). This principle has already been tested and have shown its efficiency to immerse participants in a real-like scenario without revealing the real purpose of the study [17]. The real purpose will be thus explained and detailed at the end of the experimental session and discussed with participants.

All PTC crossing will be monitored to collect the conditions of the crossing (personal as well as environmental factors; train approaching or not; safety system) as well as all behavioral and physiological measures (safe crossing or not, gaze behavior, etc.).

Around 100 participants, representative of French population will be tested per studies to collect enough data (dangerous crossing, gaze behavior, etc.) to explore the statistical effects of our tested factors (personal, environmental, safety system), and potential interaction between them. These analyses will be completed by an interview with the participant and the fulfilment of questionnaire. We will reveal the real purpose of the study and discuss openly of safety system with them to collect potential improvement of system and to validate if our immersion has been successful [18]. Finally, results of the first study will be used to improve either the methodology or the safety systems, to improve both through the project and be able to state on the safety system efficacity on behavior.

2.3 Principles of Biomechanical Studies

In addition to the cognitive and physiological analysis, we will take a specific attention to biomechanical aspect of the crossing. Indeed, through motion analysis, we can objectively quantify the impact of risk factors, surrounding infrastructures on both cognitive functions, motor behavior and postural adjustments of users. The biomechanics measurement can objectively explain the situational awareness of the users, researchers reports that safety equipment resulting a small variation over the time horizon (std) of the walking speed, gait pace, kinetics and kinematics metrics can confirm the improvement of user's situational awareness and cognitive functioning, leading to an improved safety [19, 20].

Using our novel approach, involving the platform built exclusively to this research, representing a train station and allowing a natural forward movement in the safest and most ecological situation, remains the best experimental condition as it reflects pedestrians' behavior in real life [14]. Additionally, this will allow the investigation of the impact of the major's risks factors in both environmental level (i.e. ramp) and pedestrian level (i.e. distraction) identified by applying the unsafe pedestrian level crossing framework [21].

Our methodology including markerless motion analysis, the use of inertial measurement units will bring new insights to users' safety, by improving and validating security equipment, based on their effect not only on the psychological aspect, but also

on the underlying human biomechanics such as energy costs, spatiotemporal parameters, kinematic, kinetics and muscle activity.

3 Expected Result of the Project: Evaluation Matrix

To help decision makers, we will develop an evaluation matrix including all the objective behavioral and biomechanical variables to characterize the effect of the safety systems tested. The matrix will include all the personal and environmental factors considered in the studies. To complete this matrix, technical and economic analyses will be performed to appreciate the degree of feasibility of the tested solution. This tool will be used to make decision about what kind of safety system to develop in the final stage of the project considering results of the various analyses made in the project, the current accidentology (from personal or environmental causes), and the feasibility of the solution.

4 Conclusion

In conclusion, in this project we propose to reverse the way classical development is made in industry regarding safety at PTC. While improvements are usually first implemented and tested in the real environment, we propose to first test in real-like environment the efficacity of various possible improvement on different objective measures. This method, based on scientific method, gives the advantage to select upstream improvement, based on objective efficacity results, that have the best chance to work before industrial development and installation that might be long and costly.

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Reducing Possible Sexual Harassment During Taxi Rides by Achieving Safety and Stability

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Abstract. We propose a *novel* two-sided market model, where taxi drivers and taxi passengers are matched based on *safety* relations and *gender* preferences. We discuss how increasing the safety and stability in matchings relates to reducing the chance of sexual harassment during taxi rides. Thus, we design several algorithms for returning safe and stable matchings.

Keywords: social choice · multi-layer preferences · taxi dispatching

1 Introduction

There has been an increasing number of sexual harassment cases from taxi male drivers to female passengers [3]. This is especially concerning because taxis might be the primary travel option for women from underrepresented groups such as those from cultural minorities and those with physical disabilities [1]. The existing approach for fighting sexual harassment in New York City does not allow taxi companies to track the sexual harassment behavior of their drivers. In response, we propose a novel approach for tracking this behavior. We depict both approaches in Fig. 1.

2 Related Work

Most related works consider one layer of preferences [8]. For example, Zhao et al. [10] studied stable matchings under distance preferences of passengers over drivers and identical profit preferences of drivers over passengers. Also, Lesmana et al. [7] investigated efficient and fair matchings under delay preferences of passengers over drivers. In contrast, we consider three layers of preferences. Multi-layer matchings received significantly less attention in the literature. For example, Chen et al. [2] looked at a model where agents have multiple lists of preferences. By comparison, we consider multiple layers of preferences. Thus, we are not aware of any prior work that integrates a multi-layer matching model into an approach for reducing possible sexual harassment during taxi rides.

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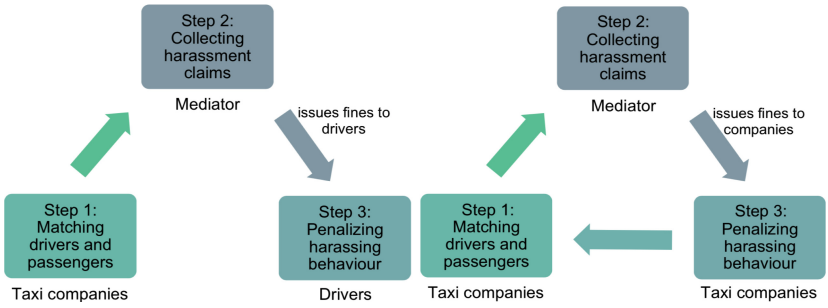

Fig. 1. Two approaches for fighting sexual harassment during taxi rides: (left) the existing approach; (right) the proposed approach. A taxi company could be Yellow Cab in New York City. A mediator could be the New York Police Department or the Taxi and Limousine Commission in New York City.

3 Our Novel Model

We let t denote a point in time when we want to match drivers and passengers. We consider n drivers from $D = \{d_1, \ldots, d_n\}$ that are available at time t. We also consider m passengers from $P = \{p_1, \ldots, p_m\}$ whose requests for rides have not been serviced by time t. As our model is a two-sided market model, we refer to the parameter $\max\{n, m\}$ as *market size*. Pick driver $d_i \in D$. We let d_i have a current location l_{d_i}. Pick passenger $p_j \in P$. We let p_j have a pickup location l_{p_j}. In practice, drivers service requests one after another. Thus, as in [10], we aim at matching $\min\{n, m\}$ drivers to $\min\{n, m\}$ passengers, each driver matched to exactly one passenger. After that, the process can be repeated with the drivers and any remaining passengers, if any.

3.1 Preferences Layers

Layer 1: Safety-threshold Relations: We rate drivers based on passenger feedback submitted through web apps, police departments, or inclusion offices. We refer to drivers as *safe* if their rating exceeds a pre-fixed threshold. Likewise, we rate passengers based on driver feedback about locations, routes, or areas. We refer to passengers as *safe* if their rating exceeds a pre-fixed threshold. We assume that passengers and drivers prefer rides that are safe for both of them to rides that feel unsafe for either of them. We let $\Sigma = (\sigma_{ji})_{m \times n}$ denote the *safety* relation, where $\sigma_{ji} = 1$ if d_i is safe and p_j is safe, and else $\sigma_{ji} = 0$.

Layer 2: Profit-delay Preferences: We let drivers have profit preferences for rides. We encode this by $\Pi = (\pi_{ij})_{n \times m}$, where $\pi_{ij} > 0$ is the *profit* $d_i \in D$ derives from servicing $p_j \in P$. Next, we denote by $\tau_j \geq t$ the preferred departure time of $p_j \in P$ from l_{p_j}, and $t_{ij} \geq t$ the estimated time of arrival (ETA) of $d_i \in D$ from l_{d_i} for picking up $p_j \in P$ from l_{p_j}. We assume that each $p_j \in P$ submits τ_j to companies and companies calculate t_{ij} for each $d_i \in D$. We let passengers have

delay preferences for vehicles. We encode this by $\Delta = (\delta_{ji})_{m \times n}$, where $\delta_{ji} = 0$ if, supposing that d_i and p_j are matched, $t_{ij} \leq \tau_j$ holds and else $\delta_{ji} = (t_{ij} - \tau_j) > 0$.

Layer 3: Gender-type Rankings: We let $\mathcal{G} = \{g_f, g_m, g_d\}$ contains the gender types g_f = female, g_m = male, and g_d = diverse. Each $p_j \in P$ can *rank* these gender types. For example, a given passenger may prefer ($\succ$) female drivers to male drivers, but be indifferent ($\sim$) between male drivers and diverse drivers. Hence, their ranking is $g_f \succ g_m \sim g_d$. We assume that passengers submit such rankings to companies and companies can rank drivers for passengers, based on the drivers' gender types. Each $d_i \in D$ can also *rank* the gender types. However, as the gender types of passengers are private, we assume that they do not submit these types to companies and companies cannot rank passengers for drivers, based on passengers' gender types.

3.2 Matchings

We consider a bipartite graph $G = (V_P, V_D, E)$, where the sets of passenger and driver vertices are V_P and V_D, respectively, and the *eligibility* relation between them is $E \subseteq V_P \times V_D$. For example, in airport shuttling, if the luggage of p_j cannot fit in the vehicle of d_i then $(p_j, d_i) \notin E$ would hold. We write $M = \{(p_{j_1}, d_{i_1}), \ldots, (p_{j_{\min\{n,m\}}}, d_{i_{\min\{n,m\}}})\}$ for a *matching* in G, where $p_{j_1}, \ldots, p_{j_{\min\{n,m\}}} \in V_P$ and $d_{i_1}, \ldots, d_{i_{\min\{n,m\}}} \in V_D$. We define the overall safety level in M as $TS(M) = \sum_{(p_j,d_i) \in M \cap E} \sigma_{ji}$. We say that matching M is *safe* if, for any other M', $TS(M) \geq TS(M')$ holds.

We let l denote the index of a preference layer in our model. That is, $l \in \{1, 2, 3\}$. We say that (p_j, d_i), which is in E but not in M, is a *blocking pair* for M on layer l if and only if (iff) p_j and d_i prefer each other on layer l to their current matches in M, say d_h and p_g, respectively: for $l = 1$, this means $\sigma_{ji} > \sigma_{gi}$ and $\sigma_{ji} > \sigma_{jh}$; for $l = 2$, this means $\pi_{ij} > \pi_{ig}$ and $\delta_{ji} < \delta_{jh}$; for $l = 3$, this means that p_j prefers the gender type of d_i to that of d_h, and d_i prefers the gender type of p_j to that of p_g. We say that M is *stable on layer* l iff, for each (p_j, d_i), that is in E but not in M, (p_j, d_i) is not a blocking pair for M on layer l. We also say that M is *(multi-layer) stable* iff, for each l, M is stable on l.

4 Computing Safe Matchings

Many sexual harassment cases during taxi rides are committed by drivers or passengers in shady areas who have already done that in the past. For this reason, our notion of safety is based exactly on driver and passenger feedback about each other. We believe that matching highly-rated drivers and passengers first is likely to lower the chance of sexual harassment during taxi rides. For computing such safe matchings in G, we need to respect the safety relation Σ and the eligibility relation E. For this purpose, we consider another bipartite graph $G_s = (V_P, V_D, E_s)$, where $E_s = \{(p_j, d_i) | (p_j, d_i) \in E, \sigma_{ji} = 1\}$. Each safe matching M_s in G_s is therefore eligible. It also has the maximum size in G_s. We can use the HopcroftKarp algorithm [5] to compute safe matchings.

Theorem 1. *There is an algorithm returning safe matchings in* $O(\max\{n, m\}^{5/2})$ *time.*

5 Computing Stable Matchings

As most sexual harassment cases occur from male drivers to female passengers, we might want to maximize the number of same-sex matches. However, this is not possible because we assumed that passengers do not submit their gender types during bookings. Instead, we consider achieving stability based on their submitted gender-type rankings. Stability also relates to reducing the risk of sexual harassment during taxi rides. For example, female passengers can simply express that they prefer female or diverse drivers to male drivers. Thus, achieving stability with the gender-type rankings of passengers over drivers would limit the number of female passengers being matched to male drivers. We let P_s denote the set of passengers matched in the safe matching M_s and D_s denote the set of drivers matched in M_s. We consider another bipartite graph $G_e = (V_P \setminus P_s, V_D \setminus D_s, E_e)$, where $E_e = \{(p_j, d_i) | p_j \in V_P \setminus P_s, d_i \in V_D \setminus D_s, (p_j, d_i) \in E\}$. We study matchings in G_e that are stable.

If we fix either layer one, two, or three, stable matchings on the fixed layer always exist because the corresponding preference relations on that layer may contain ties but are complete [6]. We investigate therefore when stability could be achieved on all three layers simultaneously.

As a first example, stability can be achieved in the case of emerging applications such as same-sex ride-sharing services [1] and "pink" taxi services [9], where all drivers and passengers have the same gender type.

Theorem 2. *With a single gender type, there is an algorithm returning stable matchings in* $O(n^4)$ *time.*

In the case of a single gender type, our algorithm eliminates edges from G_e one by one. While no more edges in G_e exist, the algorithm picks a driver-passenger pair from E_e that maximizes the profit. If there are several such pairs, then the algorithm picks one of these pairs that, within these pairs, minimizes the delay. If there are several such pairs, then the algorithm picks one of them uniformly at random.

As a second example, stability can be achieved in the case of existing applications where drivers wait in queues, e.g. in taxi hubs, airports, and cab stands, where all drivers leave and arrive at the same depot location.

Theorem 3. *With a single depot location, there is an algorithm returning stable matchings in* $O(\max\{n, m\}^2)$ *time.*

In the case of a single depot location, the travel time between the depot location to a given passenger location is the same, and, therefore, the potential delay of each driver to the given passenger location is the same. This is the key reason why matchings that are stable on the profit-delay preference layer are

also multi-layer stable. Our algorithm runs an *eligibility* version of the classical Gale-Shapley [4] algorithm, where passengers get matched to eligible drivers.

Moving to the case of multiple gender types and multiple depot locations, stability on all layers may no longer be achieved. This holds due to an impossibility result from [2], that applies to two-layer stable matchings.

As a response, we designed an experimental setup in which we wanted to test how close to stability we might get in practice. The architecture was MacBook Pro M1 2020, 16GB RAM, 250GB Disk Space, and macOS Ventura 13.0. For market size $n \in \{20, 40, 60, 80, 100\}$, we generated 10 000 instances of n drivers who are eligible for n passengers. In each instance, there were two layers of preferences, one corresponding to layer two and another to layer three. For layer two, we sampled uniformly at random each profit from $[1, 100]$, each ETA from $[1, 60]$, and each departure time from $[0, 30]$ (0 for patient passengers and $(0, 30]$ for impatient passengers). For layer three, we considered three gender types, namely 'male', 'female', and 'diverse', encoded as 0, 1, and 2, respectively. From among these gender types, based on Yellow Cab data, we sampled 75% male drivers, 20% female drivers, and 5% diverse drivers. We also sampled uniformly at random the gender-type ranking for each passenger and, thus, calculated ordinal rankings over drivers. Furthermore, we designed two natural algorithms:

- RunGS2Count3: (1) run the eligibility version of the Gale-Shapley algorithm with the preferences on layer two; (2) count how many pairs block the returned matching, respecting the preferences on layer three, and
- RunGS3Count2: (1) run the eligibility version of the Gale-Shapley algorithm with the preferences on layer three; (2) count how many pairs block the returned matching, respecting the preferences on layer two.

RunGS2Count3 returns a matching that is stable on layer two but not necessarily on layer three, while RunGS3Count2 returns a matching that is stable on layer three but not necessarily on layer two. We quantified the *stability gaps* of RunGS2Count3 and RunGS3Count2 on layers three and two by counting the pairs from these layers that block their returned matchings, respectively. The baseline of 0 is achieved when there are no such pairs.

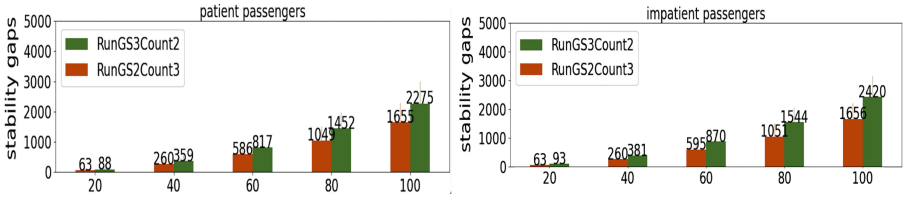

Fig. 2. The stability gaps of RunGS2Count3 and RunGS3Count2 for market sizes 20, 40, 60, 80, and 100.

Figure 2 shows our results. The gaps are bounded from above by the number n^2 of edges in the underlying graph. The gap of RunGS2Count3 on layer

three is around 20% of n^2. The gap of RunGS3Count2 on layer two is around 25% of n^2. These indicate lower profit-delay efficiency for RunGS3Count2 but also lower risk for sexual harassment because the returned matching is stable, respecting the gender-type rankings.

6 Conclusion and Future Work

We proposed an approach for fighting possible sexual harassment during taxi rides by maximizing safety and optimizing stability when matching drivers and passengers. Our findings confirm that safe and stable matchings often exist. In the future, it will be interesting to quantify the probability of sexual harassment in taxi dispatching and derive theoretical bounds on how much achieving safety and stability decreases this probability.

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A New Interactive Tool for the Holistic Evaluation of Multiple Aspects of the Transportation System

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Abstract. There are innumerable models within the transportation field, which offer a variety of detailed and specific analyses (e.g., traffic flow, fuel consumption, mode choice). However, to date there is an absence of a model providing a holistic understanding of the entire transport system. Existing models are reliant on simple assumptions outside of their specific focus to generate such system-wide results.

Against this background this paper presents a new interactive tool for the holistic evaluation of multiple aspects of the transportation system integrating research results from a variety of scientific disciplines and models. It aims to provide both a holistic understanding of the transport system and an interactive tool allowing the wider public to engage with state-of-the-art scientific research. For this purpose, it is based on a unique data eco-system that provides interfaces for transport demand, noise pollution, and emission models, and outlines the results of the model chain in an appealing and easily understandable manner.

This paper illustrates the features and the advantages of this new tool using the results of the project Connected Mobility for Liveable Places. The project aims to develop a people-centered, inclusive, and sustainable system of mobility of both people and goods.

Keywords: mobility lab · people-centered mobility · sustainable transport · models · data

1 Introduction

There is a wide variety of models and data sets used in transportation research at the moment differing considerably in granularity and scope. Model try to simulate a very specific part of reality as detailed as possible, but have to make very simple assumptions for things beyond its scope. In transportation research many models provide a detailed account of traffic flow, transport demand, fuel consumption, route choice, etc. However, due to the specific focus of each model, a holistic understanding of the transportation system is absent.

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To address this need for a holistic understanding of the entire transportation system, a new modelling framework was developed and embedded in a unique showroom called the Mobility Lab. This showroom constitutes an interactive space for the visualization of scientific results allowing the engagement of the wider public. One of the key tools of the showroom is a portable touch table, which can be used to illustrate the modelling framework and its interactive nature at conferences, fairs, etc. This touch table will be used to present the Mobility Lab at the TRA 2024.

To illustrate the key features of the Mobility Lab on the basis of a concrete use case, it is applied to visualize the results of the project "Connected Mobility for Liveable Places" (VMo4Orte), which aims to develop a people-centered, inclusive, and sustainable system of mobility of both people and goods. More specifically, the Mobility Lab is used to present the modelled impact of redesign measures (e.g., such as road closures) in a neighborhood in Berlin, Germany.

2 Visualization: The Mobility Lab

The Mobility Lab aims to visualize the scientific results to foster the interaction of scientists with the broader public. For this purpose, the illustration of results not only has to be visually appealing, but also easily understandable and, more importantly, it has to enable the audience to examine the results on their own. Consequently, the Mobility Lab was designed in a way that invites anyone looking at it to interactively engage with the scientific results by selecting different scenarios, measures, models, etc. used in the visualization.

The Mobily Lab currently shows accessibility, noise emissions (from cars traffic), and routes for a multi-purpose autonomous vehicle (called U-Shift) for two scenarios. The U-Shift vehicle is capable of transporting six passengers or 24 parcels. The noise emissions are derived by a previously descried technique (3). The traffic is derived from the models TAPAS (1) and SUMO (2).

The visualization of the results of the VMo4Orte projects focuses on the impacts of the introduction of new bicycle lanes, roadblocks, and speed reductions in the neighborhood. The impact of these measures was investigated in term of the changes in accessibility metrics and noise pollution. In addition, the demand for an autonomous, driverless electric vehicle carrying both people and goods is illustrated on different routes through the neighborhood.

3 Data Source: The Connected Mobility for Liveable Places (VMo4Orte) Project

The VMo4Orte (5) project strives to develop transferable solutions that can be used to contribute to the sustainable transformation of the transport system. One part of the project focused on evaluating redesign measures in the neighborhood together with various stakeholders. This included transportation companies, public institutions and municipalities, and companies from the mobility and logistics sector.

The redesign measures include the implementation of diagonal barriers which serve as modal filters allowing access by bike and on foot but not by car, new bicycle lanes,

and speed reductions. The modal filters divide the neighborhood into 1–4 areas, which are closed to cars. The bicycle lanes were introduced on some of the main roads leading through the neighborhood, while the speed limit was lowered from 30 or 50 km per hour to walking speed on some road segments. Independently of these measures, the demand for autonomous, driverless electric vehicles (4) carrying both people and goods on different routes through the neighborhoods was simulated in a separate scenario.

The redesign measures were developed in dialogue with the stakeholders mentioned and implemented in an agent-based, microscopic transport demand model in order to analyze the potential effects on transport demand, traffic flow, and greenhouse gas emissions. By so doing the effects of the redesign measures on accessibility metrics and noise pollution in the neighborhood could be investigated and visualized.

4 Results

One problem in urban city planning is the usage of cars for very short trips, which could be easily replaced by foot or bicycle. However, dropping pupils off at school on the way to further activities is a common but from the point of road-safety in front of schools unwanted behavior. Figure 1 shows the impact of the redesign measures on the accessibility of primary schools by car in the neighborhood of interest. The Mobility Lab enables the users to examine this impact on accessibility on their own by allowing

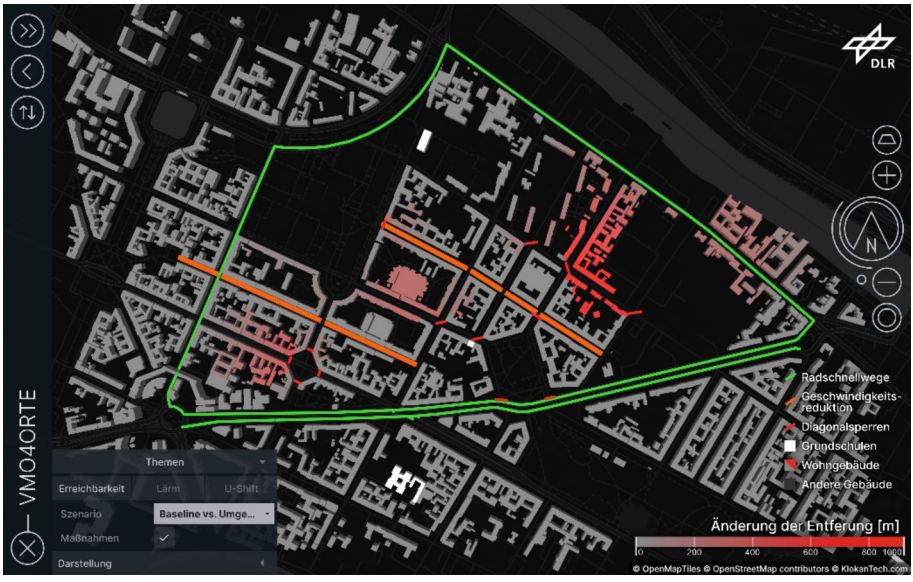

Fig. 1. The impact of the introduction of diagonal roadblocks (red lines), lower speed limits (orange lines), and new bicycle pathways (green lines) on primary school accessibility. The blue dots mark the locations of the primary schools, while the color of the buildings indicates a reduced or improved accessibility of primary schools (white) by car through the introduction of the redesign measures. The image constitutes a screenshot of the Mobility Lab. The German Aerospace Center (DLR) holds all copyrights of the image.

them to switch between the visualization of the accessibility of primary schools by car in the baseline scenario without any redesign measures and the visualization of the accessibility in the redesign scenario with the measures implemented and shown on the map. A third view shows the difference in the accessibility, which allows see which regions are affected by the measures. Additionally, the measures can be shown to verify the effects of the results.

In particular for areas in the northwestern part of the neighborhood the accessibility of residents to primary schools by car declines through the introduction of the modal filters. This can be regarded as an intended effect as one of the main reasons for the implementation of modal filters is the motivation to reduce motorized traffic in the neighborhood and to encourage people to conduct shorter trips by active modes.

In addition, by changing the traffic volume, the redesign measures also have an impact on the noise pollution in the neighborhood as illustrated in Fig. 2. Mobility Lab users can interactively examine how noise pollution changes at different times of the day through the introduction of the redesign measures. For this purpose, they can choose between displaying the noise pollution with and without redesign measures for every 5 min of the day (Fig. 2a–c). For example, one can see the differences in the results on noise pollution in the morning and evening rush hour. Additionally, a total daily change in noise pollution can be displayed (see Fig. 2d).

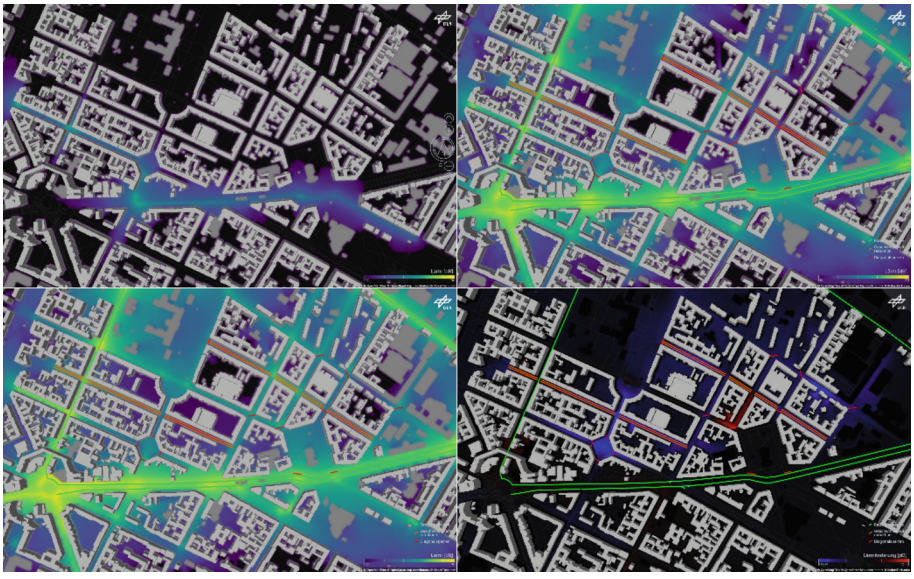

Fig. 2. **a (upper left):** The noise level at midnight in the baseline. **b (upper right):** noise level at noon with displayed measures (same as Fig. 1). **c (lower left):** noise level at 6pm with displayed measures. The noise pollution is depicted on a color scale from blue to yellow with blue areas indicating a lower level of noise pollution (30 dB) and yellow areas indicated a higher level of noise pollution (76 dB). **d (lower right):** total daily change in noise pollution due to the introduced measures. red: +12 dB, blue: −12 dB. The images constitute screenshots of the Mobility Lab. The German Aerospace Center (DLR) holds all copyrights of the images.

The strongest reductions of noise pollution are expected to occur in the areas immediately surrounding the diagonal roadblocks and on the street segments where the speed limit was lowered. Also, the introduction of bicycle lanes contributes to a small reduction of noise pollution along the main roads. However, some street segments see an increase in noise pollution through the redesign measures due to diverted traffic to avoid the diagonal roadblocks. This visualization result can help city planners redesign the measures to avoid design flaws before implementation.

Finally, Fig. 3 illustrates the potential route of an autonomous, driverless electric vehicle used for the transport of passengers in the neighborhood.

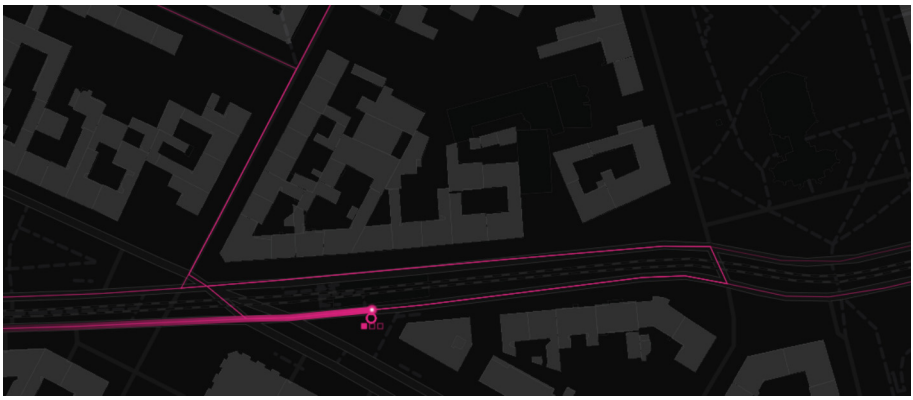

Fig. 3. The route of the U-Shift vehicle if used for the transport of passengers. The bright purple dot shows the position of the vehicle and the rectangles beneath its occupancy (1 square = 1 seat). The image constitutes a screenshot of the Mobility Lab. The German Aerospace Center (DLR) holds all copyrights of the image.

Mobility Lab users can examine the transport of goods by the U-Shift vehicle by clicking on "autoplay." Then the vehicle starts moving through the neighborhood and it can be seen where it picks up and delivers goods. In addition, the users can switch the mode from "goods transport" to "passenger transport" and the vehicle starts moving through the neighborhood with passengers getting on and off in different locations. The visualization helps to identify critical movements like U-turns or frequent repetitions due to high demand and capacity constraints.

5 Discussion and Conclusion

The Mobility Lab visualizes a new modelling framework based on a holistic understanding of the entire transportation system. It enables the wider public to interactively engage with the scientific results of models (e.g., accessibility, noise pollution, autonomous vehicles). The non-scientific users of the Mobility Lab can easily examine what impacts the redesign of the transport system would have in each of these dimensions. Furthermore, it also supports decision-makers understand dynamic city planning.

In the future the Mobility Lab will be extended to include travel demand for additional cities and emission maps created to visualize climate and air quality impacts. Other topics, like spatial and temporal energy demand and storage capacity due to electric and hydrogen vehicles are planned.

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Is Mobility as a Service Beneficial for All? Developing a Stakeholder-Based Evaluation Framework for MaaS

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Abstract. Mobility as a Service (MaaS) is considered to be a disruptive concept with the potential to reshape urban mobility. This study investigates the possible societal impacts of three possible MaaS business models in the context of Belgium. Utilizing the Stakeholder-based Impact Scoring (SIS) method, we engaged 21 stakeholders to collect their insights on impact factors and their relative importance. The research revealed that (semi-) public MaaS would have the most positive potential societal impact, indicating the importance of subsidies in fostering inclusive and accessible transportation solutions. Additionally, the study sheds light on the potential implications of MaaS, emphasizing the need for further research and stakeholder engagement to comprehensively assess its impacts.

Keywords: Mobility as a Service · urban mobility · stakeholder-based impact scoring · multi-criteria analysis · transport equity

1 Introduction

Mobility as a Service (MaaS) is globally recognized as a promising development, driven by the digitalisation of mobility incorporating new innovative transport modes such as shared and micromobility. It may facilitate a shift away from private car ownership towards sustainability and flexibility, guaranteeing user-centered, personalised transport from different mobility operators provided via one digital platform. (Sochor et al., 2018). Nevertheless, the societal impacts of MaaS have not yet been determined, and while research often focuses on the positive expected impacts (Jittrapirom et al., 2017; Karlsson, Sochor, et al., 2017a, b), several authors also claim it could have negative effects on society (Pangbourne et al., 2018; Zhao et al., 2021).

The aim of this paper is, therefore, to identify, quantify and compare the potential social, economic and environmental impacts of the different MaaS business models in the Belgian context. We apply an evaluation framework based on stakeholder-based impact scoring (SIS), a method developed to reveal the key trade-offs in decisions, instead of prescribing an economically 'optimal' solution as in cost-benefit analysis, or 'the best solution' as in conventional multi-criteria analysis (Te Boveldt et al., 2022). This approach could provide policy makers with the necessary information to develop strategies,

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increasing the positive impact of Maas, while limiting the negative externalities, as well as creating a service accessible to and beneficial for all.

2 Background

There is a notable absence of empirical data on the possible impacts of MaaS (Maas, 2022). Previous studies have predominantly relied on stated preferences (expressed opinions rather than observed behaviors), which warrant cautious interpretation, or were based on assumed impacts and externalities. Often, much attention was given to the substantial benefits that MaaS may offer, but the empirical materialization of these impacts is still to be assessed.

While the impacts can ultimately be linked to the broader social (Jittrapirom et al., 2017; Pangbourne et al., 2018) and ecological (Mulley, 2017; Smith et al., 2018; Zhao et al., 2021) aspects of sustainability as well as financial viability (Staatsblad monitor, 2023; Whim, 2023), for the purposes of this study, we have chosen to consider the directly measurable impacts on transportation. This decision is motivated by the assumption that these are the first impacts that are noticeable and quantifiable.

In studies on MaaS impacts, there is often a lack of differentiation between MaaS business models. However, it is vital to note that different MaaS models exist, leading to distinct goals. There are primarily two models: private MaaS operators focused on profitability and (semi-)public MaaS operators aiming for accessible and inclusive services covering larger areas (Aapaoja et al., 2017).

Given the limited assessment of MaaS impacts, particularly the often assumed impacts that are frequently not empirically supported, we introduce a comprehensive stakeholder-based impact scoring framework. This framework is designed to address this research question: **'What are the positive and negative impacts of the MaaS business models in the Belgian context?'.**

3 Methodology

Our methodology is based on the stakeholder-based impact scoring (SIS) method, as developed in Te Boveldt et al. (2022). This method quantifies and visualizes the impact of interventions as measured for different stakeholders. In this application of SIS, we first identified primary MaaS business models based on the literature, determined key stakeholders, and carried out a literature review and semi-structured interviews with stakeholder representatives to identify stakeholder-specific factors. To support decision-making, it is essential that the selected impact factors comprehensively capture the impact while minimizing overlap. Therefore, if several impact factors exhibited substantial overlap (collected from literature and the interviews) or were described differently across multiple interviews, a series of consolidation rounds for these impact factors were applied. Once impact factors were identified for each stakeholder group, an assessment was conducted to evaluate the potential effects of each MaaS business model on each impact factor, and performance scores were allocated in an internal expert workshop by members of the VUB Mobilise Research Group, using a 7-point Likert scale. Next, stakeholder representatives were reengaged through a weighting exercise to determine

the relative importance of each factor. Finally, based on the multiplication of the performance scores and weights allocated by the stakeholders, the final impact scores for each MaaS business model were calculated and visualised.

4 Results

In the initial phase of this SIS, the following three MaaS business models were defined based on the literature (Aapaoja et al. 2017):

(1) **Private MaaS** is a privately operated service that meets all the criteria for a MaaS. Examples of such systems in Belgium's business-to-business (B2B) market include SKIPR and Olympus Mobility, and in the business-to-customer (B2C) market, Olympus Mobility or the KBC banking app that allow booking transport services. On an international scale, systems like these are similar to MaaS Global's Whim.[1]
(2) **Multimodal payment cards**, which are linked to the employee mobility budget predominantly used for commuting often supported by a digital application. Although they are not strictly considered part of MaaS, it was decided to include them in this study due to their relatively strong presence in the Belgian market and the comparative value in the evaluation framework. They operate in the B2B market and facilitate billing and administration of employee mobility. Belgian examples include Mbrella[2] and XXimo.[3]
(3) **Semi-public MaaS,** a system offered by a public entity with the goal of providing mobility coverage for the entire territory of a city, region or country and increasing accessibility to places and services for all residents. The public transport operator in Brussels (MIVB) launched 'Floya'[4] in the summer of 2023, making it the first service of its kind in Belgium. The Flemish public transport operator (De Lijn) is also developing a similar service, but no release-date has been confirmed.

As a next step, we engaged relevant stakeholders: a total of 21 representatives participated in semi-structured interviews, including 3 regional and local governments, 3 national and regional public transport operators, 7 MaaS operators, 4 shared mobility operators and representatives, and 2 each from traveller and environmental organizations. The impact factors collected from the literature in conjunction with those from the stakeholder interviews yielded, after consolidation, a set of 15 final impact factors (see legend Fig. 1).

The performance scores representing the objective evaluation of the impact of each business model on every impact factor were determined by the VUB Mobilise expert panel. Subsequently, the stakeholder representatives were reengaged to assign weights to each impact factor on a scale ranging from 0 to 10. Out of the initial 21 stakeholder representatives, only 12 participated in this exercise, representing five distinct stakeholder groups i.e., environmental organisations, travellers' organisations, shared

[1] https://whimapp.com/.
[2] https://www.mbrella.eu/.
[3] https://www.xximo.com.
[4] https://floya.brussels/.

mobility providers, MaaS operators as well as regional and local governments (see Fig. 2).

Averaged over all stakeholder representatives, the most important impact factors were: promotion of national public transport, usage of regional public transport, reliability of transport, promotion of walking and cycling, usage of shared mobility, with respective weights of 8,28; 8,08; 7,69; 7,53 and 7,39. Although it was anticipated by both the authors and existing literature that car ownership (5,94) and car usage reduction (6,42) are key achievements of MaaS, these were not considered as relevant by the stakeholder representatives included in this research.

The multiplication of the performance scores with the impact factor weights resulted in the impact scores for each MaaS business model. Figures 1 and 2 visualize the impact scores and can be interpreted as advantages and disadvantages of each MaaS-business model and are specified by stakeholder group or by factor. The MaaS business models are projected on the X-axis, the relative impact scores on the Y-axis.

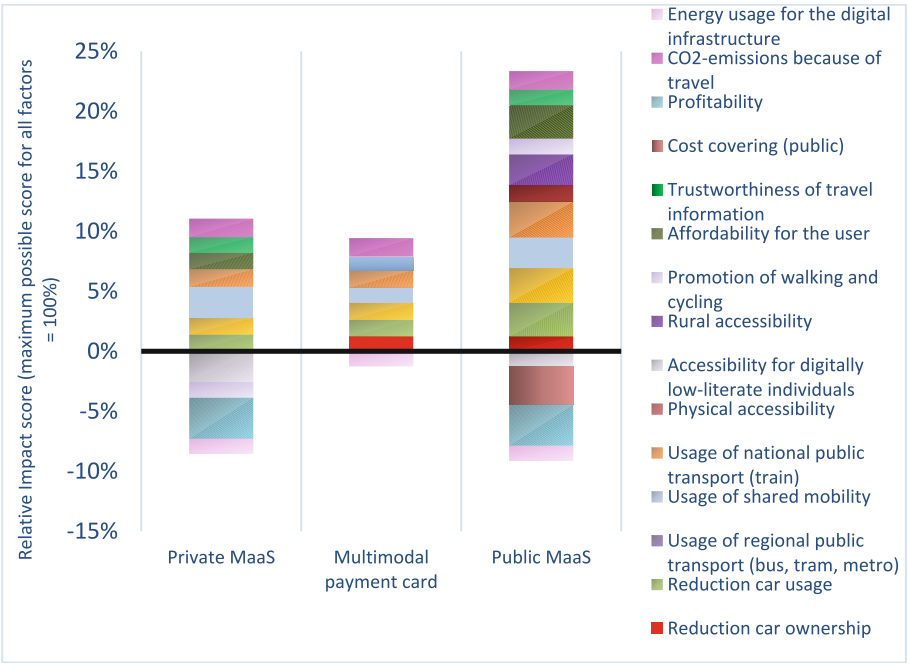

Fig. 1. Total relative impact score, breakdown per impact factor

Based on the assumptions made during the performance scoring, as shown in Figs. 1 and 2, a (semi-) public MaaS appears to have the greatest potential societal impact, with negative impacts similar to private MaaS. Both face profitability challenges, indicating a (semi-) public MaaS will require subsidies, while the private MaaS are currently often operating funded by venture capital. Private MaaS may pose accessibility issues, while this issue is not present in a public MaaS, which offers notable benefits such as boosting public transport usage (regionally and nationally), improving rural accessibility, and

increasing affordability. A disadvantage that could severely impact the critical mass of both private and public MaaS is the lack of accessibility for people with low digital literacy. Additionally, it is noteworthy that these results indicate that private MaaS would not necessarily lead to a decrease in car ownership, however, for the other two models this would be the case. Overall, the (semi-) public MaaS received significantly more positive evaluations compared to the other services, offering a fairer and more inclusive option. However, it is crucial to emphasize that (semi-) public MaaS is expected to be dependent on the availability of substantial subsidies.

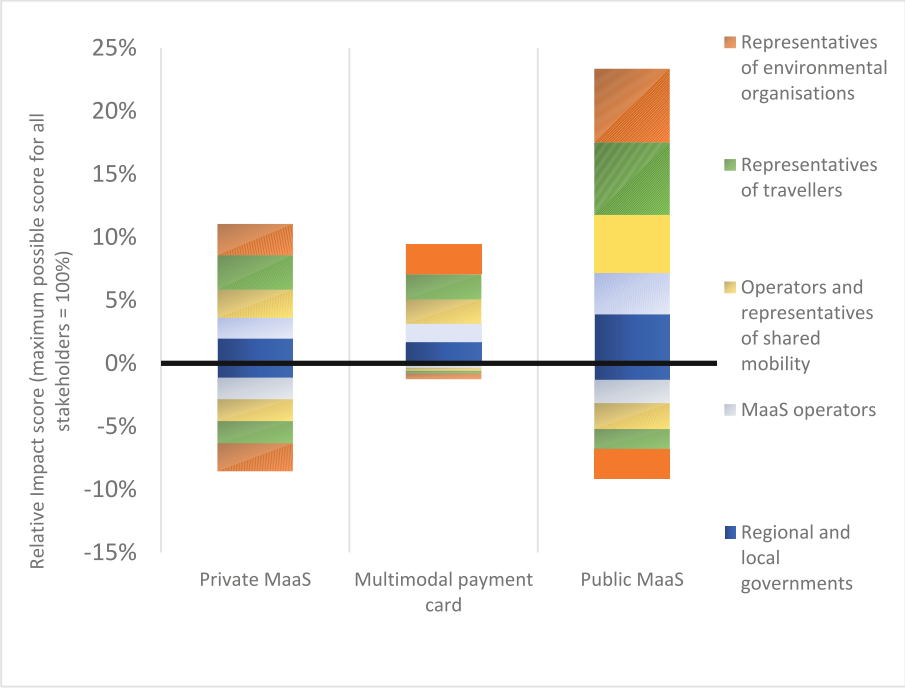

Fig. 2. Total relative impact score, breakdown per stakeholder group

5 Conclusions, Discussion, Limitations

In conclusion, this study provides insights into the impacts of private and (semi-) public MaaS business models in Belgium. However, several key discussion points need to be considered.

Firstly, the absence of weighting data from some participants, especially from public transport organizations, may have significantly affected the results.

Secondly, the study faced challenges due to the lack of trustworthy empirical data to evaluate the impact of the three MaaS business models on the stakeholders' criteria.

Nevertheless, the strength of the methodology lies in its ability to highlight underexplored impacts and to shed light on aspects that require further investigation.

In summary, although this paper provides a first step in the assessment of societal impacts of MaaS in Belgium, further research, larger stakeholder engagement, and empirical data collection are necessary to improve our insights and assessment.

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Who Benefits from Investment in Active Modes of Transport in Ireland?

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Abstract. This paper examines the benefits of investing in active travel, with a delineation between individual and collective benefits. Of the individuals who engage in active travel modes such as walking and cycling, the study identifies the groups that stand to gain the most from investment in active travel, given the potential positive impacts on health, the low-cost advantages of active travel modes and demographic factors. Distributional analysis further informs Cost-Benefit Analysis by providing greater information to decision makers about how certain cohorts are affected differently by particular infrastructure investment. These emerging techniques to measure active travel benefits can inform the 'social value' of a particular investment, including reducing social exclusion, facilitating freedom and greater social interaction particularly for disadvantaged groups who may face transport barriers. The findings from this paper suggest that investment in active travel can benefit a wide range of individuals, some directly through impacts on health and savings on transport, and some indirectly through localised effects such as decongestion and improved air quality. On a societal level, the paper highlights the environmental benefits of active travel, including reduced air pollution, reduction in carbon emissions and economic development.

Keywords: Walking · Cycling · Active Travel · Investment Appraisal · Transport Planning · Distributional Impacts

1 Introduction

Encouraging active travel, defined as travelling with a purpose using your own energy (walking/wheeling, cycling and non-motorised scooting), has preferential policy support in Ireland. With this increased policy focus, this paper explores the emerging techniques to measure the benefits of active travel, using the case study of Transport Infrastructure Ireland's Tool for Economic Appraisal of Active Modes (TEAM).

The TEAM tool came into use in Ireland in 2021, and is evolving to reflect the deepening knowledge of, and data on, the benefits of active travel. The paper reflects on the type of benefits and who they accrue to, informing the assessment of the desirability of an investment proposal from the perspective of society.

Rather than just looking at the financial costs of new active travel infrastructure, or the individual benefits that accrue, an active mode appraisal should attempt to capture the

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wider benefits provided by active travel infrastructure while being clear on who in society is benefitting. Methodological and data limitations can result in implicit distributional biases, and this paper attempts to challenge some of these biases, to improve the appraisal process.

2 Methodology

This paper uses a deliberative process [1], defined as an interrogative and investigative process to facilitate new, better informed and consensus on public policy [2]. While a large component of academic literature focuses on translating normative theories into empirical research [3], the approach taken in this paper is in the opposite direction: the paper uses empirical research from transport practitioners in Ireland to consider normative theories about how the transition to active modes of travel could be conceived, appraised and ultimately delivered in time to decarbonise the transport sector in Ireland.

TII developed a tool to appraise active travel projects, and this paper uses the tool as the starting block to discuss and produce well informed opinions that are intended to integrate knowledge and update practical approaches to active travel in Europe.

3 Literature and Policy Review

3.1 Recent Policy Changes

The vision set by the European Green Deal for sustainable travel across Europe seeks the improvement of infrastructure for walking and cycling. Key policies developed in the last three years in Ireland provide the ambition and direction for active modes of travel: the National Investment Framework for Transport in Ireland (NIFTI), the Climate Action Plan (CAP) and the National Sustainable Mobility Policy (NMP).

The new policies reflect commitments made by the Government of Ireland to reduce transport related emissions, which accounted for about 30% of all greenhouse gas emissions in 2022 [4]. NIFTI presents a modal hierarchy that officially prioritises walking and cycling over private vehicles [5]. CAP targets a 50% increase on daily active travel journeys by 2030 along with 1,000km of new active mode infrastructure [4]. The NMP includes the development of a national cycle network and the development of county and urban networks of active modes of travel [6]. National Development Plan (NDP) includes a commitment of €360 million per annum to cycling and pedestrian projects [7]. For that reason, active travel infrastructure appraisal is crucial to ensure high effectiveness for decision-makers.

3.2 Reframing Active Travel Appraisal

The methods for appraisal of active travel infrastructure in Ireland shadowed the appraisal of large transport schemes. Central to this concept of efficiency is the value of time. Over longer distances, there is no competition in time between active travel and motorised vehicular travel, as travel by active modes is considered ‘slow-travel’, with the underlying implicit assumption that ‘faster is better’. When viewed from an energy efficiency

perspective, active travel is more efficient than motorised travel from an overall energy requirement – active modes require food only, and have the lowest environmental impact in absolute terms [8]. Efficiencies in terms of health outcomes and active travel are documented in the literature, with walking and cycling for travel recognised as an easy and feasible way of achieving the minimum daily recommended amounts of exercise [9, 10].

When measured from an equity perspective, active travel is more efficient at providing opportunities, due to the low capital and operating cost requirements in comparison to other forms of transport such as vehicular travel [11, 12]. It also provides opportunities for one vehicle households, or reduces the likelihood of more than one vehicle per household. Active modes of travel provide opportunities for specific groups who may be excluded from driving – such as children, youth and older people. The cost of owning and running a private vehicle is prohibitive for many people, whereas active modes are available to able-bodied people. Improvements in technology have made active travel more accessible even to those who are not able-bodied: e.g. electric bikes, cargo bikes, hand cycles.

4 The Case of Active Travel Appraisal in Ireland

Active travel was acknowledged by policy makers as offering a wider array of impacts beyond transporting people from A to B. Collecting the evidence base to support this thesis was not straight forward. There were uncertainties in how to express and measure the benefits, and TII as an approving authority for an increased number of Greenways and portions of a national cycle network identified the inconsistencies in the approach taken to appraisal. Appraisal practitioners recognised that the parameters assessed in transport appraisal were insufficient to meet the new priorities in sustainable transport policy and climate action. TII developed an Excel based Cost Benefit Analysis tool to streamline the appraisal process. This tool is in usage since 2021, used for a variety of active travel schemes ranging from long distance greenways to retrofitting of active travel facilities on existing roads to the provision of urban segregated cycle routes [13].

4.1 TII's TEAM Tool

The TEAM tool describes the impacts of active mode travel. In the tool, the benefits are categorised according to benefits as shown in Fig. 1, along with costs categorised as the construction and maintenance costs of the infrastructure.

While the TEAM tool satisfactorily measures what the monetary impact of a proposed active travel is, it does not explicitly identify *who* the beneficiaries are.

However, it can be used as a basis to measure the distributional impacts that are required of the Irish Transport Appraisal Framework [14]. An assessment of who is and is not considered in the analysis is given in Table 1.

4.2 Distribution of Benefits

Accounting appropriately for distributional elements is essential in policy choices, although how to appropriately screen for distributional impacts is difficult, requiring considerable information on local factors.

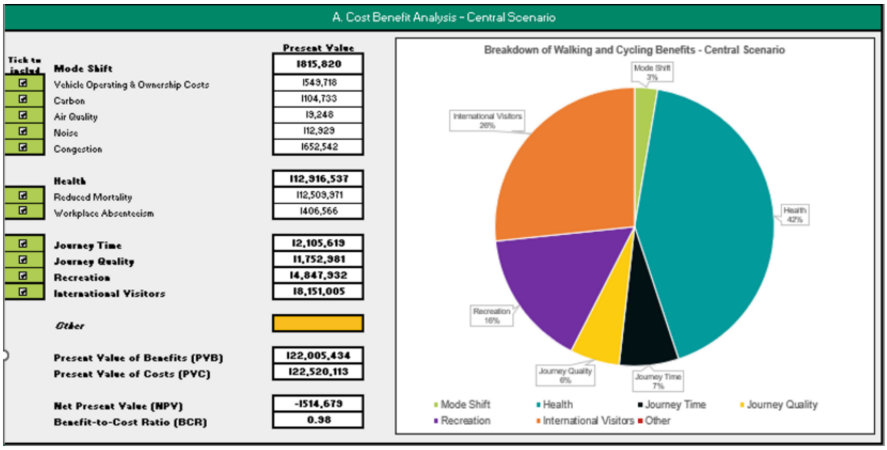

Fig. 1. Example of output of the TEAM tool. *Source; TII TEAM Tool.*

The distributional effects of an active travel benefits consist of the differing impacts across people affected by the project. An analysis of the socio-economic, social and demographic characteristics of several categories of people is undertaken, following the UK's Department for Transport's classification [15]. For each impact in the TEAM tool, a high-level assessment was identified for each social group (Table 2). While the delineation in cross checking the TEAM tool with different social groups is not always clear cut – it is clear that two social groups in particular are not explicitly represented: children aged under 16 and elderly people (aged over 70 years).

Although distribution impacts are usually calculated according to income levels, it is more relevant to distinguish the impact amongst socially vulnerable groups. Distributional equity can be presented in four forms: horizonal, vertical, spatial or intergenerational [16]. For active modes, vertical equity is the most important form because it refers to the principle of difference: assessing the outcomes of policies with reference to the well-being of the most disadvantaged [17], who should be considered into appraisals.

Methodological and data limitations can also result in some implicit distributional biases. For example, the scientific assessment that underpins the World Heath Organizations' Health Economic Assessment Tool omits the mortality impacts for those under 20 years old, as well as those over 64 for walking and 74 for cycling [18]. Effectively this results in monetised health benefits only being assumed for adults of a working age, even though other groups may be primary beneficiaries. Interestingly, the Australian transport assessment includes young male drivers, carers and First Nation people as distinct social groups [19]. Another recent recognition is the linking of the UN's Rights of the Child with children's independent mobility, defined as the level of freedom children have to make journeys on their own [20, 21].

Table 1. TEAM Tool Benefits Distribution Assessment Table

Benefit		What is measured?	Who is considered?	Who is not considered?
Mode Shift	Diverted Trips	Number of diverted trips from cars to walking & cycling	Working adults aged 15 and over	Elderly Children/youth as co-pilot Unemployed population
	Vehicle Costs	Cost savings	Individuals: Car owners	Low-income households
	Carbon reduction & Air Quality	Shadow Price of avoided Carbon	Irish society Local population (air)	Healthcare system Global population: Natural Disasters Costs
	Noise	Marginal external cost of noise	Local populations	–
	Congestion	Marginal external cost of congestion	Individuals: Car owners	Walkers & Cyclists
Reduced mortality		Reduction in relative risk of mortality	Walkers/wheelers & cyclists aged 20 to 64	Survivors car accidents Healthcare system cost of illness
Workplace absenteeism		Avoided sick days	Businesses	Elderly Children/youth
Journey time		Time savings	Working adults or children/youth educational trips	Elderly Unemployed people
Journey quality		Willingness-to-pay to use improved active mode infrastructure	Adult walkers/wheelers & cyclists	Children/youth Security and safety for certain social groups e.g.. LGBTQ
Recreation		Willingness-to-pay for infrastructure	Recreational users	–
Intl. Visitors		Visitor expenditure	Businesses	–

4.3 Integration of Distributional Equity into Cost-Benefit Analysis

To incorporate distributional equity into CBA's, adjustments in numerical values are required. The application of vertical equity within the evaluation of active mode schemes can be employed with the following methods:

- **Utility functions to allocate weights.** These distributional weights can be derived from an assumed utility function that delineates utility as a function of income,

Table 2. Scope of Socio-Demographic Distributional Impact Appraisal

Social Group	Vehicle Costs	Carbon reduction	Air Quality	Noise	Congestion	Reduced mortality	Absenteeism	Journey time	Journey quality	Recreation	Intl. visitors
Low Income Group	✓	✓									
Children aged <16											
Young adults aged 16-25						✓	✓	✓	✓		
Older people aged 70+											
Population with a disability						✓					
Black and Minority Ethnic						✓	✓				
Women							✓	✓			
Urban/rural regions			✓	✓	✓						
People without access to a car								✓	✓	✓	

incorporating the concept of diminishing marginal utility concerning income. Two types of weights can be outlined: utilitarian weights, which address the diminishing marginal utility of money, and isoelastic/Atkinson weights, which reflect an aversion to inequality in the distribution of well-being [22].

- **Shadow values.** A method to incorporate social equity objectives within the framework of CBA deviates from corresponding market prices, offering a means to promote equitable opportunities within the context of such schemes [23]. Examples of this include the use of labour costs below the real wages to induce labour-intensive solutions. Single social value for travel time savings could be used to level-out the impact of income differences and ignore increasing willingness to pay of high-income groups [24].
- **Weighting criteria**. Another alternative is to incorporate, directly within the CBA, specific weighting criteria. This approach aims to implicitly consider the decision-maker's preferences when assessing the benefits identified in the CBA.
- **Obtain additional data on disadvantaged groups**. The collection of more comprehensive data would enable further analysis to establish a willingness to pay specifically for these groups.

The choice among these methods should be guided by the specific context and objectives of the evaluation.

5 Conclusion and Implications

Categorising users into distinct demographic groups, such as different age cohorts, gender, socioeconomic strata, and abilities is an important element of appraisal. By segmenting users, this paper aimed to show how benefits are distributed across diverse

populations and identify how Irish appraisal can improve. This would facilitate a more targeted policy response considering different groups and communities. The main focus of this study was to extend beyond measuring impacts of active travel investment, using the tools developed within the Irish appraisal process to provide insight into who is impacted. There are implications for individuals, distinct cohorts and groups within society that should be considered in investment decisions.

Evaluating the potential impacts of an active travel infrastructure investment on diverse social groups is a significant challenge. However, it is a crucial step to ensure their balanced inclusion in the decision-making process. Further work needs to be performed on the integration of distributional equity into TEAM.

The TEAM tool was developed as a modular tool that is set up for continuous improvement. Although TEAM has tried to improve CBA, these types of methodological limitations and distributional questions mean that CBA should not be used as the only decision-making tool for active mode investment decisions. These decisions require a more comprehensive and holistic assessment.

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Strengthening City-Citizen Engagement: A Mobile App to Enhance Pedestrian Safety and Comfort

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Abstract. This study focuses on providing meaningful information to vulnerable road users (VRUs) to support their objectives and perceptions while navigating urban spaces, employing a novel route planning concept. Through three focus group sessions, a comprehensive survey was conducted to identify the needs and concerns of VRUs, leading to the development of an integrated and collaborative mobile application for active mobility. The application encompasses route calculation, prioritizing safety, comfort, civic participation, and empathy. The solution aims to bridge citizen users and city managers, facilitating alerts, historical information on safety and comfort, and collaborative problem-solving and sharing of urban attractions. A prototype of the concept was developed and extensively tested by potential users, and subjective evaluation and feedback demonstrated the usefulness and added value of the integrated and collaborative approach. This study highlights the proposed solution relevance and differentiation from official alerts, user experiences, and civic participation, positioning it as a comprehensive solution for active mobility.

Keyword: Civic Participation · Active Mobility · Collaborative Approach

1 Introduction

Urban centres are grappling with the challenges posed by increasing traffic, including pollution and congestion. To promote sustainable modes of transportation such as walking and cycling, it is crucial to address the deterrents affecting citizens' perceptions of safety and comfort [1]. Fear of traffic-related injuries [2], fear of falling related to infrastructure and infrastructure maintenance [3], and harmful behavior of drivers [4] negatively influence walking and cycling trips. Similarly, high levels of air and noise pollution, lack of vegetation [5], bad weather conditions, slopes and long commuting distances [6] cause discomfort when walking and cycling.

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Conventional solutions like route planners enjoy extensive usage and primarily aim to assist users in discovering the optimal path between two locations, taking into account their mobility preferences. Presently, these options predominantly concentrate on two factors: time and distance, which may not adequately accommodate various individual perspectives. By introducing novel elements and diverse factors, such as air quality, noise levels, accessibility, or population density, it becomes conceivable to envision a tool that encourages users to embrace more environmentally sustainable modes of transportation. This transformation must be coupled with civic engagement and a sense of empathy to enhance its efficiency and effectiveness.

Hence, this study centers on delivering valuable data to VRUs to aid them in achieving their goals when traversing urban environments, utilizing an innovative route planning approach. The suggested solution seeks to connect everyday citizens with urban administrators, enabling the dissemination of alerts, historical data regarding safety and convenience, as well as fostering collaborative solutions and the sharing of information about urban points of interest. A prototype of the concept was developed and extensively tested by potential users.

The remainder of this article is structured as follows: the next section presents the research approach that was followed. Section 3 details the proposed solution. Section 4 presents the evaluation results and Sect. 5 draws the main conclusions.

2 Research Approach

The proposed solution's definition was grounded in the User-Centered Design process, which employs various methods to assess user needs and objectives, incorporating elements of usability, user experience, and accessibility [7]. This approach was merged with the Spiral Model methodology [8], advocating an iterative process for continuous assessment and improvement. The initial phase involved conducting discussion group sessions with potential users. The insights gleaned from these sessions, in conjunction with findings from the literature review, informed the establishment of system requirements and functionalities. This served as the foundation for creating a prototype of the mobile application, employing the Figma tool. To validate the concept and assess the prototype's effectiveness, usability tests were conducted with potential users.

2.1 Focus Group

Three focus group sessions were held virtually and lasted an average of 110 min each, with the presence of 11 participants. Participants were students, workers and people in a situation of unemployment, aged between 32 and 54 years old, residing in Portugal. Issues of urban mobility and the use of technologies, aspects of security, comfort and information sharing were discussed. A complementary online survey was prepared and made available to participants to clarify basic questions about the topic.

Regarding the most used means of transport, all participants walk, 90.9% use public transport, 54.5% use car sharing services, such as Uber or Bolt, and 27.3% cycle. In relation to activities carried out using active means of transport, 90.9% of participants walk to shop, go to college, work, banks and pharmacies and on weekends they walk

for leisure on the beach or in the neighborhood, 18.2% cycle for medium distances and when the weather is good and 9.1% run on weekends as a sport on beaches or parks.

Participants were asked what safety information they found useful to receive before and/or during a trip using active modes. They would like to have access to information such as alerts about accidents, terrorist attacks, storms, floods, earthquakes; history of accidents, floods, catastrophes, robberies. The same question was asked, about information related to the comfort they would like to receive, to which they responded information such as meteorology and weather forecast, operation of public lighting, notice of works on public roads, population density, travel accuracy, timetable and indications of routes with cycle paths.

Finally, participants were asked what technology could be used to share this information with citizens during their travels. They suggested mobile applications, information panels on highways, SMS via cell phone, collaborative platforms between users, public services and municipal managers and sound messages via applications for cyclists. Participants also recognize that sharing this type of information during travel would allow them to share experiences and information in real time, report problems, attest to the accuracy of the system and foster a culture of collaboration and empathy.

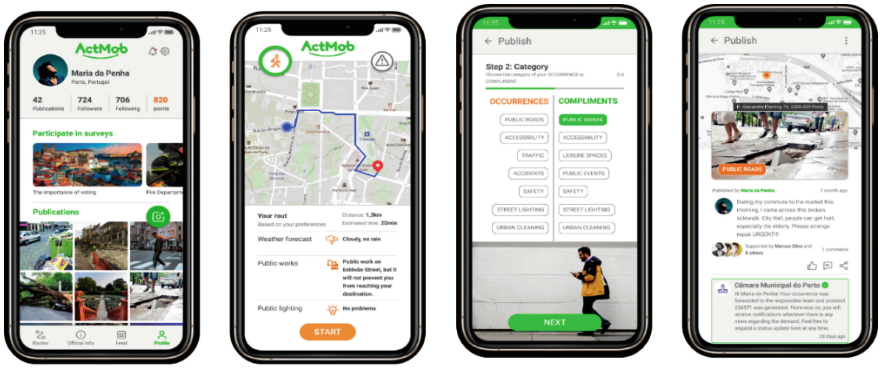
2.2 Usability Testing

The usability tests were carried out in person, with 11 participants in total, aged between 21 and 45 years old, students and workers. In relation to gender, 6 were male and 5 were female.The tests consisted of performing 5 tasks that characterize the main functions of the proposed solution: (i) Simulate login or registration, follow the steps until you reach the "Profile" screen; (ii) On the "Profile" screen, participate in a survey and return to the "Profile" screen; (iii) On the "Feed" screen, try to simulate a publication with a photo that would be in the cell phone gallery/album; (iv) On the "Routes" screen, start a route and, until you reach the final destination, access some information on the map (official or marked by another user); and (v) On the "Official Information" screen, view all available information and close.

After completing the tasks, a brief interview was carried out about the experience as a user of the application. The expectation was to receive brief responses, with suggestions for improvements based on what they had experienced. The average interview time lasted around 3 min, following the script: (i) What did you think of the structure/organization of the application?; (ii) What did you think of the design and visual aspects of the app?; (iii) What did you like most and what you did not like most?; (iv) Do you have any suggestions for improvement?

3 Proposed Solution

The proposed solution is an integrated and collaborative application for active mobility, with route calculation and a focus on safety, comfort, civic participation and empathy (see Fig. 1). It seeks to integrate citizen users and city public managers, with alerts and historical information related to safety and comfort, as well as collaboration on problems and attractions of the urban territories covered.



(a) (b) (c) (d)

Fig. 1. Proposed solution screens: (a) landing page; (b) plan a journey; (c) select category of occurrences and/or compliments; (d) publish an occurrence and/or compliment

After downloading the application, the users are invited to register what will allow them to plan walking or cycling routes, starting from their location to another desired location, whether in everyday situations (going to college, work, market, hospital, etc.), leisure or practices sports. The application calculates the expected time and the most comfortable route option according to the preferences indicated by the user during registration for both types of active mobility. Thus, they will be able to receive prior information on meteorology, population density, renovation works on public roads, streets with public lighting, routes with cycle paths, as well as real-time alerts, via text or voice, of accidents, fires, traffic jams, catastrophes, natural disasters and terrorist attacks.

With regard to citizen involvement, through their user profile, they will be integrated into a virtual community network in their city, in which they will be able to contribute information about safety and comfort based on their experiences during or after a trip (through the publishing of images and texts), reporting problems to managers or signaling positive aspects so that other users can experience them. The civic participation of citizens through the application, in addition to allowing them to act as collaborators in the search for a solution for their municipality, also establishes a relationship of empathy with other users, whether they are permanent residents or even temporary residents (visitors or tourists). Considering a reward system, each support from other users for their post will correspond to one point.

On the other hand, city managers and authorities will be able to create real-time alerts about accidents, fires, traffic, terrorist attacks and natural disasters; issue communications with information about public transport shutdowns, works on public roads and extraordinary events in the municipality; consult reports, records and complaints reported by citizens through the application; respond to complaints or requests from citizens and respond with an expected resolution of the reported problem(s); publicize campaigns and events related to safety and comfort in active mobility (e.g.: opening a park or public space for sports); and carry out public consultations, surveys, via the application, on a specific subject for decision-making, considering user responses.

4 Evaluation Results

Regarding the usability tests all participants were able to complete the proposed tasks before the stipulated time, with few usability errors. Within the performance metrics per task, effectiveness was evaluated at 100%, as everyone performed the tasks sucessfully, regardless of the time and number of errors. Likewise, the degree of efficiency was considered high, as everyone completed the tasks within the expected average time and with a very low number of errors (a maximum of two errors).

The estimated time to complete the five tasks was 13 min, considering that the participants wanted to read each textual information, even though it was explained in the initial instructions that the texts from publications and research from official bodies were fictitious. The longest time spent on the test was 8 min and 48 s and the shortest was 4 min and 9 s. This made it possible to demonstrate that the projection of the application, its structure, organization and design corresponded well to the implementation of the main expected functionalities.

After completing the tasks, a brief interview was carried out. The responses regarding the structure of the application represented a good acceptance of the application. The general organization and main menu dividing it into four categories or main sections was a positive point in the participants' opinion. Responses such as *"good information and easy to find"*, *"intuitive"*, *"friendly"* and *"well organized"* reflect the ease with which everyone completed the tasks ahead of schedule. Although one answer mentions the word *"confusing"*, this is specifically related to the Profile and Route categories, as they *"contain too much information"*. As for design, there was also good acceptance in terms of colors, typography, hierarchy of information, alignments, illustrations and icons. Spontaneous responses such as *"very beautiful and easy*", "good and pleasant design", or *"I liked the bright colors, they gave a happy tone"* reflected the participants' experience with the visual elements as something good and suitable for using the application.

When asked what they liked and what they did not like about the application, the answers were linked to the comparison with other similar platforms (although not specific to active mobility) or to the differences found or expected. Aspects that participants like positively: *"I liked the fact that it has more advantages over Waze and Google Maps, as it helps to report data directly to official bodies"*, "*The official alerts during the route are very clear"*, *"Very complete and useful for the active community"*, and *"I liked real-time information related to the route and also the publication history of other users"*. In the case of the aspects they did not like, excluding the answers they could not identify any, the participants made the following observations: *"Thinking about the purpose of the application, it didn't give as much emphasis to searches in the Profile"*, *"I found the map a little confusing, perhaps because the top menu is still not working well"*, and *"For publication, I expected to find the camera first, then enter the address and then the description"*.

5 Conclusion

This study focuses on providing meaningful information to VRUs to support their objectives and perceptions while navigating urban spaces, employing a novel route planning concept. The application encompasses route calculation, prioritizing safety, comfort,

civic participation, and empathy. It aims to bridge citizen users and city managers, facilitating alerts, historical information on safety and comfort, and collaborative problem-solving and sharing of urban attractions. Citizens will be integrated into a virtual network of communities in their city, in which they will be able to collaborate with information on safety and comfort based on their experiences during or after a trip, reporting problems to managers or signaling positive aspects for other users to experience. The civic participation of citizens through the application, in addition to allowing them to act as collaborators in the search for a solution for their municipality, also establishes a relationship of empathy with other users. On the other hand, city managers will be able, for instance, to create real-time alerts about accidents, fires or traffic, consult and manage denouncements, records and citizen complaints through the application and carry out public consultations.

A prototype of the concept was developed and extensively tested by potential users. The tests allowed to observe that there was good acceptance of the application proposal and a positive response regarding usability. The execution of tasks within the expected execution time, meeting the intended effectiveness and efficiency metrics, revealed a very small margin of error. Likewise, opinions and suggestions were essential for analyzing the prototype and can be considered for subsequent implementation of future solutions.

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The Role of Social Robots in Autonomous Public Transport

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Abstract. Autonomous Public Transport (APT) is a developing innovation with the potential to transform our current transport systems. APT can potentially provide an affordable, safe, and convenient travel solution for daily travel. Recent studies in the field of APT have identified that among several concerns, safety, and trust played an important role in positively impacting user acceptance of APT. A potential solution to address some of these concerns is integrating "Social Robots" into APT. By creating agents that are designed to be distinct entities from the autonomous vehicle, designed to interact with humans socially and intuitively, these robots can potentially improve passenger experiences and the perceived level of safety for the passenger. This could help to build trust in the technology. Using existing literature, this paper explores the benefits and drawbacks of integrating social robots into APT, including improving passenger satisfaction, safety, and efficiency, as well as privacy and security issues.

Keywords: Autonomous · Public Transport · Social Robots · User Acceptance · Personal Safety · Trust in Technology

1 Introduction

The pressure on public transport has been ever-increasing due to the increasing population in cities, making it challenging to provide reliable and accessible alternatives (Bramley and Kirk 2005). Autonomous technologies can prove to be a viable solution, especially for public transport. Offered to users as driverless shuttle buses via a fixed schedule or on-demand apps, Autonomous Public Transport (APT) could provide a cost-effective, adaptable, and safe travel alternative to personal cars (Pakusch and Bossauer 2017, Fagnant and Kockelman 2015). However, for APT to be generally accepted, user concerns such as personal safety and trust in the technology must be taken into account (Goldbach et al. 2022, Mouratidis and Serrano 2021). Social robots capable of human-like interaction may offer a solution to this problem (Fortunati et al. 2020).

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Their ability to communicate, provide assistance, and create individualized experiences can help redefine the relationship between passengers and public transport (Deveci et al. 2023). However, it is likely that social robots in APT could bring about various challenges, such as ethical considerations, concerns regarding the relationship between humans and robots, and privacy and data security issues (Nørskov 2017). Therefore, it is crucial to understand the dynamics between autonomous systems and social robots and how users can benefit from their combined potential. Through an exploration of existing research, this paper aims to understand the role of social robots in APT, including improving passenger satisfaction, safety and efficiency, and privacy and security issues.

2 Passengers' Acceptance of APT

Rail-based APT has been operational for several years. However, there has been a surge of interest in road-based APT in recent years (Sitinjak et al. 2023). APT can bring about significant benefits to public transport users, such as reduced human errors and accidents (Yuen et al. 2020), increased efficiency (Fagnant and Kockelman 2015), ensuring inclusive and accessible alternatives (Lim et al. 2017), reduced costs (Bergqvist and ˚Astrand 2017) and potential reduction in energy consumption and emissions (Pakusch and Bossauer 2017). These advantages can improve the user experience and promote a sustainable transport system. In order to realize the potential of APT and for it to be widely accepted, it is crucial to understand users' needs, expectations, and attitudes. While recent studies have found that APT acceptance is generally more favorable than personal AVs (Nordhoff et al. 2018), several concerns have also been highlighted. Among others, **safety** and **trust** were identified as crucial concerns in literature, impacting users' APT acceptance. While there are many factors associated with safety and lack of trust in the technology, in this paper, we focus on how social robots can address the following factors:

1. the feeling of not having control (in emergency situations when there is no host on board, lack of sufficient information) (Herrenkind et al. 2019, Goldbach et al. 2022);
2. the need for more mature technology (due to lower speeds, operation in heavy vehicular, or pedestrian traffic) (Mouratidis and Serrano 2021, Choi and Ji 2015);
3. lack of authority or supervision (users might believe that human intervention is crucial in difficult situations, given the immature state of the technology) (Kassens-Noor et al. 2020, Kaszas and Roberts 2023);
4. lack of personal safety (e.g., potential threat to self due to inappropriate activity within a small space, lack of safety equipment within the bus, or fear of software hacking) (Eden et al. 2017, L´opez-Lambas and Alonso 2019)

Some of these factors show great potential for social robots to play a role. In the following sections, we explore how social robots can potentially help remedy some of the above-mentioned concerns and help in building the feeling of safety and trust in users of APT.

3 The Role of Social Robots in APT

Some of the concerns passengers have while riding APT may be addressed by deploying robotic hosts onto the buses. These robots would be **distinct agents from the bus itself**, much like a human bus assistant or conductor is separate from the bus they operate on. By separating the agent from the environment that potentially causes passengers distress as detailed in Sect. 2, it is possible that the robot can reduce those feelings of unsafety, uncertainty, and insecurity.

3.1 The Feeling of Control

As mentioned in Sect. 2, passengers may feel a lack of control over their situation if there is no host on board, or if they are not given information about the source of problems in an APT context. A robot can fill the role of an information-giving assistant in an autonomous bus. When designing such a robot, care must be taken to give it the ability to give passengers the information they require and want at appropriate points in time. If the robot is incapable of giving information that passengers want at critical moments, then passengers may feel an even greater lack of control, as even the agent that is designed to help them does not know what to do. The breakdown of trust in such situations may persist even after the robot repairs the misunderstanding or apologises (Esterwood and Jr 2023). Fortunati et al. (2020) found that around 50% of humans who interacted with a large, slow-moving social robot wanted there to be either social or mechanical features allowing them to stop the robot if its movements were unsafe. One way to prevent the robot's presence from causing the perceived feeling of being unsafe is to attach the robot to the bus or make its embodiment part of the environment, although this could make it hard to communicate the separation between the robotic agent and the bus.

3.2 Robot Authority in Scenarios Where the Technology May not Be Mature

As mentioned in Sect. 2, passengers may feel that a human presence is needed to resolve situations where APT vehicles get stuck in traffic or cannot resolve their route due to immature technology (Kassens-Noor et al. 2020, Kaszas and Roberts 2023). In situations where the vehicle can recover and get back to its planned route, but where this is not immediately clear to the passengers, robots can inform passengers and resolve concerns. Robots can provide information about the destination and mode of transport to the passengers who need it – this may be especially necessary if buses are not on set routes and passengers are unaccustomed to the idea of APT.

3.3 Personal Safety

Robots can function as a social presence in a bus to reduce the feeling of being alone with other passengers, or being alone in the bus if no one is sharing the ride. This would build on the ability of robots with social capabilities to build trust with human partners, as explored by Law and Scheutz (2021). While robots may not be able to *resolve* unsafe situations such as bus collisions or passenger-on-passenger violence or abuse, the presence of a robot may work to increase passengers' perceived safety. This in itself could prevent certain unsafe situations from occurring in the first place.

3.4 Limitations of Robots in APT

When deploying robots in public spaces, care must be taken to address the situations that appear when the robots are vandalized or attacked by humans (Salvini et al. 2010). Additionally, depending on the embodiment of the robot, a robot in a bus needs to be able to mechanically handle sudden turns or stops without causing harm to the passengers by driving into them or hitting them. One way to address this is to use robots that are attached to the bus. Alternatively, a virtual agent on a screen can be used to avoid the problem altogether, but virtual agents have been shown to result in less positive social interactions than fully embodied robots (Lee et al. 2006). Passengers' concerns about the lack of maturity of the technology behind APT, resulting in low speeds and sudden stops, cannot be completely resolved by a robot. The robot can remind passengers that they should put on their seat belts and how long the trip will take. However, a passenger who is expecting a faster ride or who assumes that the seat belt warning is superfluous will still be negatively surprised by the quality of the ride.

4 Conclusions

Through an exploration of existing research, this study investigates barriers to the adoption of Autonomous Public Transport (APT), primarily related to safety and trust. Literature suggests that social robots could help promote APT by supplying control, data, and safety. Despite these potential benefits, issues such as robot vandalism and vehicle responsiveness remain unresolved. Social robots offer some solutions to concerns, but concerns related to technology maturity and ride quality problems in APT via Social Robots are yet to be addressed. To further explore the role of social robots in APT acceptance, we installed a Furhat Social Robot in one of the shuttle buses that were part of the on-ground Autonomous Bus Trial in Sweden[1]. We are currently in the process of collecting both qualitative and quantitative data from real-life passengers who interacted with this robot during the autonomous bus ride.

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Evaluation of Pedestrian Crossing Accidents Using Artificial Neural Network

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Abstract. Most of European cities face increasing problems caused by excessive traffic of conventional fuel-based transport modes. To reverse this situation, sustainable urban mobility policies have been promoting soft modes of transport, such as walking. Despite the advantages of walking in reducing traffic congestion and pollution, cities have not always evolved to accommodate the needs of pedestrians. According to the European Commission, in 2020, 20% of road fatalities in the European Union (EU) and 21% in Portugal were pedestrian. Pedestrian fatality rates per million population was 9.7 for all EU countries and 13.1 for Portugal. In European and Portuguese urban areas, 36% and 27% of the fatalities were pedestrians' and 49% and 56% of all pedestrian fatalities were elderly's (respectively). In pedestrian infrastructures, crossings are considered the most critical element due to conflicts between vehicles and pedestrians. It is then essential to identify and minimize risk factors that increase the probability of accidents in these locations. The proposed work intends to assess this challenge by using Artificial Neural Network (ANN) to create pedestrian severity prediction models and identify road and pedestrian risk factors for accident occurred in or near urban crossings. The official Portuguese database on run over pedestrian accidents occurred between 2017–2021 was analyzed with ANN considering two scenarios: pre-Covid-19 and during Covid-19 period. Results obtained demonstrate that the use of ANN can promote a proactive infrastructure management, suggesting that crossings traffic lights operation, lighting, shoulders and pavement conditions, high speed limits (51–90 km/h) and pedestrians moving in soft modes are critical factors.

Keywords: Road Safety · Pedestrian Accidents at Urban Crossings · Artificial Neural Network (ANN) · Severity Predictive Model · Risk Factors

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1 Introduction

1.1 Framework and Objectives

Despite the advantages of walking to reduce traffic congestion and pollution, cities have not always evolved to accommodate the needs of pedestrians and walking has, in many cases, been neglected in the development of transport systems [1]. Due to their vulnerability, accidents involving pedestrians show higher severity when compared with other kinds of accidents, with a significant rate of morbidity, disability, and death. Estimates suggest that approximately 12 million road accidents involving pedestrians occur every year worldwide and cause the deaths of about 270000 people (around 23% of all traffic fatalities) [2]. Between 2010 and 2020, the absolute number of pedestrian fatalities fell 39% in the EU27 and 69% in Portugal. The number of road fatalities in the same period decreased 32% in the EU27 and 43% in Portugal [3–5]. Therefore, the proportion of pedestrians in the number of road fatalities decreased in the last decade 11% in the EU27 and 9% in Portugal. In 2020, 20% of all traffic fatalities were pedestrian and pedestrian fatality rate per million population was 9.7 in the EU. For Portugal, these numbers were 21% and 13.1, respectively [6, 7]. For the same year, inside EU and Portuguese urban areas, 36% and 27% of the fatalities were pedestrians' and 49% and 56% of all pedestrian fatalities were elderly's (>65 years) (respectively) [5, 6]. Therefore, an understanding of the risk factors affecting pedestrians' safety is essential to define effective measures to protect pedestrians. Quantitative safety assessment is generally preformed through Accident Prediction Models (APM). Several Pedestrian APM have been applied to roads sections [2, 8], intersections [9–15] and crossings [14, 15]. In view of the above, this study aims to produce pedestrian severity prediction models and identify road and pedestrian risk factors for accident occurred in or near urban crossings using Artificial Neural Network. The pre-Covid19 and Covid19 periods are considered separately to assess whether the restrictions imposed on the movement of vehicles and people, during the pandemic, modified the risk factors, number and severity of pedestrian crossing accidents. The methodology was applied to the 2017–2021 ANSR (Portuguese National Road Safety Authority) database.

1.2 Pedestrian Accidents

Recently two scientific papers were published with an extensive bibliometric review about pedestrian safety studies [16, 17]. In one of the studies, Mirhashemi et al. (2022) [16] identified 7 clusters for highly cited papers about pedestrian safety: pedestrian accident frequency models, pedestrian injury severity models, traffic engineering measures in pedestrians' safety, global reports around pedestrian accident epidemiology, effect of age and gender on pedestrians' behavior, pedestrian crowd dynamics and evacuation and distraction of pedestrians. When choosing the best modeling approach, the following issues were considered: over-dispersion, under-dispersion, time-varying explanatory variables, temporal and spatial correlation, low sample-mean and small sample size, injury-severity and crash-type correlation, under-reporting, omitted-variables bias, endogenous variables, functional form, and fixed parameters. In the second study, Shrinivas et al. (2023) [17] performed a systematic analysis of 93 articles about the impact of variables on the

severity of pedestrian injuries. They examined a total of 904655 pedestrian incidents from 19 different countries and categorized risk factors in 7 areas: pedestrian features (age, gender and race), driver's features (age and gender), vehicle features (vehicle type and speed), road and environmental features (weather, road type, traffic control devices and lighting condition), accident features (collision type and pre-crash movements), built environment (network connectivity, accessibility, and land use), and spatial and temporal patterns. In total, 204 factors were examined. When modelling, the authors suggest considering 15 variables: road environment (urban/rural), driver gender, driver intoxicated, hit and run, land use, lighting, maneuver, number of lanes, pedestrian age, pedestrian behavior, pedestrian gender, pedestrian intoxicated, road geometry, road type, and speed limits. Concerning methodologies, recent studies have used Multiple Correspondence Analysis (MCA), random parameter logit and probit models, and Machine Learning (ML) techniques such as Artificial Neural Network (ANN), Support Vector Machine (SVM), Boosting algorithms or Bayesian models [16].

1.3 Machine Learning Applied to Accident Data

Accident analysis is complex due to the presence of human behavior, which is difficult to predict and model due to the high subjective variations in people's decision making. Traditionally, statistical modeling techniques have been used to predict accidents and classify their severity: Poisson regression, binomial regression, negative binomial regression, Poisson-lognormal regression, gamma regression, zero-inflated regression, generalized estimation equations, negative multinomial model, random effects model and random parameters model. However, the limitations of these approaches have been widely explored, offering an opportunity to use new approaches, such as ML techniques [18]. ML can be divided into supervised, unsupervised, and semi-supervised learning. In supervised learning, the response values of the cases in the training set are known and the model response to the current pattern of inputs is evaluated, allowing changes that bring the model response closer to the expected (known) response. Data accident can be considered in this category.

Theoretically, given a set of input data (x_i, y_i), where x is the vector of the variables that represent the predictive attributes and y is the label of the class that the case belongs to, the model's task is to learn a target function f that maps each set of attribute x in one of the predefined y classes or label (attribute that describes a characteristic of the phenomenon of interest, in this case, pedestrian injury severity). As in pedestrian injury severity analysis the class is discrete, it is a classification problem. Despite the use of ML techniques in a variety of road safety problems, examples of its application to pedestrian accidents are still limited. Some examples include bayesian model [9], association rules mining [13], gradient boosting [2] and ANN [10–12, 19].

2 Method

2.1 Accident Data

The pedestrian accident data analyzed in this study was provided by the Portuguese National Authority of Road Safety (ANSR). The information concerns 24774 pedestrians involved in 24211 accidents with victims (fatal, serious, and minor victims) that occurred

in mainland Portugal and the Azores and Madeira islands, between 2017 and 2021 (5 years). The data was split in two datasets to evaluate the effect of the Covid19 pandemic on number, severity and risk factors associated with this type of accidents.

2.2 Variables and Descriptive Statistics

The data preparation process for descriptive analysis and subsequent modeling included the following main steps: selection of run over pedestrian accidents; data organized by pedestrian involved in accident (one line by pedestrian); selection of accidents in urban environment and urban streets coded as 'pedestrian hit' ('run over and run away' and 'animal hit' accidents were eliminated); selection of relevant pedestrian actions: 'crossing a marked crossing', 'crossing a marked crossing without respecting traffic lights' and 'crossing outside a pedestrian crossing, at less than 50 m from a crossing'; definition of two injury severity groups: unharmed+minor and serious+fatal; based on the local speed limits, definition of speed classes: 0–30, 31–50 and 51–90 km/h; database division in two datasets: Pre-Covid19 (from 1/January/2017 to 17/March/2020) and Covid19 (from 18/march/2020 (first confinement) to 31/December/2021); consideration of 3 hourly time periods: morning and afternoon peak periods (8–10 h and 17–19 h) and intermediate period (between peaks, i.e., 11–16 h). Other variable data classes were created based on the distribution of data along the days of the week and months of the year, according to weather condition, pavement grip condition, vertical design, circulation direction, type of intersection, vertical signs, local speed and pedestrian age.

The evaluation of the variables' percentages revealed that in general, there were no significant changes between the Pre-Covid19 and Covid19 periods (less than $\pm$ 2%). However, an increase of 1.3% in the number of pedestrians with serious and fatal injuries was verified. For the independent variables, the most significant variations were the number of pedestrians involved in accidents occurred between 11am and 4pm (+2.9%), during the daytime (+6.4%), with a similar decrease at nighttime with lighting (−6.9%), clear weather conditions (+4.6%) and rain (−4.5%). There was also an increase in pedestrians involved in accidents occurred in wet or humid pavement (+5.1%) and a decrease for pavements in good condition (-4.8%). The monthly variation was not analyzed due to the different datasets time span.

To produce the predictive models for pedestrian severity and evaluate the importance of the predictive variables, the Multilayer Perceptron (MLP) procedure available in the Neural Network option of IBM SPSS Statistics 28.0.0.0 is used. The aim is to produce 3 prediction models for each dataset (Pre-Covid19 and Covid19): a complete model with all the considered predictive variables, a model for 'road characteristics' variables and a model for 'pedestrian' variables. In the modelling process, 70% of the dataset is used for training and 30% for testing, and the automatic architecture option is selected to build a network with one hidden layer. To minimize the total error, the Batch type of training with Scaled conjugate gradient optimization algorithm (to estimate the synaptic weights) is considered. The default SPSS training options are adopted. Tables 1 and 2 present the main outputs of the Pre-Covid19 and Covid 19 models. Several analyses were conducted with all the independent variable classes and using only the variables selected as aggravate/contributing condition for pedestrian accident occurrence. The two approaches revealed similar results, so only the models generated

Table 1. Pre-Covid19 models

Model	Complete	Road characteristics	Pedestrian
Training % incorrect predictions % correct classification	7.2% 92.7%*	7.3% 92.7%*	7.1% 92.9%*
Testing % incorrect predictions % correct classification	7.3% 92.7%*	7.1% 92.9%*	7.4% 92.6%*
ROC Area under the curve	0.668 for class 1 0.668 for class 2	0.567 for class 1 0.567 for class 2	0.647 for class 1 0.647 for class 2
Top 10 Independent variable importance	LSp: 51–90 km/h PT: Cement LS: Off T: Moving on skate, scooter or others PC: Poor S: Unpaved shoulder PT: Stone L: Night, no lighting VS: Giving way LSp: 31–50 km/h	LSp: 51–90 km/h VS: Stop PT: Stone PT: Cement S: Unpaved shoulder LSp: 31–50 km/h HS: With marks separating direction/lanes of traffic LSp: 0–30 km/h LS: Intermittent PC: Poor	A: > 65 years old T: Pushing a bicycle, Stroller or people with Physical disabilities A: 50–64 years old T: Pedestrian in group T: Moving on skate, scooter or others PA: Crossing a marked crossing without respecting traffic lights A: 0–9 years old A: 10–17 years old T: Isolated pedestrian PA: Crossing outside a pedestrian crossing, at less than 50m from a crossing

Number of cases = 9568 (92.8% Unharmed+Minor, 7.2% Serious+Fatal)
Dependent variable: Injury severity (class 1 = Unharmed+Minor, class 2 = Serious+Fatal)
Independent variables: Temporal (Hour H, Day of the week DW, Month M), Road environment (Luminosity L, Weather W), Road characteristics (Horizontal design HD, Vertical design VD, Shoulder S, Circulation direction CD, Intersection I, Vertical signs VS, Horizontal signs HS, Light signs LS, Pavement type PT, Pavement grip PG, Pavement condition PC, Local speed LSp), Pedestrian (Age A, Sex, Type T, Pedestrian action PA)
*All cases of the dependent variable classified in class 1

Table 2. Covid19 models

Model	Complete	Road characteristics	Pedestrian
Training % incorrect predictions % correct classification	8.6% 91.4%*	7.8% 92.2%*	8.5% 91.5%*
Testing % incorrect predictions % correct classification	8.2% 91.8%*	9.9% 90.1%*	8.4% 91.6%*
ROC Area under the curve	0.630 for class 1 0.630 for class 2	0.604 for class 1 0.604 for class 2	0.626 for class 1 0.626 for class 2
Top 10 Independent variable importance	T: Moving on skate, scooter or others VS: Stop LS: Off LSp: 51–90 km/h L: Blinding sun S: Unpaved shoulder PT: Cement PC: Poor L: Night, no lighting LS: Intermittent	PC: Poor LSp: 0–30 km/h I: Roundabout LSp: 51–90 km/h PT: Stone PT: Asphalt LS: Intermittent I: 4-leg intersection S: Unpaved shoulder VS: Stop	T: Pushing a bicycle, stroller or people with physical disabilities A: 18–24 years old PA: Crossing a marked crossing without respecting traffic lights T: Pedestrian in group T: Moving on skate, scooter or others PA: Crossing a marked crossing A: 10–17 years old A: 25–49 years old T: Isolated pedestrian A: 0–9 years old

Number of cases = 3310 (91.5% Unharmed+Minor, 8.5% Serious+Fatal)
Dependent variable: Injury severity (class 1 = Unharmed+Minor, class 2 = Serious+Fatal)
Independent variables: Temporal (Hour H, Day of the week DW, Month M), Road environment (Luminosity L, Weather W), Road characteristics (Horizontal design HD, Vertical design VD, Shoulder S, Circulation direction CD, Intersection I, Vertical signs VS, Horizontal signs HS, Light signs LS, Pavement type PT, Pavement grip PG, Pavement condition PC, Local speed LSp), Pedestrian (Age A, Sex, Type T, Pedestrian action PA)
*All cases of the dependent variable classified in class 1

with all variables classes are presented and analyzed. Although the percent of incorrect predictions obtained for the training and testing phases is acceptable (7.1% to 9.9%), the classification results show that all cases are classified in class 1 (unharmed or minor injured pedestrians). To evaluate the adequacy of the modeling process options, several analyzes were carried out considering SPSS available options, however, similar results were obtained. The model outcomes can be justified by the significant imbalance between

the dependent variable classes and possibly because accidents involving seriously injured and fatal victims do not present significantly different characteristics from accidents involving unharmed and minor injured. To confirm the previous statement and evaluate the discriminant power of the models, ROC curves were produced for each dependent variable category. All curves presented an area under the curve between 0.5 and 0.7, indicating a weak discrimination ability [20].

Concerning the risk factors, 7 of the variables identified in the 'Top10 independent variable importance' of the two complete models were the same: LSp: 51–90 km/h, L: Night, no lighting, LS: Off, S: Unpaved shoulder, PT: Cement, PC: Poor and T: Moving on skate, scooter, or others. For the road characteristics models, 7 of the most important variables were also the same (3 identified in the complete models): LSp: 0–30 km/h, LSp: 51–90 km/h, S: Unpaved shoulder, PT: Stone, PC: Poor, VS: Stop and LS: Intermittent. A similar situation occurs with pedestrian models, with the 7 common variables: A: 0–9 years old, A: 10–17 years old, T: Isolated pedestrian, T: Pedestrian in group, T: Moving on skate, scooter or others, T: Pushing a bicycle, stroller or people with physical disabilities and PA: Crossing a marked crossing without respecting traffic lights. For the pedestrian models, it appears that the age classes 50–65 and > 65 years old, identified in the pre-Covid19 period, are replaced by the young and middle age classes (18–24 and 25–49 years old) in the Covid19 period, highlighting the increased care with seniors in the pandemic period. From the results analysis it is possible to suggest interventions aimed at improving the lighting conditions and traffic lights operation in urban pedestrian crossings, an adequate maintenance of shoulders and pavements, especial attention to urban areas with higher speed limits (51–90 km/h) and raising awareness among pedestrians moving in soft modes or pushing strollers or people with physical disabilities.

3 Conclusions

As main conclusions, it is possible to highlight that, although the prediction models produced for pedestrian injury severity present a high percentage of correct classifications, the evidence that pedestrian injuries are essentially minor (around 92%) and possible little differentiation between factors contributing to 'serious injuries+fatalities' and 'unharmed+minor injuries', may justify the weak discriminating power of the models. Regarding the risk factors, the results obtained revealed a certain consistency between models, suggesting that the main interventions aimed at reducing pedestrian casualties should focus on improving pedestrian crossings traffic lights operation, lighting, shoulders and pavement conditions. Special attention should also be paid to urban areas with higher speed limits (51–90 km/h) and in raising awareness among pedestrians moving in soft modes or pushing strollers or wheelchairs. Regarding the comparison between the pre-Covid19 and Covid19 scenarios, a significant decrease was verified in the annual number of accidents (around 30–35%) and differences were found for some pedestrian age classes. The importance of classes 18–24 and 25–49 years old increased in the Covid19 period contrasting to the previous importance of 50–64 and >65 years old in the pre-Covid 19 period. Future developments include evaluating other software and machine learning algorithms to identify those that can better accommodate categorical variables and less balanced distributions of the dependent variable classes.

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A Serious Game as a Tool for User-Centered Design of Mobility Solutions

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Abstract. Before the implementation of new mobility solutions, it is often difficult to encourage and enable potential users to participate in the design process, to predict acceptance, and to determine the influence of individual design parameters on use intentions. A serious game involving repeated mobility choices and, at the same time, fun to play might be a useful tool to allow for user studies and participation in this situation. We developed a concept of such a game in the context of intermodal transport. A first prototype was implemented and subjected to an early test with respect to user experience and usability through an evaluation with seven experts. At the current state of development, flow experience, measured by the flow short scale (FKS), was medium. Usability, measured by the system usability scale (SUS), was low, and the heuristic evaluation yielded many hints for improvement. Based on the insights gained, the development of the game will be continued to prepare it for a user test assessing the potential of the method for studying user preferences in the transport system.

Keyword: user design methods · intermodal networks · early prototyping

1 The Challenge of User Participation in Early Design Phases

1.1 Motivation

Before the introduction of new mobility solutions, it is often difficult to enable potential users to participate in the design process, to predict their overall acceptance of the to-be-developed solutions, and to determine the influence of individual design parameters on use intentions. This difficulty arises from the multitude of design options and potential interactions of design, user and context characteristics, while, at the same time, it is difficult to convey a vivid idea of how it feels to use the mobility solution, or another product or service, respectively. Moreover, it is often a challenge to encourage users to participate early in the design process.

Within the framework of the DLR project “Connected Mobility for Livable Places”, we aim to develop a new method for exploring user preferences in mobility and involving users more actively in early phases of the design of mobility solutions. The practical

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problem we address is the attractiveness of intermodal transport links to users. Given the EU's defined climate targets, particularly the goal of carbon neutrality by 2030 [1], there is an imperative need for sustainable changes in mobility. One approach to reduce emissions in the traffic sector is to shift traffic volume from motorised private transport to non-motorised transport modes and public transport. In order to continue to meet people's mobility needs in the process, it is necessary to understand users' pain points and requirements with regard to the intermodal transport. Furthermore, it would be useful to have a virtual laboratory by which the effects of changes in the transport system on user acceptance can be studied without having to implement them in the real world. A serious game appears to be a promising approach for these purposes.

1.2 Serious Games as a Research Tool

It is challenging to establish a consistent definition of the term *serious game* because serious games are applied with various objectives and heterogeneous approaches across multiple disciplines [2]. According to Michael and Chen [3], serious games can, in general, be described as "games for purposes other than entertainment". Among other things, they offer a motivating environment to present and teach specific skills and knowledge. They are used, for example, in the areas of healthcare, public policy, strategic communication, defence, training and education, stealth assessment, and citizen science [4].

The features of serious games that are of interest in the context of our research are as follows: (1) serious games offer the possibility to depict a complex world with its relevant elements and effective relations, (2) they allow users to interact with this world and experience the consequences of this interaction, (3) features of elements and relations in the game world, such as design features of mobility options and context variables, can be changed systematically and with relatively little effort, (4) this allows for experimentation in context and the analysis of how user preferences and behaviour change depending on the design of the world, and (5) users have an intrinsic motivation to engage in the interaction. This combination makes serious games an interesting alternative to traditional methods of user research as, for example, interviews, surveys, or classic choice experiments, which are usually only moderately fun to the participants. Often, additional external incentives are required to encourage participation. The acceptable duration of assessment and thus the amount of data that can be assessed are limited. Moreover, it is often difficult to give the users a vivid understanding of mobility variants that are not available in reality so far.

In order to make the choices that users make in a serious game a valid reflection of real decisions, it is important that the relevant incentive structures of the real world are reflected in the game. For example, research has already shown that the travel duration and the price associated with a given mobility option are important features for user decisions [5]. Therefore, as in reality, a subjective cost needs to be associated to these features of a mobility option in the game, too. This can be achieved, for example, by assigning a duration to the act of traveling in the game that is proportionate to the time that would be needed in reality, and by introducing a currency to the game that can be used to acquire equipment useful to the character and that also needs to be spent for mobility. For the methodological development of our game, we have two consecutive

goals. At first, we want to create a game world that replicates the incentive structure of the current mobility system as realistically as possible. If this is successful, the game can be used to study the effects of any constellation of design and context variables that is of interest.

2 Conceptual Design of the Game

2.1 Methodological Framework

The game is intended to be both a research tool to understand the rules governing user acceptance of mobility offers, and a design tool to study user acceptance towards new design options. The methodological framework is a choice experiment [6]. This method allows to determine the relative importance of design parameters and other variables for user choices and can also be used to investigate "what-if" questions related to the design of new products and services, such as the design of intermodal transportation links. Our approach considers all three major sources of variance in acceptance: system design, context, and user characteristics. Variables of system design and context will be purposefully varied in the game. The dependent variable is the user's resulting mobility choice. User characteristics with potential relevance for mobility behavior will be assessed as control variables.

2.2 Game Concept

In the game, players have to repeatedly choose one of several mobility options to reach their destination in order to realize their missions. Players assume the role of an up-and-coming influencer, striving to amass as many followers as possible. To achieve this, they travel to different locations in order to capture photos adorned with trending hashtags. The game starts in the influencer's home. Upon waking up, the player is prompted with currently trending hashtags (such as #Pumpkin), current weather conditions, a promising destination, and the required luggage. Considering the circumstances, as well as the cost and duration, the player chooses from a variety of transportation options. After stepping into the outside world, the player is presented with an animated sequence featuring the selected mode of transportation and environmental conditions. The animation's duration corresponds to the chosen mode of transportation, for instance, cycling takes longer than driving a car. Upon arriving at the destination (e.g., a cafe), the player's task is to take a photo, with the aim of including as many hashtags as possible in the photo, as this attracts more followers. The photo mode is creative, allowing the player to adjust focal length, aperture, and filters. After taking a photo, the player can "post" it on a virtual social media platform. Transitioning back to the apartment through the transportation animation, the player is presented with a reward screen displaying the increase in followers and virtual currency, essential for affording various modes of transportation. Finally, the player heads to bed, before a new day with photo challenges starts. See Fig. 1 for some impressions from the game.

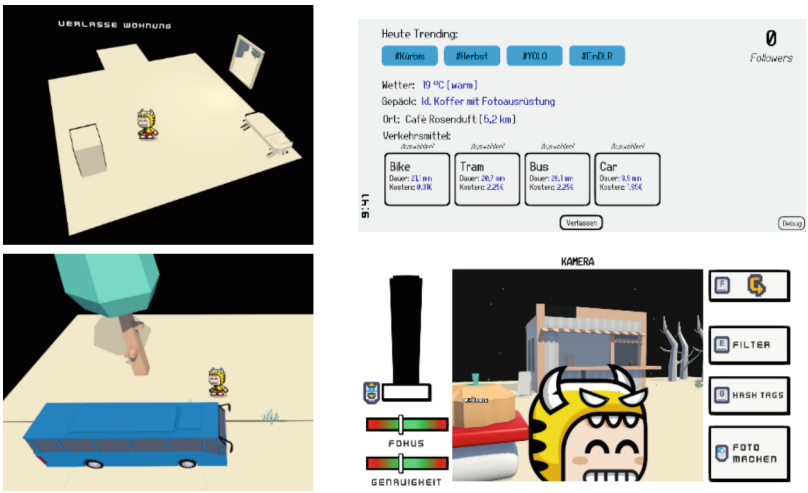

Fig. 1. Screenshots from the game prototype. Top left: About to leave the house. Top right: Learning about currently trending hashtags, the context of travel (weather, luggage, destination, distance), and the available mobility options. Bottom left: On my way! Bottom right: Taking the selfie at the trending location and with the trending objects. Copyright 2024 by DLR.

2.3 Study Design

The possibilities for varying service and context characteristics of the travel in the game are considerable: From potentially relevant variables and their conceivable levels, thousands of combinations are possible. For development, the following independent variables were chosen: weather, with temperature (–1°, 8°, 19°, 31°) and precipitation (yes vs. no), luggage (none, backpack, photo suitcase, both), travel distance in km (0.8, 2.1, 5.2, 12, 19) means of transportation (foot, bike, pedelec, e-scooter, bus and tram, car, train), travel duration, and price. For the latter two, three levels (low, medium, high) are implemented whose exact values will vary depending on the travel distance and the means of transportation. The medium values for these combinations have been researched to reflect realistic values in the current transportation system in Germany; the low and high values are derived from the medium ones by subtracting or adding 10%. User characteristics (e.g. age, gender, mobility habits) will be assessed as additional variables to include in the analyses.

3 Implementation of the First Prototype

We develop the prototype using the Unity game engine. To reach a high number of potential participants, we chose the web browser as our target platform, in order for the prototype to run independently of the operating system (e.g., Windows, iOS, Android, or Linux). This way, participants do not need to install the prototype on their system to use it. We host the game on a DLR website to ensure data protection and make sure that everyone is playing the same version after updates. This allows us to change conditions during an evaluation, for example. Each participant receives a random identifier and

after each play session, a list of all decisions and conditions together with the identifier are sent to a database.

4 First Prototype Evaluation: User Experience and Usability

A first evaluation of the prototype was done with respect to user experience and usability with experts from DLR. Participants were instructed to play three rounds of the game, provided via a web link. After that, they answered the flow short scale (FKS) [7] and the system usability scale (SUS) [8] with regard to their experience in playing the game. After the experience sampling, participants were asked to do a heuristic evaluation concerning the usability of the prototype [9]. They were instructed to click through the game again and consciously look out for elements, features or design decisions that violate one of the 10 usability heuristics that were listed and briefly explained on the same page. Participants were asked to note their observed problems and make recommendations on how to fix them. Finally, they were asked to go through all the problems again and provide a rating for each one, from *0 = I don't think this is a problem at all* to *4 = Usability disaster: must be fixed before the product can be released.*

5 Results

Seven experts took part in the evaluation. All worked at DLR. Their age ranged from 24 to 46 years ($M = 33.0$, $SD = 8.3$), four were women, three men. Their fields of expertise comprised human factors, usability and user experience ($n = 6$), or development of interactive applications ($n = 2$). Three are part of the author team.

Overall *flow* experience, as measured by the FKS seven-point scales, was mediocre ($M = 3.8$, $SD = 0.6$), mirroring nearly equal scores on the two flow subscales s*mooth automated progression* ($M = 3.8$, $SD = 1.0$) and *absorbedness* ($M = 3.9$, $SD = 0.8$). *Concern* was very low ($M = 1.5$, $SD = 0.5$). Participants' ratings on the FKS nine-point scales concerning subjective difficulty of playing the game ($M = 2.6$, $SD = 1.5$) and task demand ($M = 2.6$, $SD = 1.5$) ranged from low to medium. Self-assessed ability in playing computer games was very heterogenous in the expert sample, however with a majority of values in the lower part of the scale ($M = 3.7$, $SD = 2.1$).

SUS scores for overall usability of the game prototype ranged between 30 and 45 ($M = 38.7$, $SD = 4.9$). This result needs to be interpreted as representing poor perceived usability of the prototype so far [10].

The results of the heuristic evaluation can only be presented in overview. Not all participants provided severity ratings; therefore, results are ordered here by the number of individual mentions of problems. These can touch the same problem, that was reported by multiple participants. Most individual mentions related to a lack of clarity about the tasks and the options and interaction possibilities in the game, and a lack of exits from different situations. A medium number of comments related to the situation that, so far, nothing prevented the character from falling into nothingness when they reached the outer rim of the game environment, and that apart from the tutorial, there was no help information available so far. A number of mentions referred to non-consistent availability of information on how to interact with the game, poor legibility of the font

used, inconsistent use of languages, and so far non-existent error messages and solution options offered by the system in case of errors. Individual comments referred to the inputs used to control the game, the possibility to provide more keyboard shortcuts, and the complexity of the map used to visualize the route options in the game.

6 Discussion and Outlook

We developed a concept for a serious game to assess user preferences in mobility. A first prototype of the game was implemented and tested through an expert evaluation.

The results show a lot of possibilities for improvement. This is not surprising at the current state of development, since the prototype was tested once it had first reached a playable status. The early evaluation is part of the planned development process. The results give the development team valuable insights on how to optimise the game in terms of user experience and usability, in order to maximise its potential as a research tool. The next steps will be another usability and user experience test conducted with users, in which also the functions for data assessment will be consolidated. After that, the game will be rolled out to test the potential of the method for studying user preferences in the transport system.

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A Comprehensive Literature Review on Road Traffic Prediction Methods

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Abstract. This paper presents a state-of-the-art review of prediction models used to anticipate road traffic congestion. We present, on one hand, a classification and comparison of those models and, on the other hand, the results of our experimental tests. We provide a comprehensive list of prediction models such as Statistical models, Deep learning and hybrid models, Ensemble models, models based on big data, shallow learning models, naive methods, and traditional machine learning models like Support Vector Regression and Artificial Neural Networks (ANN). In addition to that, our paper also outlines various problems faced by road traffic users in congestion and the associated models designed to mitigate these issues. Experiments were performed to help users choose the appropriate algorithm, focusing on models such as Artificial Neural Networks (ANN), K-Nearest Neighbors (KNN), classification algorithms, as well as linear and nonlinear regression models.

Keywords: urban traffic congestion · urban traffic prediction · road traffic engineering · road traffic management · road traffic planning · deep learning model performance

1 Introduction

Road traffic congestion has been an issue in Burkina Faso for nearly 10 years. This phenomenon has lot of consequences on human beings such as health issues, economic issues etc. In this paper we address the problem of road traffic congestion through an exclusive algorithmic perspective. Our paper is organized as follow: in the second section of the paper, we present the related works; in the next one we present our methodology, and in the fourth section we present a comparative analysis of prediction models, types of problems, data types and data sources. In the fifth part of this paper we present our results and in the last one we present a discussion followed by our work's limitations.

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2 Related Works

For the prediction of road congestion, lot of models are used [1]. We can categorize them in 7 groups as follow: the first group of models is composed of Deep Learning (DL) as Gate Recurrent Unit (GRU), LSTM and hybrid models as Bidirectional-Graph Recurrent Convolutional Network (Bi-GRCN), LSTM-ATT [2]; second group of models is about Ensemble Learning as ADA, Random Forest (RF); in the third group of models we can find shallow learning as KNN, SVR; the fourth category discusses traditional automatic learning models as ANN, SVM; the fifth group of models is composed of Naive methods as Last Value (LV); the sixth group of models is about Statistical methods as Kalman Filters, ARIMA [3]; in the seventh and last group of models we can find big data model as MapReduce and Apache flume. Among those models the most used at the moment we write this paper, are the DL models.

3 Methodology

We searched online literature reviews, survey and state of the art papers on platforms and libraries such as Scopus, Web of Science (WoS), Google Scholar, Alabama university, Carnegie Mellon university. The keywords and their equivalents used for the research are expressions like survey road traffic congestion, review traffic congestion manage, state of the art road congestion prediction etc. From nearly 200 papers scanned, we selected those dating between 2019 and 2023 in order to output a study based on the most recent road traffic congestion prediction models; we ended up with 60 significative relevant papers for our study. We then identified the shortcomings limits of each model. In this work we were seeking to find through the literature the model which seems to be the most efficient in the short-term of road traffic congestion prediction. According to the above it appears that knowledge graphs allows the integration of external factors. So we ended up finding that unifying three models such as the BiGRCN [6] model, those using knowledge graphs [5] and those using the mechanism of attention (ATT) [2] will consist in a novel insight and will give out a performing road traffic congestion prediction hybrid model. We believe, according to our knowledge that this unification was never done before. In the next section, we compare analysis of prediction models.

4 Road Traffic Prediction Models, Types of Problems, Data Types and Data Sources

4.1 Models Comparison

This section presents a comparison of prediction models according 8 criteria of analysis that are minor performance degradation, modeling of external factors on the prediction, process sequential data, etc. as presented in Table 1. We arrived at the selection of criteria by retaining from each reading those which are of

interest such as learning from less data. The compared models are the following: statistics models, Deep Learning and hybrid models, ensemble models, etc.

We discuss various models used for road traffic prediction [1]. Among statistical methods, we have ARIMA variant, SARIMA that is used as model for short-term traffic flow prediction [3]. The authors examined how traffic flow periodicity fit a statistical processing model for real-time data. However, they noted that these models have limitations in predicting short-term traffic flow due to data non-linearity and uncertainty. Big data models such as map reduce, on the other hand, process data in batches, and are therefore unsuitable for real-time interactive data analysis [7]. So, the machine learning methods like ANN, and Dynamic Bayesian Networks (DBN) or Bi-GRCN as hybrid models are used the most. In Table 1, we propose a global analysis of the models presented above.

The next section present models according to road traffic problematic, also according to the data types and data sources.

Table 1. Models' comparison with 8 criteria

Categorization of prediction models	Comparison characteristics	Minor performance degradation [8]	Best result for low prediction horizon values[9]	Ability to learn quickly with limited data [10]	Spatial dependence modeling [11]	Temporal Dependency Modeling [12]	Prediction type [6]	Process sequential data [9]	Modeling of external factors on the prediction [13]
(1) Deep Learning and hybrid models	Bi-GRCN	–	–	–	yes	yes	traffic flow	–	no
	ANN	–	–	–		yes	–	no	–
(2) Ensemble Learning	ADA	–	–	–	–	–	traffic flow	–	–
(3) Shallow learning	LR	yes	-	yes	–	–	–	–	–
(4) Traditional automatic learning	SVM	–	–	–	yes	yes	–	–	–
(5) Naive	LV	–	yes	no	–	–	–	–	–
(6) Statistical methods	ARIMA	–	–	–	yes	yes	time series	–	–
(7) Big data models	MapReduce	–	–	–	yes	yes	–	–	–

4.2 Models Classification According the Types of Problems They Address and the Data Types Used in Their Settings

In this section, we classify models according to the issues they address as presented in Table 2. We observe for example that the Bayesian learning model address the traffic state estimation using down-sampled data. The ANN model is used for merging multi-sensor data for vehicles localization on the road network using a fusion of multi-sensor data. GCN was used to capture the spatial and temporal characteristics, derived from GPS information; the attention mechanism is added to the GCN to optimize the attention of different time series [14].

Now, we briefly present the data type used by the prediction models as presented in Table 3. Some of the data used in the model's settings come from the geolocalization services as online platform or dedicated organizations. Data are essential to train prediction models. Traffic speed data have been used to evaluate the KNN, GRU, Graph Convolutional Network (GCN), ATT, LSTM

and CNN models. Traffic flow data, travel time and traffic state data are used in GRU, GCN, ATT, LSTM and CNN methods. In addition, GPS trajectory data has been used in fog calculation model as well as in the Gradient Boosting Decision Tree - Deep Neural Network (GBDT-DNN) model [14], while vehicle position data in the fog calculation method can be used to determine the number of vehicles on a road network.

Table 2. models according to problem types

Model	Type of problem
Bayesian learning	traffic state estimation with under sampled data
fog computing	A low-cost automobile traffic monitoring system, providing insight into the speed variation in the center of the city at different dates and times
GCN	capture spatial and temporal features, derived from GPS information
gradient boosting decision tree GBDT, DNN	travel time estimation with GPS trajectory data
support degree algorithm, credibility algorithm	overcome conflicts between multi-sensor traffic data and single-sensor traffic data uncertainties

Table 3. models according to data types

Prediction model	Data type
LSTM-CNN	Location Services Data
KNN	vehicle speed data from Bluetooth and Waze app
fog computing	calculation of fog GPS tracks and position of vehicles
GBDT-DNN	GPS track data
GRU, GCN, ATT, LSTM, CNN	traffic flow data, traffic speed data, travel time data, traffic state

4.3 Identification of Data Types According to Their Data Sources

In this section, we explore avenues for exploring potential data sources as presented in Table 4. Data acquisition is a real challenge for researchers interested in urban road traffic problems. Different data sources provide different traffic data. We have vehicles equipped with GPS and smartphones that allow the collection of types of data related to the trajectory of a vehicle and also related to its position; those collected are input to prediction models to capture the spatial dependencies, the detection of a vehicle. Such systems allow to count the number of vehicles on a section, to conjecture when traffic is lost, or to detect certain moving behavior on the road network, etc. Others uses video clips and images of

the road for the acquisition of data which are processed in order to have a better prediction of the road flow. Still others go through the use of probe vehicles to obtain their data or obtain it directly from existing databases on the internet such as KAGGLE. Data recorded by insurance companies on vehicle speed are also used [15].

Table 4. Data sources according to the collected data

Data type	Data source
vehicle trajectory	Vehicles equipped with GPS, Smartphones
Location	Cellular device of users, google map platform
detection of vehicles,	mobile devices (smartphones), Bluetooth Low Energy (BLE) beacons
detection of travel behavior	data from mobile phones
cell phone data, real-time bus location data, transit schedule data	geographic mapping software
vehicle speed variation	sensor placed near roads
traffic state data	free shared online data
Vehicle speed	the navigation applications like Waze, Google Maps, here, INRIX
traffic density data	road cameras

5 Experimentation and Results

We used anaconda, TensorFlow [16], and we did integrate libraries such as Jupiter, NumPy, and Sklearn and we used Visual Studio Code as IDE. We were interested in testing the ANN model, the K-Nearest Neighbor Algorithm, the Classification algorithms, linear and nonlinear regression. Our experiments were made in the first step with generated synthetic data and then in the second step with experiments on real datasets to see the effectiveness of taking into account external information on traffic speed prediction tasks.

The results shows that ANN model satisfies at 89%. We think that using collective dataset can reduce error rate in the prediction system.

6 Discussion and Conclusion

A careful study of road congestion makes it possible to understand that several factors influence road traffic. Thus, we looked for models that are both complex and robust to take into account several parameters, as is the case with the ANN model [1].

In this paper, our goal was to make a literature review and a comparison of the prediction models used to anticipate road traffic congestion. These models have been categorized into seven categories. We have proposed a presentation of the prediction models, the types of issues they address and the type of settings data they take as input, and we proposed an identification of traffic data

according to their source of acquisition. We have carried out experiments which have shown that Deep Learning models are suitable for predicting road traffic. In our future work we will combine Bi-GRCN, knowledge graphs and ATT to consider external factors in congestion forecasting.

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Optimized Motorway Infrastructure for Efficient Public Transport

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Abstract. On the high-level road network, traffic peaks and traffic volume-related congestion occur throughout Europe especially in urban and metropolitan areas. This is associated with time loss for vehicle occupants and an additional burden on the environment due to increased pollutant emissions. Therefore, motorway operators want to establish an ecologically and efficient transport system and search for alternative measures to use the existing road surface, rather than construct additional lanes as part of their capacity availability strategy. With minor adaptations of the existing infrastructure, an improved public transport accessibility with more attractive public transport travel times and an increase of the traffic performance in the environmental alliance could be achieved. To make more efficient use of the existing road surface and capacity, this study wants to quantify the potential of allowing rapid public buses to use the hard shoulder to bypass congestion. The rail infrastructure and the motorway network have interchanges throughout, but just a few direct transfer and mobility hubs. Therefore, this study aims to foster the linkage of the rail infrastructure and the urban and regional public transport network by investigating efficient interchanges on the motorway, which allow stops without detours and support short travel times.

Keywords: Rapid Public Bus Operation · Hard Shoulder · Multi - and Intermodality

1 Introduction

The European Commission's communication on the European Green Deal sets out the highly ambitious objective of achieving climate neutrality by 2050, for which transport emissions will need to be further reduced. Still mobility must be guaranteed, but simultaneously unnecessary mobility should be avoided, necessary mobility should be shifted towards sustainable alternatives and improvements in traffic management must be applied. Therefore, significant changes in the mobility system must be initiated to decrease the share of car trips and increase trips done via public transportation. Notably, the phenomenon of urban sprawl increased in recent years that resulted in an increase

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of the population living in the suburban regions but working in urban centers. This led to more private car trips and consequently even more congestion on urban motorways. A feasible solution to face this problem is to promote the use of public transport. On motorways this could be done by establishing additional bus priority lanes to reduce bus travel times. However, existing road infrastructure often does not enable road widening to provide additional dedicated bus lanes. Thus, traffic management measures focus on enhancing public transport and to use the already existing road infrastructure in a more optimal way without substantial new investments and construction works. In this regard, bus operations on hard road shoulders during traffic congestion hours could be advantageous, as described in [1].

Nevertheless, certain issues remain unsolved, such as special infrastructure solutions to serve bus stops at the motorway to guarantee fast travel and transfer times. In addition, allowing bus operation on paved shoulders requires a re-arrangement of the existing road cross-section design, with specific signing and road markings that should be supported by traffic regulations. Similarly, the impacts of changes on bus operation need to be examined, to provide a basis for future applications of similar traffic schemes. Also, the potential of rapid bus operations on motorways is unknown in Austria, but could be answered by field tests or adopting traffic demand models.

2 Literature Review

The term, hard shoulder bus priority measure refers to the general allocation of road space to buses on either periodic specified hours or permanent basis. Hard shoulders can be found already in quite a few countries such as: the UK (see [2]), the Netherlands (see [3, 4]), Germany (see [5, 6]), France (see [7]) an also Canada and in the US (see [8, 9]).

The allowance of public transport on hard shoulders affects traffic aspects, but also safety, economic and environmental aspects. Regarding traffic aspects [8, 10]. State, that using shoulders as additional travel lanes leads to an increase in roadway capacity, savings in travel time, and a positive influence on traffic flow. [11] highlights that the delay for the bus stays at a minimum and connecting lines can be reached in time. This circumstance boosts continuity of the public transport and therefore the overall level of service. In terms of safety aspects some countries found decreases in accidents associated with allowing traffic on shoulders (see [12]). Concerning economic aspects [13] outlined a reduction in the overall fuel consumption by about 4%. Therefore, also in terms of environmental aspects, the literature shows a decrease in the amount of pollution, and only a minor impact on the environment because of damage to the landscape, soils, water resources and biodiversity since no additional land for road space is needed. In general, there is a consensus that bus operation on hard shoulders is associated with shorter travel times for the bus and lower investment and exploitation costs for infrastructure operators compared to other forms of bus-dedicated (HOV) lanes.

3 Methodology

As outlined in the literature review it is necessary to build a bridge between the public transportation and the individual road system to establish a required, ecologically efficient overall transport system. Seamless mobility offers with a positive climate balance

cannot be borne by one mode of transport alone but must be based on a strong co-operation and interlinkage of public and individual transportation mode. As the motor- and expressway network in Austria is an existing and well-developed infrastructure, however the use of the motorway network as a public transport carrier is largely uncharted territory in Austria. Available capacity suggests the use of express buses along the motorway network to close existing gaps and to serve as a feeder for existing public transportation lines and hubs. Bus operations on hard shoulders can be implemented on motorway stretches when all infrastructural requirements are met and the importance of implementing the measure has been confirmed by the road authority together with the bus operator.

In this paper, the potential of inter- and multimodal hubs at motorway stops is investigated to improve the traffic quality on the high-ranking road and rail network. Within a planning and conception phase, it will be investigated which interactions between private and public transport are perceived to be able to reduce existing barriers, which arise particularly in rail transport due to the "first & last mile".

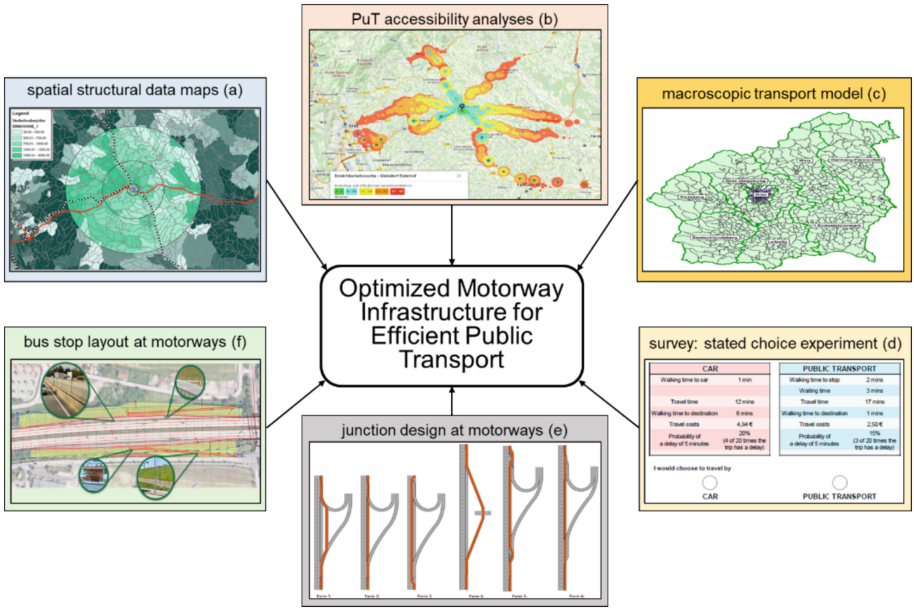

Fig. 1. Methodology overview (Source: ARCGIS, routeplaner.asfinag.at, ASFINAG, TU Graz)

Figure 1 summarizes the methodology. At first a regional location analysis based on spatial structural data maps (a) provides and evaluates suitable bus stop locations close to the motorway using predefined criteria for linking the high-level road network with the rail network and regional and urban bus transport. Based on these structural data maps also accessibility analyses of public transport (PT) are performed (b). A potential analysis of the traffic demand is carried out using a macroscopic, multimodal transport model for the agglomeration area of Graz, Austria (c). The modelling covers fares, parking

costs and availability, travel times for public and private transport as well as reliability of transport modes. As a result, the modal shift potential is obtained based on transport performance indicators, such as the number of journeys, congestion hours saved and transport performance saved (passenger-km), which can be converted into CO2 savings. To model the trip distribution and mode choice within the macroscopic traffic demand model, we conducted a survey with stated choice experiments (d). The survey includes a socio-demographic section and questions about the motives of the usual commuting behavior of participants. The reported home municipality, work/education address and car availability delivered the basis for a personalized stated choice part of the survey. The stated choice part of the survey provided data for the estimation of the utility functions for the macroscopic traffic model.

The subsequent conception phase will focus on the design of motorway intersections where bus stops are located and use cases of bus stops (e) leading to specific bus stop layouts at motorways (f). In the case that the stretch for bus operations on the hard shoulders passes multiple on- and off ramps, there are different forms to choose from, as described in [14]. With links to the rail infrastructure, as well as the urban and the regional public transport network, efficient hubs can be created directly on or in the direct vicinity of the motorway. This allows public transport stops to be reached without detours by express-bus lines. We classified four different Use Cases of public transport and multimodal stops at motorways (UC1-4) to guarantee short transfer points for passengers to use the newly installed rapid bus system using hard shoulders, see Fig. 2.

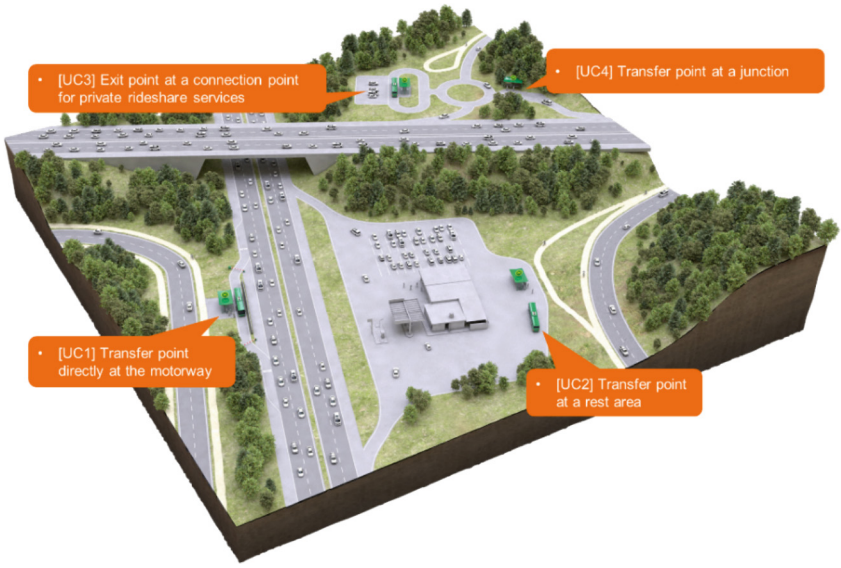

Fig. 2. Use Cases of public transport and multimodal stops at motorways (Source: ASFINAG)

4 Results and Discussion

The obvious advantage of implementing bus operations on the hard shoulder is the reduction of travel time delays for public buses. This allows stable timetables to be met and makes the connection more reliable and attractive for passengers and can lead to a desired modal shift from private car to public bus. Implementing this measure has still a few disadvantages. During operating times, the hard shoulder cannot be used for maintenance and service vehicles. Another disadvantage is that there are still some implementation costs as infrastructure changes must be made in terms of e.g., road markings or lane widening. Vehicles are also not allowed to use the hard shoulder to form the emergency corridor, which conflicts the general campaigns for the emergency corridor in Austria and can possibly cause confusion.

Nevertheless, results showed, that with minor adaptations of the existing infrastructure (e.g., by giving priority to express-busses on the motorway network, by building dedicated hubs), an improved accessibility and attractive travel times of the public transport can be achieved. However, the current legal framework in Austria and several European countries hinders the adoption of rapid busses on hard shoulders at motorways. Therefore, a central goal of the ongoing project is to analyze the current legal, technical, financial and organizational framework, define relevant use-cases and to obtain exceptions for pilot-testing operations. By offering attractive public transport services with comparable travel times and good service frequency the OEVAS project explicitly addresses today's users of individual motorized transport, to encourage them to change modes.

Making use of synergies that have emerged during the OEVAS project, the Austrian motorway operator ASFINAG, together with federal and public transport authorities, have identified a suitable location for a field test of rapid bus operation with a physical implementation of UC1 – Transfer point directly at the motorway. Based on the methodology described, this bus stop will be integrated into the service of bus lines operating in the region to improve travel times on relevant commuting relations. Accompanying the research conducted in OEVAS, the field tests will give practical insights in terms of necessary legal adaptions, the share of responsibilities as well as costs and planning processes, thus giving a comprehensive basis for further decision-making in multimodal transport policy. Moreover, the conducted stated choice experiment will generate additional knowledge about the perception of commuters on rapid bus operations on motorways and on the access (home end of a trip) and egress (activity end of a trip) stages of a transit trip, since the overall performance of a transit service greatly depends on its first-and-last-mile connections. The results of the survey will be transferred to the traffic demand model and will allow detailed successive potential analysis.

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Investigation of Vibration and Frequency Transmission to Riders from Electric Kick-Scooters on Various Urban Pavements

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Abstract. In the urban area, the sidewalk used for cycling and electrical kick-scooters is usually presented in the wide range from asphalt to brick pavements. The current research work is based on the establishing of the vertical vibration and frequency range transferred from driving e-scooters on different type of pavements to the rider. The most used type of the electrical kick-scooter in sharing application without wheels suspension and with pneumatic tire with recommended inflation pressure 3.4 bar (50 psi) is under research. The vibration analysis is performed by measuring the vibration level and performing an additional Fourier Transform spectrum analysis. Measurements were done using a t-sample measurement design and based on a one-sample statistical method for estimating uncertainty in repeated measurements of data processing. In the research, the mechanical impedance of the driver is taken into consideration, allowing for an estimation of the overall driver's comfort. The obtained results allow to define the critical risk of vertical vibration frequency transferred to the human during driving the electrical kick scooter in an urban area on the different pavements, which can help in re-thinking the road infrastructure development for micro-mobility.

Keywords: Micro-mobility · e-scooter · comfort · sensitivity · vibration · frequency

1 Introduction

Micro-mobility is currently a significant global trend in the city transport innovation, with introduction of electric kick scooters representing a major breakthrough. The personal and shared e-scooters are lightweight, inexpensive vehicles which can be personally used or rented for short distance trips, typically in dense urban areas (Fig. 1a). They offer a faster mode of transportation than walking and can potentially address issues such as pollution, traffic, and parking associated with motor vehicles. These attributes have made electric kick-scooters a viable solution for "first" and "last mile" (short distance – up to 3 km) transportation needs and, for some cases, even on longer distance (from 5 km) travel use [1]. Therefore, this new trend is bound to make a micro-mobility vehicle

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one of the main research directions for transport researchers, especially in sustainability and comfortable way of using. Research studies [2–4] dedicated to the evolution of electric scooter systems have identified several main key research directions. These include: Safety considerations – risk of use; Evaluation of energy and environment impact; Development issues pertaining to e-scooter systems.

Simultaneously, while conducting a review of the primary research directions concerning e-scooters, a new and more relevant area of investigation emerged – the pursuit of enhancing the comfort and usability of e-scooters. Assessing the level of comfort experienced during travel across different transportation modes leads to a wide range of findings, given that each mode is linked to distinct travel behaviours and driving/riding characteristics [5]. Concurrently, there has been a growing focus on researching the vibration characteristics of e-scooters and their impact on human riding comfort. This direction of investigation is closely linked to the quality of road pavements and how any vehicle interacts with them during travel [6]. In the urban area, the sidewalk used for cycling and electrical kick-scooters is usually presented in the wide range from asphalt to brick pavements (Fig. 1b) which generates a different level of vibrations transferred to the driver during the drive on them (for this type of pavements the current research was performed).

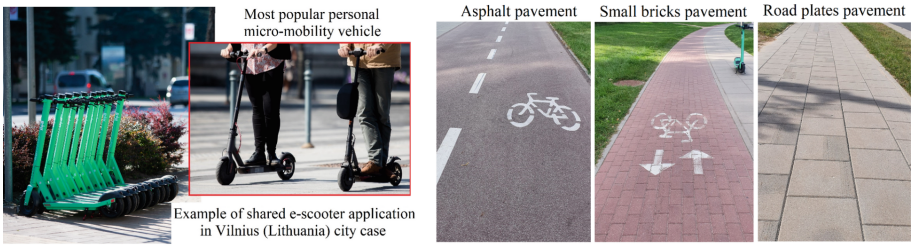


Fig. 1. Micro-mobility trend and its areas of use in Vilnius (Lithuania) city case: a – E-scooters applications (partly based on [7]); b – Sidewalk/cycle road pavement types.

Finally, although the main transport studies in this direction has provided insights into the influence of road pavement vibrations on different types of vehicles, there remains a necessity for additional investigation, especially for e-scooters. Further research should encompass diverse pavement types and integrate frequency domain analysis to offer a comprehension of the comfort related to e-scooter rides.

2 Methodology Explanation and Riding Vibration Influence

During e-scooter use, two main types of human vibration exposure are observed [8]: hand-arm vibration (HAV), which occurs while holding the e-scooter handlebar, and whole-body vibration (WBV), experienced through contact with the e-scooter deck. Generally, the vibrations experienced by the rider while using an e-scooter originate from two primary sources: the operation of the engine and the interaction with the road

surface. The intensity of vibrations resulting from the tire-road contact depends on the quality of the road surface and the speed of the e-scooter. These vibrations exhibit varying frequencies depending on the specific measurement position on the e-scooter. Regarding HAV and WBV research [8–10], it was established that vehicle drivers experience whole-body vibration exposure levels ranging from 0.4 to 2.0 m/s^2. The vibrations are found to be highest in the frequency range of 2 to 4 Hz. The threshold of sensation, or the minimum level of vibration required to be detected like discomfort, can be from 0.5 to 2 m/sec., regarding [8–10]. When exposed to vertical vibrations, maximum sensitivity is typically observed within the frequency range of 4 to 16 Hz. More about the discomfort for each type of vibration in line of frequency influence on humans' body (based on [10–12]) is shown on Fig. 2a.

The analysis undertaken relied on vibration analysis, a method that involves monitoring vibration levels and investigating patterns within vibration signals. This process encompasses two key aspects: analysing the vibration signal's time waveforms directly and examining the frequency spectrum obtained by applying the Fourier Transform to the time waveform. Secondary, according to obtained results from the vibration analysis, the comfort evaluation of the e-scooter use should be performed. To ensure a successful analysis, a series of steps has been developed and illustrated in Fig. 2b. These steps outline the process to be followed in order to obtain meaningful results and insights from the vibration analysis.

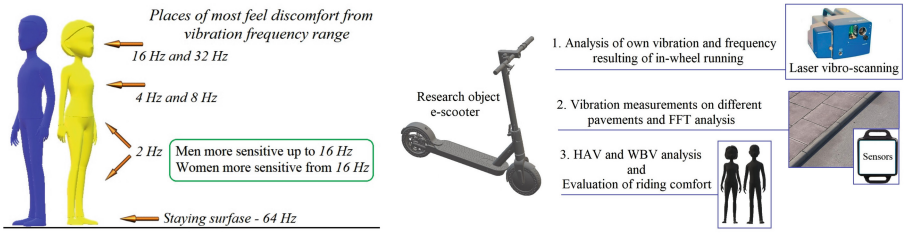
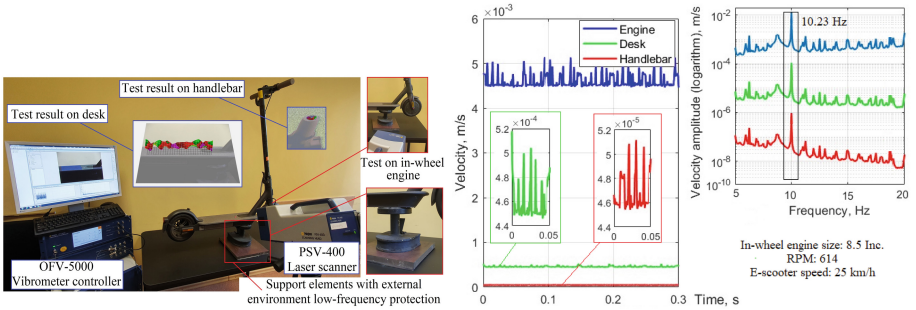


Fig. 2. Research actuality regarding the vibration and proposed methodology: a – Discomfort feeling derivation by staying; b – Proposed steps of methodology in research.

The pre-experiment involves conducting the vibration analysis on the components of the e-scooter, such as the desk – rider stands and the handlebar used for controlling the e-scooter to assess the self-vibration generated by the engine. The main experimental measurements entail real-time operational analysis on different road pavements. This analysis provides insights into the actual vertical vibrations experienced by the rider during the e-scooter rides. The collected measurement data is then processed and analysed, focusing on the vibration levels and frequency analysis in HAV and WBV. The main analysis and subsequent discussion revolve around the evaluation of the rider comfort, primarily based on the frequencies of vibrations transferred to the rider.

3 Pre-experimental Part of Research

In the pre-experiment, a test bench (Fig. 3a – test in laboratory of VILNIUS TECH), which encompasses several crucial components, is used. During the measurement tests, the primary focus lies in analysing how vibrations from the in-wheel engine are transmitted to the desk surface (for WBV analysis) and handlebar (for HAB analysis) of the e-scooter through its connection elements. To capture these vibrations accurately, the PSV Sensor Head is utilized, which records data points for a duration of 1 s. The in-wheel engine is operated at a speed of 25 km/h (maximum legally possible speed [13]), specifically for the e-scooter. The tests employ a t-sample measurement design, utilizing a one-sample statistical method to assess the uncertainty in the repeated measurement of data processing [14]. The resulting vibration amplitudes on the scanned surfaces of the e-scooter elements and its frequency transformation are displayed in Fig. 3b (MATLAB R2022a).



a b

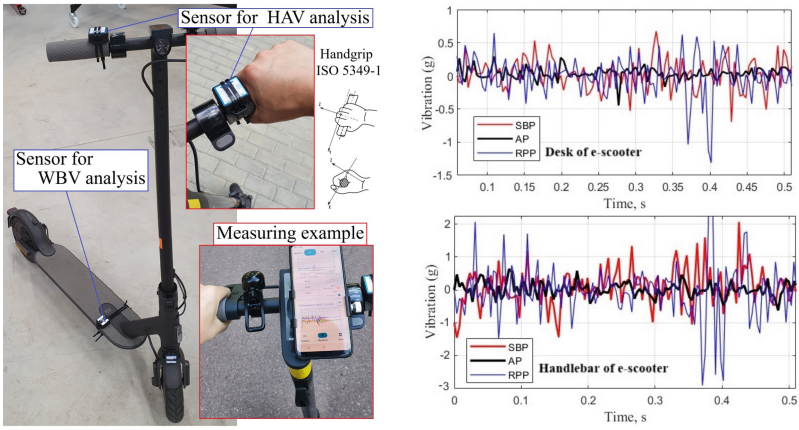
Fig. 3. Pre-experimental part of the research: a – View of the test bench; b – Results from the measurements on e-scooter components.

The vibration level produced by the electrical engine in the e-scooter during measuring was recorded at positions: the in-wheel engine surface, the desk surface where the rider stands, and the handlebar arm. The significant dampening effect observed at the desk and handlebar can be attributed to their combination with rubber material, which absorbs vibrations effectively. The main resonance frequency was identified at 10.23 Hz, confirming that all vibrations are dependent solely on the in-wheel operation conditions (specifically, the e-scooter speed of 25 km/h or engine 614 rpm). Furthermore, it is noteworthy that the vibration values recorded, especially for the engine, desk, and handlebar, are much lower than 0.5 m/s, which is unlikely to cause discomfort. In general, the e-scooter's own vibration is well damped and does not significantly affect the rider's comfort during the ride.

4 Main Experimental Part of Research

However, the main vibrations that could influence the e-scooter rider's comfort and possibly affect health assessment stem from the vertical vibrations experienced while driving on sidewalk pavements. The objective involved gauging vertical vibrations to

conduct an analysis of HAV and WBV while riding an electric scooter on a linear pathway, following the guidance depicted in Fig. 4a. The resulting averages of the vertical vibration outcomes (MATLAB R2022a) are showcased in Fig. 4b, categorized by the type of road cycle (sidewalk) pavements.



a b

Fig. 4. Experimental part of the research: a – View measuring setups and equipment; b – Measured vertical vibration.

The achieved results displayed – driving on asphalt pavements causes vertical vibrations that are sensed by the driver but do not necessarily induce discomfort. On the other hand, smaller brick and road plate pavements generate significantly higher vibration levels, which are transferred to the rider. These vibrations can potentially lead to discomfort during prolonged drives. Furthermore, it is important to note that the rider's arms experience vibration levels higher than those experienced by their legs, almost twice as much.

5 Comfort Ride Evaluation in Line of Frequency Analysis

The findings of the frequency analysis are depicted in Fig. 5, providing significant insights into the vibration attributes of the e-scooter. This visual representation aids in comprehending the frequency range within which vibrations impact the rider.

The achieved results displayed – those vibrations during driving on different sidewalk pavements will have influence on the feeling of the rider in a different way (more detailed information can be gained with the combination of the information in Fig. 2a). At the same time the vibration transferred to the rider's legs and hands are got in the different frequencies that extend an uncomfortable ride.

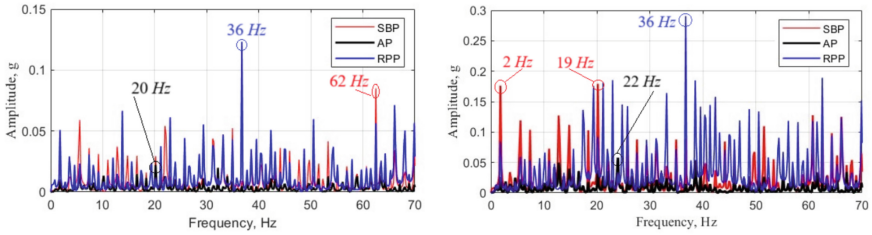


Fig. 5. Frequency analysis results from the vibration on: a – Desk of the e-scooter; b – Handlebar of the e-scooter.

6 Conclusions

The collected measurement data is processed and analysed, focusing on vibration levels and frequency analysis in HAV and WBV analysis. Firstly, it was established that the e-scooter's own vibration is well damped and does not significantly affect the rider's comfort during the ride. Furthermore, it was found that the rider's arms experience vibration levels higher than those experienced by their legs, almost twice as much during the ride. These vibrations can potentially lead to discomfort during prolonged drives in different places of the rider's body, depending on the ride pavements. Additionally, it should be pointed out that the use of the IMU human sensor for extended research is required in possible health assessments.

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A User-Centred Validation Methodology for Assessing the Cross-Modal Transferability Impact of Technologies

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Abstract. Methods for the transferability of know-how, best practices and technologies across transport modes constitute an advantage for the mobility ecosystem. Transferability is an added value for practical and efficient solution design, development and implementation, as well as for solution scaling up to other transport modes.

However, transferability methods oftentimes lack systematic planning and consideration for stakeholders' and users' needs and requirements. For that reason, the present contribution offers a User-centred transferability validation methodology to assess the transferability impact of solutions, best practices, lessons learnt, and technologies across transport modes. The following methodology is the outcome of a process (ongoing) carried out in several European projects, showing promising results for cross-modal transferability between Aviation, Road, and Maritime modes. The contribution presents the User-centred transferability validation methodology rationale that led to its design, the methodological implications for its use, the results obtained in the course of its application, and the lessons learnt and future research directions for the methodology.

Keywords: Human Factors · User-centred design · Transferability · Cross modality · Impact assessment

1 Introduction

Each transport mode has its own unique challenges and opportunities. However, to reach the strategic goal of an integrated mobility ecosystem and to develop more efficient and sustainable transport solutions, great value would come from the increased transferability of best practices, experiences, and lessons learnt across different transport modes.

The *User-centred transferability validation methodology* proposes a Human Factors (HF) driven and structured approach to undertake cross-modal transferability activities between transport modes. The benefit of the *User-centred transferability validation methodology* is threefold. First, the methodology proposes a coherent strategy for cross-modal transferability initiatives, avoiding "silver-bullet" approaches. In fact, for cross-modal transferability to work at its best, it is advisable to consider different solutions and different levels, trying to establish a coherent framework and identifying supporting

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actions and pre-requisite solutions. Second, the methodology assesses the solution's transferability suitability and feasibility by ranking it on two main criteria: safety benefits expected and applicability. Lastly, cross-modal transferability can be considered as an added value for practical and even more for efficient technologies as well as for their scaling up to other modes of transport in the mobility ecosystem.

The *User-centred transferability validation methodology* was developed and successfully applied in the Horizon 2020 projects EXCROSS [1], Drive2theFuture [2], and PANACEA [3], where aviation mode knowledge was transferred to the road mode and vice versa; and for the transfer of aviation resilience resources to the maritime mode in the SEAHORSE FP7 [4, 5] project.

2 Methods

The *User-centred transferability validation methodology* is a structured approach to undertake the exchange and integration of solutions. It is based on two main principles:

- User-centred transfer, intended as the identification of cross-transferability opportunities on the basis of stakeholders and user needs.
- Customisation, intended as the adaptation of proposed solutions to the characteristics of the target transport mode (Fig. 1).

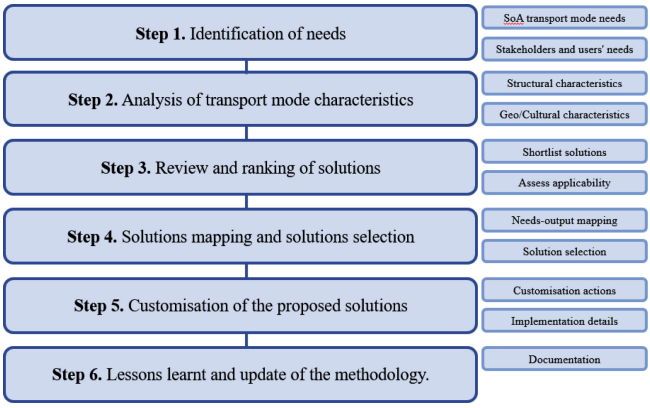

Fig. 1. The six steps of the Cross-modal transferability validation methodology.

The *User-Centred Transferability Validation Methodology* is structured into six steps:

- **Step 1. Identification of needs.** This first step has the objective of identifying which are the needs to be considered for the transferability of solutions by drawing both from the most relevant need trends identified by the European Union (EU) for the transport of the future; and the stakeholders and users' needs from the specific transport mode.

A selection of needs coming from the literature [6, 7] (used i.e., in Drive2theFuture and PANACEA) include among others, 1) sustainability, 2) automation, 3) inclusion and user-centredness, and 4) security and safety.

Differently, in order to have a good understanding of the transport mode needs, two elements are investigated:

- Stakeholders' and Users' needs: These could be related to "pure safety" issues, but also to operational aspects (performance and cost), having an indirect impact on safety. The target time window may be extended from immediate needs to future ones, to emerging challenges.
- Target Scenarios description: Stakeholders' and users' needs are placed in a context, by describing the applicative scenarios of operation as narratives. Scenarios should be co-designed with stakeholders and users to clarify the timeframe, the type of operation being carried out, the technological components, and highlight the needs to be addressed.

- **Step 2. Analysis of transport mode characteristics.**

The second step aims to elucidate the distinctive characteristics of the specific transport mode to which the proposed solution will be transferred. A comprehensive understanding of the target transport mode involves supplementing information about stakeholders, users, and target scenarios with an analysis of the sector's structural characteristics.

Examples of structural characteristics that have proven relevant are the degree of centralisation, of standardisation, the presence and power of regulatory bodies, how homogeneous (or fragmented) is the transport mode culture, the safety culture maturity level, the HF maturity level, the quality and availability of safety data and safety indicators. These characteristics describe the organisational setting and the market structure. They may not directly relate to safety, but they provide the framework in which the proposed solutions should work. At this stage, the support of experts of the target domain and safety experts is essential to have a good picture of the context of application of the proposed solution.

- **Step 3. Review and ranking of solutions by stakeholders, users, and transport mode experts.** This step involves two main decisions. First to shortlist candidate solutions, then to qualitatively assess their potential applicability to the target transport mode. The two decisions are done in sequence but are tightly interrelated. A focus group is carried out, involving experts of the various transport modes to review and rank the solutions together with stakeholders and users. Participants should be equally distributed among these four types of actors: experts of a specific safety critical domain; safety experts, either specific to a mode or transversal; end users, i.e., organisations, companies, or persons that will directly use the proposed solution; and stakeholders, i.e., organisations, companies, or persons that will not directly use the proposed solution, but will be indirectly impacted, for instance being part of the same domain. They will then rate the candidate solutions on three criteria: Availability: assess if the solution or something similar is already present in the domain, even if not properly working; Applicability: what is the feasibility of the proposed solution,

and how hard will it be to implement; Expected impact: which is the expected safety benefit and what is the order of magnitude. Following the focus group, a survey based on its results is prepared and launched with the aim of collecting and integrating more information from a broader set of non-technical and non-expert respondents representing the general public opinion.

- **Step 4. Solutions mapping and solutions selection based on their applicability to the target transport mode needs.** This step maps the outcomes of the previous step on the needs identified at the very beginning of the process. The expected outcome of the mapping is a more articulated description of the solution potential application to the target transport mode. A workshop with relevant partners is held with the objective of collecting inputs from experts to refine and finalise the task. This is the key step of the process, so the participation should be as large as possible, involving experts, end-users, stakeholders and safety experts.

Solutions selection for transferability is then based on their applicability to the target transport mode needs. This step deepens the areas of special attention, critically reviewing the proposed solutions at the light of the target transport mode characteristics. The expected outcome are the shortlisted solutions to be implemented. The selection process considers technical and organisational feasibility, economic viability (cost in terms of resources and effort), and time to deliver benefits (estimation of the time required to develop, implement, and adopt the identified solution). At this stage, a coherent strategy to implement the solutions is defined. As a minimum, the strategy should make explicit the overall objective of the cross-modal transferability initiative (e.g., improve safety culture, increase the technology support for operators, improve the results of incident investigations), the key building blocks (for safety culture: e.g., measure safety culture, design safety culture initiatives, implement them) and how they map on the proposed solutions. The time frame and the relative links between the different solutions is tracked here.

- **Step 5. Customisation of the proposed solutions.** Before proceeding to the actual transfer of solutions, a work group is formed to define the required customisation actions that should be set up. Examples of customisation are allocation of roles and responsibilities in the organisation differently than in the original solution; reducing the scope of applicability; supporting material; longer training sessions required, and so on. Customisations need to address the details of the implementation, anticipating potential problems. In general, they may be related to any of the following aspects: Role of users and stakeholders; Tools, procedures, and guidelines; Governance and regulatory framework; Time and spatial scope, Expected outcomes.
- **Step 6. Lessons learnt and update of the methodology.** The last step produces and provides documentation of lessons learnt on the analysed solutions' transferability impact to promote an iterative and long-term evolution and update of the methodology itself.

3 Results and Discussion

When it comes to the findings of the *User-centred transferability validation methodology*, the Drive2theFuture project highlighted four factors that emerged as relevant to be considered when evaluating the transferability of solutions between transport modes:

1. *Stakeholders and users.* They differ from transportation mode and culture due to their specific needs, requirements and behavioural patterns that influence the design, operationalisation, and implementation of solutions.
2. *Technology* (equipment, systems, sensors, etc.). Different technologies are used to manage networks, transport people, transport goods etc., and they differ based on the specific social, environmental and technical requirements.
3. *Regulations.* They are designed to ensure safety and efficiency of transport modes, and differ based on geographical and cultural dimensions, e.g., infrastructure, vehicles, mobility patterns, cultural identity, social norms, etc.
4. *Legislation.* Legislation and regulatory processes may vary for each specific transport mode and geographical area.

EXCROSS identified various common topics with high potential for cross-modal transferability:

1. *Driver state monitoring.* The cognitive and physical state of the driver, including the tools and techniques used to monitor, identify, and predict a psychophysiological state (such as alertness and fatigue) is studied in all transport modes;
2. *Training.* Ensuring that staff and operators receive proper training to handle both normal and emergency situations is indeed shared by all transport modes;
3. *Automation.* Perception, values, and prioritisation of automation within an organisation, as well as efforts to foster information sharing, knowledge exchange, and collaborative frameworks across various transport modes is a shared relevant topic as well.

The findings of these projects align with the results of the MEDIATOR project [8]. Specifically, the importance of driver state monitoring for predicting driver fitness and the need to maintain driver involvement in AI decision-making processes have emerged as key considerations shared across aviation, rail, and maritime domains.

4 Conclusions and Way Forward

The *User-centred transferability validation methodology* exploits a Human Factors approach and a User-centred framework in which stakeholders and user characteristics, tasks, workflows and processes are given extensive consideration in the customisation and transfer of the developed solutions. All the steps of the methodology involve stakeholders, users and/or experts in order to continuously co-design and monitor needs and requirements, keeping the human in the centre of the cross-modal transferability process.

Overall, the *User-centred transferability validation methodology* process already allowed to assess and elaborate common issues, approaches and lessons learnt across different transport modes (e.g., HMI, "driver" behaviour, ethical decision making, etc.); to address explicitly the ethical and legal issues associated with "driver" and/or vehicle decision making processes under different circumstances, as well as explore solutions to overcome the ethical and legal challenges relating to connectivity and automation; and to investigate new "driver" training needs and certification requirements for new technologies/levels of automation, including effects on employment and skills.

The next goal for the *User-centred transferability validation methodology* is to expand its application to the Railway mode and evaluate the transferability of the same solutions across diverse European cultural and geographical contexts, aiming, thus, to consolidate and systematise the methodology.

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Incorporating Individual Preferences in Multimodal Trip Planning

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Abstract. Despite that a lot of research has been carried out for the development of routing algorithms, research for multimodal trip planning is still limited. Even more scarce is the research on incorporating individual preferences in multimodal trip planning; yet, this incorporation is essential since not all users are willing (or they are not equally willing) or capable of using all the different modes of transportation. The main contribution of this paper is the conceptualization of how multimodal trip planners' results can be customized based on: a) user's responses in a specific set of questions that aim to capture their preferences, b) the revealed preferences of the users that are automatically collected. The first case is being demonstrated within this paper for the case of Thessaloniki, Greece. The developed multimodal trip planner identifies various alternative combinations of shared modes and walking and for each combination calculates the travel cost, travel duration and number of modes changes. The alternative combinations are being prioritized based on a generalized cost function. The outcomes of this paper can be of interest for researchers, who develop trip planners, and for MaaS operators and authorities that are intending to offer multimodal planning services.

Keywords: multimodality · shared mobility · trip planner · user preferences

1 Introduction

During the last years, great efforts are being made for the promotion of sustainable modes of transport and the substitution of private car trips [1]. Also, modern transportation systems are becoming more and more multimodal, due to the appearance of new transportation services, e.g. shared micromobility, on-demand services. In the framework of urban mobility, multimodality is in many cases equalized with the emerging concept of the Mobility as a Service (MaaS), which is defined as a "user-centric, intelligent mobility distribution model in which all mobility service providers' offerings are aggregated by a sole mobility provider, the MaaS provider, and supplied to users through a single digital platform" [2]. MaaS firstly appeared in 2014 as a concept [3] and currently constitutes a topic that concentrates not only great research interest, but also practical interest since several implementations have been deployed [4, 5].

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Despite the fact that a lot of efforts are being made for promoting multimodality, it still seems that this task is a challenging one. The combination of different transport modes in a single trip and the related transport mode changes create a disutility for the users. For eliminating this disutility appropriate infrastructure (e.g. multimodal hubs) is needed, as well as tight co-operation between mobility providers. Indeed, in the literature is acknowledged that only by establishing partnerships between the operators, integrated and multimodal offerings can become a reality [6].

In the context of integrated and multimodal offerings, multimodal trip planning has an essential role to play [7, 8]. Actually, multimodal trip planning refers to the provision of real-time information about how a user can utilize the different available services for optimizing his/her trip. Even in cases where the user is familiar with the context, multimodal trip planning can be beneficial, since in modern transportation systems the supply is dynamically changing (e.g. availability and locations of vehicles, disruptions) and as such there are no standard optimal routes and choices in general.

Multimodal trip planning is much more complex comparing with routing algorithms, since they have to consider inputs and outputs related with several transport modes and it can also be costly due to the required transfers between the various modes. This complexity and special attributes can result in failures, i.e., results that do not have an actual value for the users. This could be the case if multimodal trip planning neglects users' needs and proposes generic solutions that can't meet the expectations of individuals.

The present paper presents the steps of developing a multimodal trip planner. Yet, the main contribution of this paper is the proposal of how individual preferences can be considered when developing a multimodal trip planner, by also demonstrating the example of a real-life multimodal trip planner that was developed for a small-scale MaaS system in the city of Thessaloniki, Greece. It is expected that this paper can set the ground for further promoting the concept of individualized multimodal planning.

2 Methodology

2.1 Problem Definition

In Thessaloniki a MaaS system was launched in April 2023, aiming to promote multimodality and boost a modal shift in favor of shared and electric modes. In this first phase, the MaaS system operates is a small-scale, with a limited number of vehicles and stations. More specifically, the system constitutes of 5 shared mobility hubs, where e-cars, e-bikes and e-scooters are available. For further extending the spatial coverage of the system and covering additional origins-destinations, 3 virtual stations were developed, where only e-bikes are available. As such, e-bikes can act as a first/last-mile solution in some cases and connect additional (popular) areas with the shared mobility hubs.

For solving the multimodal trip planning problem, the first step was to identify the various alternative unimodal and multimodal solutions that can be reasonable from users' perspective. Considering the spatial allocation of the shared mobility hubs and the bike-sharing stations, 12 alternative solutions were identified, as presented in Fig. 1.

The second step was to define the criteria, based on which the various alternatives will be assessed for providing to the user the optimal one or a ranking of the alternatives. For this prioritization task, 3 criteria were defined, namely travel time, travel cost and

number of transfers between different transport modes. The calculation of travel time was made with the aid of the OpenTripPlanner (OTP), which is an open source software capable for providing passenger information and transportation network analysis. Travel cost was calculated considering the travel times and the cost of using the various modes in Thessaloniki's MaaS system.

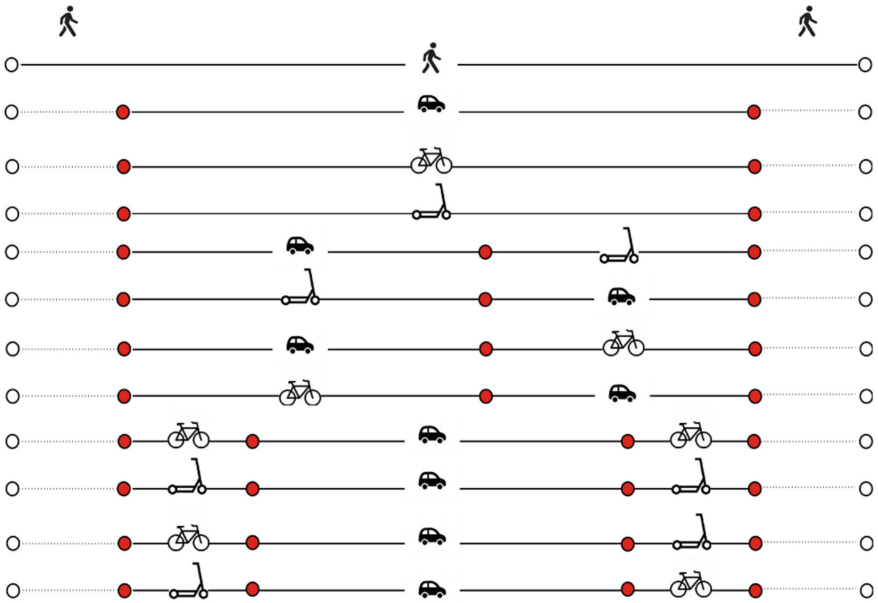

Fig. 1. Representation of the 12 alternative solutions.

2.2 Prioritization of Solutions Through Stated Preferences Survey

Since the different criteria are measured in different units, a way to combine the different criteria in a single generalized cost equation is needed. For doing so, a stated preference (SP) approach was followed. A very short survey was designed, consisting only of 4 different SP scenarios. In each scenario, the respondents had to select between two different trips. The trips were different with regards to the travel cost, the travel time with the different modes and consequently the number of transfers between the modes. An example scenario is presented in Fig. 2.

The short survey was distributed within March 2023. During this period 100 valid responses were collected, resulting in 400 observations. Based on the 400 observations a simple binary logistic regression model was developed for estimating the impact that the various criteria have on the choice of respondents. The results of the binary logistic regression model led to the following generalized cost equation.

From the coefficients derives that the users are more willing to use a shared car and less willing to use a shared e-scooter. This outcome probably reflects on the one hand

Trip 1	Trip 2
Travel time with shared car: 35 mins.	Travel time with shared bike: 8 mins. + Travel time with shared scooter: 15 mins.
Travel cost: 3.5 €	Travel cost: 5 €
▭	▭

Fig. 2. Example scenario in the SP survey.

the car-oriented culture in Thessaloniki and on the other hand the unsafe built environment for riding an e-scooter. Moreover, from the coefficients can be acknowledged that the number of transfers between different modes creates an important additional burden to the users, especially in the city of Thessaloniki, where travelers are not used to multimodality.

$$GC = -0.18\,tt_c - 0.236\,tt_b - 0.37\,tt_s - 0.275\,tt_w - 1.073\,x - 3.925\,n_t \quad (1)$$

where:

- tt_c, tt_b, tt_s, tt_w is the travel time with car, bike, scooter and walk respectively,
- c is the total cost of trip,
- nt is the number of transfers between different modes.

2.3 Prioritization of Solutions Through Detection of Users' Revealed Preferences

The SP approach that was presented in Sect. 2.2 can be an efficient one for prioritizing the alternative solutions considering users' input, yet it doesn't completely account for the different needs among the users. What is more, an additional drawback of SP is that in many cases stated choices do not reflect actual choices.

Nowadays, information and communication technologies (ICT) have an essential role in urban mobility. Actually, ICT triggered the newest generation of shared mobility systems and made possible the deployment of MaaS systems. A high percentage of travelers currently uses mobile apps either for receiving information about mobility services or paying and getting access to the mobility services. In the latter case, a vast amount of data is being collected that is very useful for understanding individuals' mobility patterns. In the framework of multimodal trip planning, this data can form a much more accurate (comparing to SP) source for understanding users' actual preferences and therefore for proposing solutions/trip chains that can meet more suitably their needs and expectations. As such, the single generalized cost equation presented in Sect. 2.1 can be dynamically updated per user, by always taking into consideration the previous choices of the users.

3 Results

In the case of Thessaloniki's MaaS system, the multimodal trip planner development and specifically the part that is related with the prioritization of the solutions relied on the approach that is described in Sect. 2.2. The multimodal trip planner service was made available to the users both as a stand-alone web app and as an integrated feature in an already existing MaaS app.

Figure 3 presents the user interface (UI) of both aforementioned cases. As it is shown, the user can indicate the origin and the destination that he/she is planning to carry out. The multimodal trip planner results are presented with the aid of a map; the different legs of the trip chain are shown with different colors. Also, the service provides not only the optimal trip plan, but also other alternative solutions that are not exceeding specific thresholds. In this way, the user can easily compare and select among the solutions that are highly prioritized.

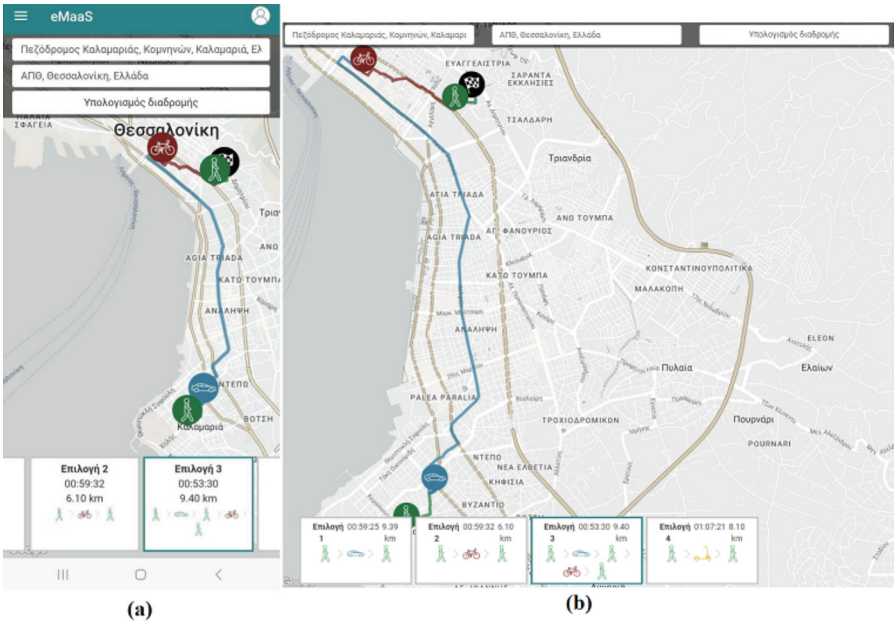

Fig. 3. Multimodal trip planner: a) integrated in app, b) as a stand-alone web app (The app is available at: https://play.google.com/store/apps/details?id=gr.brainbox.emaas&hl=el).

4 Discussion

This paper presents a research effort for developing a multimodal trip planner, that combines optimally various shared and electric mobility services. This multimodal trip planner developed for the city of Thessaloniki and it was integrated in an already existing MaaS app. This service is scalable and it only requires real-time data about the availability of vehicles and the locations of stations.

A main contribution of the paper is the presentation of two different approaches about how the various alternative unimodal and multimodal solutions can be prioritized for providing the optimal results to the user. In the case of Thessaloniki, the SP approach was followed and resulted in an equation capable of assessing the solutions using users' responses as an input.

The prioritization of solutions through the detection of user's revealed preferences is still an ongoing work for Thessaloniki's multimodal trip planner. At this stage, the work focuses on defining a mechanism about how the previous mobility choices of the users, as captured by the MaaS app, should impact the priority of the solutions. The incorporation of user's revealed preferences will result in multiple alterations of the generic generalized cost equation (Eq. 1), for fitting better to the preferences of the different users. Yet, prioritizing the solutions based on mobility choices that are solely captured by the MaaS app has the shortcoming that the impact of walking distance remains fixed among all users, which is actually a parameter with a significantly varying impact on the choices of different users.

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Art Competition as a Creative and Participatory Tool for Promotion of Sustainable Mobility

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Abstract. The City of Turku has created an innovative and inclusive movable bicycle garage that has been promoted alongside with urban sustainable mobility in an unconventional way, by arranging a participatory art competition. The competition brought together the city's different departments, local artists, media, and the citizens of City of Turku to discuss and think about the themes surrounding sustainable and electric mobility in a multidisciplinary manner. In this paper we will cover the process of arranging an art competition as a way of marketing and as a participatory tool, using the City of Turku's work as a case example. The paper will analyse the difference between the concepts of art and advertising as a way of communicating and affecting people. We will also examine how art can be used to engage people's emotions to affect their behaviour and help them make better and more sustainable mobility choices in their everyday lives.

Keywords: Sustainable mobility · art · inclusion

1 Bike Garage for All

In simplicity a bicycle garage is a place for storing bicycles, but it is not enough. By adding other services and art to a garage, the City of Turku has built an inclusive public space which meets the needs of cycling citizens. It is a space for promotion of cycling as a mode of transport for a versatile target group. The bicycle garage in Turku provides storing facilities with the possibility to frame lock all types of bicycles, such as cargo bikes and tricycles. The garage has a bike repair station, and it will soon have an INSOC e-bike charging station which uses solar power to operate. INSOC is being created as a part of the USER-CHI project funded by EU's Horizon 2020 program [1].

Bicycles are accessible and affordable, and the garage offers a space for people to use services equally, disregarding their social or economic circumstances. By providing safe and sheltered storage for bikes, especially in the connection with other mobility hubs, it is a great enabler of sustainable travel chains around the year.

In this case the City's Urban Mobility Solutions unit worked together with the Museum Services to arrange an art competition to promote sustainable mobility in the city in an extraordinary way. The competition allowed us to engage with different stakeholders at many stages such as local artists, the public and city employees.

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2 Process

2.1 Definition of Needs

As a part of the User-chi project the city of Turku built a bike garage that serves the citizens of the area from all walks of life. The design of the bike garage takes accessibility and safety into account. The garage's sliding doors open automatically, the entrance has a gradual ramp, and it has two see-through walls and good lighting for safety. To keep the two non-transparent walls neat, we decided to fill the walls with art. We came up with an idea of arranging an art competition and promoting sustainable mobility through it. We defined the themes of the artwork to be sustainable mobility, e-mobility and especially e-bikes. The themes focused on the topics that are related to the User-chi project.

It is important for the institutions and organizations to distribute art to enable the art to interact with its audience [2]. The process of the art competition for the bike garage went beyond merely distributing art, in that it engaged with different stakeholders to promote sustainable mobility as a topic and concept with the makers of art. Encouraged by this, we decided to hold an open art competition to allow people to get as involved to the competition as possible. This meant that any artist would be free to apply to the competition with their idea for the artwork, and any citizen could vote for their favourite piece.

2.2 Execution

The process of arranging an art competition began by discussing with the City of Turku Museum Services. They had previous experience in organizing art competitions although they had not previously had the citizens participate in the selection of the artwork this actively. We created the guidelines for the competition and planned the marketing campaign. We formed a multisectoral jury that consisted of representatives from the User-chi project, Museum Services, and a local artist organisation. We decided that the weight of the jury's vote would be 2/3 and the citizens' 1/3.

In November 2022 we started promoting the competition to artists in various ways. We published an article on the competition on City of Turku website [3], spread the word on social media and contacted a local art school to encourage their students to take part in the competition. We reached out to the media with a press release. Some local newspapers [4] published news articles on the competition.

By the deadline of the competition in February 2023, we had received six artwork ideas from five different local artists. They had thought about the phenomenon of e-mobility profoundly to create something innovative. The jury rated the artworks based on how well the artwork fit the selected themes of mobility, how realistic the execution plan was and how interesting and innovative the artwork seemed. The jury ended up with three concepts that moved forward to the public vote.

The public vote took place in March 2023 on the Voice Your Opinion service, which is a platform used by the City of Turku to allow citizens to partake in various types of city development. We promoted the vote through a press release, an article on the city's website and by using City of Turku's various social media channels linked to public transport, museums, and sports services. This way we reached a large demographic of

people with different interests and habits. The outcome of the jury, and the public opinion varied a lot. In the end, as the points were counted together, the public's favourite artwork won.

In May 2023 the winner of the contest was announced to the public. The winner was Heidi Vuorio with her artwork Watt is Love. We shared the announcement on the city's website, social media and a local newspaper wrote a piece on the competition [5]. The execution of the artwork began in June 2023 and the artist painted the artwork on site which attracted a lot of attention from passers-by. The artwork was finished at the end of June 2023 right before the opening ceremony of the bike garage. The target group of the event was media, the steering group and the local consortium of the User-chi project and other stakeholders related to the bike garage. We took the opportunity to promote the new cargo bikeshare service in the city alongside the new garage, artwork, and the User-chi project.

2.3 Outcome

The decision of having the two walls of the bike garage painted has turned out to be very sensible. The walls of the garage have remained neat, and the colourful artwork has brightened up the Kupittaa area where the garage was established.

Most of the feedback on the artwork was received while the artist was painting her artwork. The feedback was solely positive. People were interested in seeing what kind of artwork the artist was working on and wanted to discuss the functionalities of the bike garage. The artwork has redeemed its place as a conversation starter.

Looking back at the long process of arranging the art competition it would have been more feasible to use some other service for the public vote as the citizens found the Voice Your Opinion service slightly difficult or confusing to use.

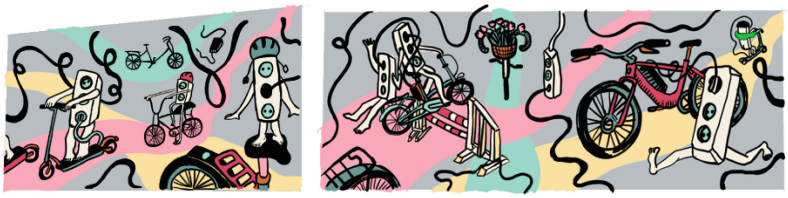

Fig. 1. A draft of the artwork "Watt is Love" by Heidi Vuorio.

3 Analysis

3.1 Art vs Advertisement

As humans, we tend to act within the given set of societal rules, either by following the rules or working around them, and sometimes even against them. In our case, the empty walls of the bike garage formed both a challenge and an opportunity. For the city the empty wall inviting to be filled with graffiti was a challenge, while for the artist it formed

an opportunity. By combining challenge with opportunity, we decided to invite art into the empty space. The empty public space is also a prime location for advertisement, and while it might help promoting important causes a decision was made to create an arts-based approach for promotion of sustainable mobility.

Sara Pastore speaks about the importance of art as an expression of being human and how museums are spaces which invite to observing the human [2]. The same sense of humanism is attached to the bike garage. The aim of it is to enable human behaviour which promotes the wellbeing of the individual and in extension also the wellbeing of the collective society. It is not a bold reach to consider the walls of the garage a space which invites the promotion of wellbeing and the observation of human behaviour. The fact that the winning artwork by Heidi Vuorio is depicting personified extension cords is poetically emphasizing the human (see Fig. 1).

By pointing to this appreciation of the human being, it is inevitably clear that giving space to advertising would not have been as worthwhile in this public space. In Išoraite, M.; Jarašuniene, A.; Samašonok, K.'s paper the person who is the target audience of advertising is described as a consumer, almost lacking in any agency, reduced to a set of needs and causal reactions [6]. While successful advertising speaks to the audience it is still in close connection to the act of consuming. Išoraite, Jarašuniene and Samašonok say that "Advertising shapes interests, fashions, habits, traditions, and opinion, performs cultural, aesthetic, and sometimes scientific public education, and defines the benefits of goods/services, their meaning, price, and quality." [6] and by this definition at first glance it might be very attractive to consider using advertising as the method to get message across to the public. However, while advertisement may mange to influence behaviour to this extent, it is done in less direct manor, and as Išoraite, Jarašuniene, Samašonok say later in the article, borrowing Korenkova et al. that consumers, in other words, the audience, are subject to much advertisement daily [6]. This subjection to numerous sources of advertisement can result in an overload, which is another negative the case of the bicycle garage seeks to avoid. Thus, by choosing to use art over advertisement the aim was to give the observing audience more agency while promoting the important topic.

3.2 Art Engages Emotions to Affect Behaviour

Ellen Dissanayke says that art's value in arousing sympathy is noted already by early art historians [7]. In the case of the extension cord people on the bike garage's walls, the sympathy grows from a form of recognition. There the painted characters (see Fig. 1) are using different modes of transport that the observer can recognise and feel the feelings the depicted vehicles and their use awakens. This way of engaging the observers' emotions shows how the garage manages to capture the attention of the audience. In fact, it demands the attention, and the audience is willing to submit to the demand, much more than that of advertisement set to entice you towards certain services, products, or behaviour.

Art's way of speaking to a person's emotions is a part of the social construct of art. Dissanayke points out that while art is said to contribute to order, for example by portraying constructs of society which are expected to be in a certain way, it can also in some cases break the rules and "break up with the familiar, disordering the expected and acquainting us with the unusual" [7]. Thus, emphasising the rules by disobeying them,

and helping the audience to learn to expect the unexpected, and that way helping to make people more flexible when facing novelty. The bike garage, as a concept might not be exactly novel, however, it is planned to be the space for bike related innovation and piloting. The first of many being the INSOC solar charging platform which is a product of the USER-CHI project. This provides yet another valid reasoning for the choice of using artwork in promotion of electric mobility, specifically for light e-vehicles, in connection with the bicycle garage.

4 Outcome in Projects

Getting the bicycle garage and finding a place for it in the city was not easy. Sometimes the art competition was overshadowed by the discussions with installers, service providers or other bureaucracy. However, it is very important to look at the lessons learnt and the outcome of the whole process, and to keep records of it for the next project not to have start from scratch. The art competition engaged many different stakeholders to discuss and express sustainable and electric mobility. The result of these discussions can be seen conveyed in the artwork. Also, the public were invited to engage in the process, by helping to choose the artwork. This type of stakeholder engagement was low threshold and still provided many new ways of looking at sustainable mobility.

The artwork on its own has been a functioning form of marketing for e-mobility, sustainable mobility, the local bike services brand, and the USER-CHI project, as the competition prompted the artists to consider these topics in their proposal. The competition also gave an interesting and straightforward reason for the citizens to think about the large variety of ways to move more sustainably. Furthermore, this process allowed us to raise awareness on how a bike garage could be so much more than just a location to store your bike. It can and it should provide additional services and allow safe parking for versatile bikes. By doing this, we wanted to challenge other bike parking service providers to raise the bar.

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"Please Hang in There!": User Acceptance as a Key Element for a Successful Charging Infrastructure

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Abstract. The growing demand for electric cars in Europe necessitates planning tools designed to meet user needs in charging network design. One such product is CLICK – a charging infrastructure planning tool. During the demonstration phase of CLICK, technical and user acceptance feedback was collected and will be evaluated in this paper. The evaluation will focus on possible drivers and barriers in the design of CLICK to optimize the spatial planning of charging infrastructure. In addition to the space requirements, the subjective perception and the resulting acceptance are of elementary importance for the success of nationwide availability of electric mobility and the (partial) substitution of cars with combustion engines. Evaluating CLICK's user acceptance contributes to better identifying user needs and preferences. Hence, the tool can be developed in accordance with those needs and increase its attractiveness. The main research questions are: How satisfied are users with the current charging infrastructure planning tool CLICK? What opportunities and obstacles can be derived for the implementation of charging infrastructure?

Keywords: e-mobility · Europe · user acceptance · charging infrastructure · planning tools

1 Why User Acceptance Matters

Annual electric car registrations in Europe increased by 50% from 2020 to 2021 [1]. The European Union (EU) supports that development by additionally introducing policies that incentivize the reduction of CO_2 emissions [2]. Following those increasing numbers, the desire for a broader availability of charging points and more interconnected charging infrastructure can be assumed. According to the Consumer Monitor 2022, one of the main barriers for battery electric vehicle (BEV) users is the overview of the public charging points and their user perception [3]. Correspondingly, there is also an increasing demand for user-friendly charging infrastructure. Charging infrastructure planning

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tools will facilitate coping with this demand. Therefore, an existing incentive exists for implementing a planning tool to plan charging infrastructure. The USER-CHI project is meant to unlock the massive potential of electromobility in Europe by designing electric charging networks around user needs and deploying an interoperability platform. CLICK aims to be an easy-to-use question-and-answer online tool for the top-down location planning of charging infrastructure. Therefore, it supports users such as transport and city planners in meeting the growing demand for charging infrastructure. CLICKs' purpose is to optimize the location planning of new charging infrastructure in cities, matching the users' needs, preferences, and habits with the existing charging technologies available in the market. CLICK analyses inputs provided by users (e.g., employees of municipalities, car-sharing companies, and housing companies) and estimates the optimum charging infrastructure to be deployed in the city. Furthermore, CLICK can be fed with actual utilization data of charging infrastructure within individual planning areas [4]. This enables a post-planning process of monitoring the utilization, enabling demand-oriented expansion of the charging infrastructure network.

This paper is meant to evaluate the data collected from the user acceptance questionnaire and workshops of CLICK [5]. The main research questions are: How satisfied are users with the current charging infrastructure planning tool CLICK? What opportunities and obstacles can be derived for the implementation of charging infrastructure?

2 Methodology of User Acceptance

In this paper, user acceptance is defined as a scale of subjective assessment, measuring the users' satisfaction with CLICK and its usability on various elements. The measurement of user acceptance is done through multiple measurement scales described in the USER-CHI methodology section (Sect. 2.2). The user groups are defined by their representation of real-world usage. The list of user groups of CLICK includes municipalities, private and commercial EV-fleet owners (e.g., car-sharing companies), and e-mobility planners (e.g., charging point operators (CPOs)). They are meant to replicate the targeted population as closely as possible to get information on how the software can be further improved.

2.1 Definition of User Acceptance

"User acceptance" is defined more precisely in psychology as a person's attitude towards a product, technical system, or parts of a system. By attitude, mostly satisfaction, and usefulness are the main parts of it, as mentioned by van der Laan et al. (1997) definition of the user acceptance scale [6]. For USER-CHI and CLICK, satisfaction and usability indicate user acceptance. For example, in the kick-off workshop of USER-CHI, possible barriers that may negatively affect the perception of EVs, also in terms of user acceptance, were defined. Those include legal, infrastructural, financial, and transparency barriers [7]. They are meant to assist in the understanding of the current limitations and underutilized possibilities of a given product or service. In the context of CLICK, it means that due to user satisfaction being directly connected to the input of user data, improving its limitations through implementing the gathered feedback from the side of the users directly and positively influences its possibilities. Conversely, this means

that the acceptance of CLICK relies on the users' understanding and handling of their possibilities, knowledge, and data input.

2.2 USER-CHI Methodology

Three main methods were used to collect user acceptance feedback [8]: TAM, SUS, and NPS. The **TAM (Technology Acceptance Model)** [9] explains how perceived utility and ease of use affect technology adoption, while the **SUS (The System Usability Scale)** [10] provides a global usability assessment using a Likert Scale. For its ease of use, the respondents' opinion on the feature(s) of a product or service is measured. The third method is the **NPS (Net Promote Score)** [11]. It is a customer loyalty and satisfaction measurement in which customers are asked how likely they are to recommend a product or service.

In summary, all three methods were used for CLICK in two steps: workshops (qualitative) and a questionnaire (quantitative). CLICK gathered technical feedback in workshops (online/in person) as a first step. As a second step, a user acceptance questionnaire collected feedback per participant right after the workshop.

3 First Results of User Acceptance of CLICK

The feedback results are separated by their source: workshops (Sect. 3.1) and the user acceptance questionnaire (Sect. 3.2).

3.1 Results from the Workshops

The feedback from the workshops included responses from users in Barcelona, Rome, Turku, Budapest, Florence, and Murcia. It is mainly technical feedback, referring to the functionality, usability, and results created with CLICK. Users suggested adding more points of interest and requested better explanations of CLICK's usability and calculations.

Users from Murcia, Barcelona, and Rome sought clearer explanations of CLICK's calculations and data handling, particularly regarding variable weighting. Another point addressed that different types of public transport stations should not be considered equal in the calculation. Barcelona added that the tool should first ask for the type of charging poles needed and then calculate the number of charging points. For the users, it was also unclear how private space was defined. For Barcelona, it was unclear how to upload inhabitants per district and individual road types, while Murcia was unsure about citizens' data. Budapest would provide maps from geo information systems (GIS) rather than using Open Street Map (OSM) information. Nevertheless, the OSM in-load option was seen as a positive feature of CLICK.

According to all the cities, more points of interest (POIs) should be added in CLICK. Mentioned POIs are, e.g., restaurants, public parks, malls, and offices. Additionally, aspects like the ratio of the charging type (AC, DC, or HPC) or the amount of EVs should be individually adjustable. Overall, the cities received CLICK very well, and they were eager to test and evaluate the tool to customize it for their purposes. CLICK

has already created a big interest in Finnish municipalities, and the city of Turku will introduce them to the tool. On the other hand, Budapest wants to use CLICK to develop a new e-mobility concept.

3.2 Results from the User Acceptance Questionnaire

The questionnaire focused on the usability of CLICK and the workshops conducted. The rating scale reached 1 = "I disagree" to 4 = "I agree" (Table 1).

Table 1. User Acceptance Questionnaire result in the format: value (amount of same value answers)

Question Scale 1–4, 1 = low/I disagree. 4 = high/I agree	Average	Highest	Lowest
1) Overall Impression on CLICK	3,33	4 (4)	2 (1)
2) Would like to use CLICK in the future	3,22	4 (6)	1 (1)
3) Features of CLICK are unnecessarily complex	1,56	4 (1)	1 (6)
4) Would need the support of a technical person to be able to use CLICK	2,11	4 (1)	1 (3)
5) Too much inconsistency in the handling of CLICK	1,44	2 (4)	1 (5)
6) CLICK will improve my planning performance	3,00	4 (2)	1 (1)
7) CLICK will increase my productivity	2,67	4 (2)	1 (1)
8) Learning how to use CLICK is easy	3,67	4 (6)	3 (3)
9) I have the necessary skills to use CLICK	3,11	4 (3)	2 (2)
10) I intend to be a heavy user of the CLICK system	2,33	4 (1)	1 (2)
11) The webinar was easy to follow	3,67	4 (4)	3 (2)
12) How easy was it to use CLICK for locating new charging infrastructures compared to similar tools?	2,86	4 (3)	1 (2)
13) How likely would you recommend the CLICK solution to a colleague Scale 1–10, 1 = I would not recommend. 10 = I would highly recommend	8,78	10 (4)	7 (3)

Overall, CLICK is considered consistent and shows the potential to improve performance and productivity. Moreover, the questionnaire results revealed two exceptional cases. In one case, a participant would not consider using CLICK as it would not increase productivity. In the other case, a participant had difficulties utilizing the tool and did not consider his/her skills adequate. However, the participant agrees with the ease of usage of CLICK and would highly recommend the tool to others. Those two cases portray opposite perspectives, coming to the same conclusion. Both agree that CLICK is easy to understand and would both highly recommend the tool to their coworkers.

4 Conclusion for the Charging Infrastructure Planning

User acceptance represents the strengths and weaknesses of CLICK at the same time. The input from the user acceptance questionnaire and the feedback from the workshop still have limitations when using standardized methods. As user acceptance input is based on one's interpretation of the scaling and answer, standardized methods would make further work difficult. Not using standardized methods allows for flexible interpretations of its outcome for further development, and the work direction of it would depend on who reads the results. Additional qualitative interviews for more detailed feedback are recommended, especially regarding user satisfaction.

Furthermore, a conflict between accessibility and flexibility must be worked on as there is a risk of integrating feedback, which can cause a decrease in user acceptance through a form of survivorship bias [12]. More useability could lead to a lower quality of user experience, or lower useability could come with a more satisfying experience. The feedback received so far mainly suggests changes to CLICK rather than mentioning what is already perceived as well-functioning. This lack of positive feedback can potentially change aspects of the tool that users did not desire to change. Therefore, in the second part of CLICK's demonstration phase, positive feedback from the users should also be asked for. In this way, the developers of the tool know which aspects to work on and which aspects to maintain.

User-friendliness and perceived usefulness are interconnected and interdependent, and the results of this study confirm this. However, evaluating both remains relevant because they address different usage questions and needs. For instance, when considering the initial planning phase, these stages are more about sharing knowledge among various professionals involved rather than making technical decisions. In this regard, when using CLICK, someone who is not an expert in planning charging infrastructure will be highly interested in the ease of tool use, transparency of underlying model assumptions, and the readability and credibility of the outputs. If these requirements are met, the user would be more inclined to recognize its validity and accept its use. In more advanced planning phases (e.g., when speaking about AC/DC/HPC charging stations), for users who may already have experience with other PSS, the evaluation of usefulness becomes more critical, and the focus shifts more towards the validity of results in relation to local specific sociodemographic, legal, and environmental conditions. The need for data standardization, which would facilitate processing in tools like CLICK, is a well-known issue and is not addressed in this paper. In this sense, we acknowledge that the potential of artificial intelligence in handling non-standardized data is significant. However, the use of AI in the context of user acceptance of tools has yet to be considered.

The demonstration and development phase of CLICK is special and very fruitful, as it includes diverse test users from different countries and with different positions and backgrounds. The constant exchange with those users helps to customize a tool that municipalities, housing companies, charging point operators, and many more can use in the future as the need for planning tools is growing. The city of Turku has already introduced CLICK to other Finnish municipalities that expressed their interest, and Budapest wants to develop a new e-mobility concept with CLICK. Future work could verify how well CLICK's plans align with existing infrastructure.

It is important to note that the tool is still under development, and the user acceptance analysis is ongoing to reflect the users' demands in the final version of CLICK. Therefore, user acceptance is and will always be important when developing planning tools. It is especially important to remember how positive user experience leads to a positive feedback loop, while negative user experience can lead to a downward spiral. So "please hang in there" – in this case, user acceptance becomes a make-or-break issue on whether a product in the developing field of supporting tools flourishes or gets overshadowed.

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AWARE2ALL: Human Centric Interaction and Safety Systems for Increasing the Share of Automated Vehicles

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Abstract. The AWARE2ALL project is designed to address the new challenges of Highly Automated Vehicles (HAVs) from a human-centric perspective. These vehicles will allow occupants to engage in non-driving activities, rising research questions about occupant behavior, activities, and Human-Machine Interfaces (HMI) to keep them aware of the situation and the automation mode. The project aims to ensure safe operation of HAVs by developing safety and HMI systems that provide a holistic understanding of the scene. This includes continuous monitoring of the interior situation and advanced passive safety systems for occupant safety, as well as a surround perception system and external HMI for the safety of Human Road Users (HRUs). AWARE2ALL is paving the way for HAV deployment by effectively addressing changes in road safety and interactions between different road users caused by the emergence of HAVs. It is developing innovative technologies, assessment tools, and methodologies to adapt to new scenarios in mixed traffic. The project builds on previous research and aims to mitigate new safety risks associated with the introduction of HAVs.

Keywords: Internal HMI · External HMI · Occupant Safety · HRU Safety

1 Introduction

In 2020, one life was lost every 25 min in European roads, for a total of 18,844 fatalities. Shockingly, road accidents were the leading cause of death for individuals aged 5–14 and the second leading cause for those aged 15–29. Notably, over 46% of these fatalities in Europe in 2018 were comprised of Vulnerable Road Users (VRUs), including pedestrians, cyclists, and motorcyclists. Troublingly, it was estimated that human error played a role in roughly 95% of all road traffic accidents.

Highly Automated Vehicles (HAVs) have the potential to improve road safety by reducing crashes due to driver error and also by representing an alternative to high-risk drivers (e.g., drunk or distracted drivers). However, HAVs may introduce additional

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safety risks that must be addressed: component failures, increased risk-taking, unconventional seating position and occupant postures, increased vehicle travel, interaction with VRUs and also mixed traffic interacting with Human Driven Vehicles (HDVs) [1]. The obstacles for HAVs introduction in the market mainly come from safety and human factors concerns [2]. Hence, the expected new safety-critical situations must be addressed, especially those involving human road users (HRUs), that includes VRUs and HDVs.

2 AWARE2ALL Approach

2.1 Concept

The focus is to ensure reliable integral safety of the occupants with special attention to the new variety of possibilities that automated driving functions will bring to vehicle occupants (including leisure activities) and ensuring safe control transitions between SAE levels when necessary. The AWARE2ALL concept is supported by three main actions:

- development of an integral safety concept that automatically takes decisions according to the occupants' state, overall situation (interior layout, exterior scene, etc.) to guarantee always that even if a crash is unavoidable, the severity is minimized.
- inform the occupants adequately about the autonomy and decision state of the system as well as about the driving situation, to ensure that occupant alertness is adequate for the current driving mode. This information is adapted to the occupants' types and roles, enabling them to respond timely to any required actions.
- inform road users adequately about the systems' state and intentions and adapts to the user type, thus promoting safe interaction.

AWARE2ALL will pave the way towards the development of an Integral Safety approach to match the demanding requirements of new vehicles addressing diverse SAE automation levels, like L4 with the occupants playing different roles (see Fig. 1).

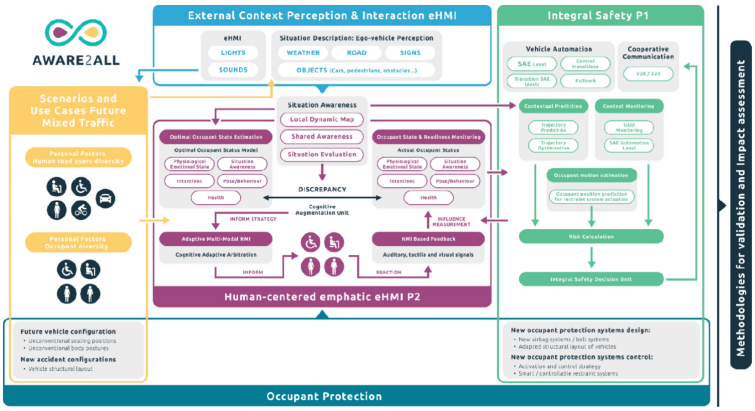

Fig. 1. AWARE2ALL overall concept.

The Integral Safety pillar (P1) will integrate components from the two other pillars: exterior (P3) and interior (P2) situation awareness building, using collaborative perception and interaction technologies.

AWARE2ALL will develop new interior and exterior interaction design concepts to optimize the interaction between all scene occupants (interior and exterior). Occupant monitoring and driving readiness assessment will enable reaching an advanced awareness level between the human and the vehicle in all traffic situations, in order to achieve safety and comfort in the emerging automated transport ecosystem.

This approach includes the definition and monitoring of ODD to ensure the safety of the automated driving under all circumstances defining Minimal Risk Maneuver and Fallbacks to ensure the safety of both occupants and other traffic participants. AWARE2ALL will advance the information presentation so that the occupant can always fully understand the circumstances under which the automated driving functions are operational, the vehicle's status and the traffic situation.

- **The integral safety system** consists of connected active and passive safety systems. The active safety uses traffic environment information to generate a risk field to optimize the planned trajectories for crash avoidance and/or crash severity mitigation. This information is shared with HRUs via the eHMI. The passive safety system will get the vehicle dynamics prediction information from the active safety system and generate the occupants' body motion prediction for adapting the restraint system activation accordingly. In case that a collision is unavoidable, the HAV would warn the HRUs via the eHMI, iHMI, and OMS.
- **The Human-Centered Cognitive Augmentation (HCCA)** concept involves creating a shared understanding of situation awareness (vehicle/occupants) using iHMI and OMS. It assesses occupant's current states based on various factors like traffic conditions, automation levels, and personal traits. The OMS proposed by AWARE2ALL includes physiological observations and behaviour descriptors. The cognitive augmentation unit calculates differences between optimal and observed values. An adaptive multimodal HMI is adapted on this information. Driver reactions are measured through HMI interaction and OMS feedback, closing the loop. OMS also locates occupants of the vehicle, improving safety systems.
- **Perception system**: allows identification of the external situation of the vehicle and of the HRUs with whom the vehicle must interact. The system will be able to detect and analyse the HRU's attention, through a combination of sensor fusion and object detection that will be performed simultaneously allowing to generate a representative map of the vehicle's environment. 2D image analysis processing will be involved, but also 3D point-clouds generated with LIDAR (useful as validation reference to improve system reliability).
- **Communication system**: allows interaction with HRUs using multi-modal interfaces, like exterior lighting configured according to vehicle's perceived surroundings and by the communication strategy (warning signs, symbols, etc.). Also, new technologies will be explored, like using microLED for taillights, an immersive technology where the picture elements (pixels) are the light source that is programmable and can be controlled individually to create the patterns, and DLP (Digital Light Processing) or MLA (microlens array) for the use in ground projection. Within the project, different

uses of lights will be investigated to determine those with higher impact on the behaviour of road users. The other interface to be explored will be sounds and the use of the AVAS (Acoustic Vehicle Alerting System).

3 AWARE2ALL Use Cases

AWARE2ALL systems are currently under development in a total of four demonstrators, one virtual (Demo 1), two physical (Demo 2 and Demo 4) and one hybrid (Demo 3) that will include a physical prototype that will run in a static driving simulator.

Demo 1 - Passive Safety Virtual Prototype: This demo will include the 3D simulation model of the new vehicle interior configuration with seats, belt systems and airbag systems for crash simulation in LSDyna or PAMcrash. The configurations are defined for forward facing and rearward facing seating positions and cover also one variant for a seat integrated restraint system with advanced body-in-white and interior structure adaptations. The advanced airbag systems will handle the occupant diversity by closed-loop control functions activating variable filling curves and ventilation times31 using airbag contact sensor technologies.

Demo 2 – L4 Shuttle Fallback: To showcase an automated L4 shuttle, deploying strategies for fallback and emergency situations on system components/sensors failure including fail-operational functionalities, such as AEB, evasive maneuvering, or safe/comfortable stops. The systems will exploit V2X interconnection protocols with other agents, including connected vehicles and infrastructure elements.

Demo 3 – iHMI and OMS: A Renault platform driving simulator with environment visualization based on openStreet maps and vehicle dynamics simulation including active safety features. AWARE2ALL OMS and iHMI solutions will be integrated. The Active Safety features will be based on a new trajectory optimization architecture creating a risk field based on object motion prediction, crash severity prediction and ego-motion prediction using a reference path from navigation function.

Demo 4 – eHMI and HRU: Based on a Seat or a Cupra platform, that will support in the systems integration. In this vehicle the external perception system will be implemented using the AWARE2ALL platform sensors.

4 Testing and Validation Approach for AWARE2ALL

AWARE2ALL seeks to expand its comprehension of all the different user and stakeholder groups involved or affected by the safety solutions it develops. This expansion aims to ensure and enhance the inclusion of social groups that are at risk of exclusion. AWARE2ALL embraces principles and practices from the social sciences and humanities (SSH), such as “co-creation” and “inclusive methodology”.

Scenarios and use cases will be crafted based on real-world driving situations, considering factors that influence the behavior of HAVs and their interactions with other vehicles and pedestrians. For instance, a scenario might involve an autonomous vehicle navigating a busy urban street during rush hour, where pedestrians are crossing, and vehicles are maneuvering between lanes. Different dimensions are considered:

User Persona Definition: The creation of diverse User Personas is of paramount importance in safety and communication projects involving autonomous vehicles. It is vital to understand the needs and challenges faced by individuals with varying abilities when developing new safety and communication systems for autonomous vehicles. Ensuring the accessibility of these technologies to everyone, regardless of their physical abilities, is a fundamental objective in autonomous vehicle development. Accessibility serves as a cornerstone, guaranteeing the usability of this technology by a wide range of individuals. Age, gender and racial bias represent a significant challenge for HAVs.

Human Road User: When establishing the parameters for defining a scenario, it is imperative to account for the presence of HRU – all individuals involved in the given scenario. In addition to examining their characteristics and the challenges they encounter in their daily lives, it is equally essential to ascertain their roles within our scenario, their geographical positioning, and the activities they might be engaged in. The two primary HRU profiles encompass: (1) **occupants:** individuals situated within the autonomous vehicle; and (2) **VRUs:** as non-motorized road users, such as pedestrians and cyclists, as well as motorcyclists, scooter riders, and individuals with disabilities or those experiencing reduced mobility and orientation.

Road Types and Infrastructure: Motorways or highways are designed for high-speed travel and are typically multi-lane, predictable and straightforward, with well-marked lanes and limited pedestrian or bicycle traffic. Rural roads are narrow, winding and often lack markings or signage. They may also have unexpected obstacles, such as animals or farm machinery. Urban roads present the most complex challenges for autonomous vehicles. They are crowded, with a wide variety of vehicles, pedestrians and cyclists sharing the same space. In addition, urban roads often have complex traffic patterns, such as one-way streets and roundabouts.

Environment Conditions: Environmental conditions can affect the safety and efficiency of driving on different types of roads, such as motorways, rural roads, and urban roads. Adverse weather conditions, such as fog, rain, or snow, can affect visibility and traction and influence the behavior of both human and autonomous drivers.

5 Safety Parameter Identification and High-Level System Requirements with KPIs

Evaluating the safety of a system requires the definition of safety parameters, metrics, and the subsequent Key Performance Indicators (KPIs) derived from these metrics. The following definitions clarify these terms in context:

- **Safety Parameters:** These are quantifiable or observable factors directly associated with the safety of road users. They serve as foundational indicators for evaluating safety.
- **New Risks from Automated Driving:** The project addresses novel risks arising from the unique configurations introduced by automated driving. From a passive safety perspective, these new configurations significantly impact seating positions, including rearward-facing positions in the first row of seats..

- **AWARE2ALL's Safety Integration:** AWARE2ALL seeks to incorporate previously marginalized groups into safety assessments and safety development, taking measures to minimize accident severity. The advent of highly automated vehicles introduces new parameters for assessing accident severity, that must account for both unconventional seating positions and the diversity of individuals involved, ensuring consistently high safety standards.
- **Active Vehicle Safety:** to proactively prevent accidents or mitigate high-risk situations to safeguard passengers and external VRUs. The criticality vary for different categories of accident opponents, determined by absolute thresholds or relative weightings of metric numerical values. Developing and evaluating active vehicle safety involves challenges such as determining the relative weights of individual safety parameters and comprehensive safety metrics.

6 Conclusions

This paper presents the first steps of AWARE2ALL project towards the development of new methods and tools to ensure safety of HAVs (shared cars and shuttles) in mixed traffic, protecting both diverse occupants (elderly, disabled, women, men) of the vehicle and the HRUs (VRUs, HDVs) that interact with the vehicle. The AWARE2ALL holistic approach covers the automotive value chain (universities, RTOs, TIER1 and OEM) to support the introduction of HAVs by offering an integral solution able to face future safety critical situations.

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Influencing Alertness Through Remote Coaching for Professional Drivers

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Abstract. This paper presents a focused look at findings related to driver fatigue from Use Case A (UCA) of EU project PANACEA (grant agreement number 953426). UCA considers safety drivers of autonomous shuttles. For safety and regulation reasons all shuttles have a driver present ready to intervene if needed. In practice, this means that the safety driver is responsible for ensuring the safety of both passengers and surrounding road users. 8 shuttle safety drivers (100% of those available) participated. Subjective driver sleepiness was reported daily at the start and end of each shift using the Karolinska Sleepiness Scale. Potential risk for driver sleepiness was calculated using the Bordeaux Sleepiness Scale (BOSS). Overall, sleepiness was a rare experience (mean KSS start shift = 3, mean KSS end shift = 3.1). However, those identified as potentially at-risk using BOSS had some experiences of sleepiness (KSS = 7) on some shifts. The PANACEA system uses input from sensors in the vehicle, workplace depot and on the driver, creating a holistic monitoring and assessment system. This detects professional drivers who are not fit to drive and supports them and their employers to manage the situation and adopt preventive measures.

Keywords: driver monitoring · driver sleepiness · driver fatigue · AV shuttle

1 Background

1.1 Driver Fatigue

Alertness is important for road safety. Alert drivers are more likely to exhibit safe driving behaviors and make safe driving decisions. Conversely driver fatigue is associated with increased crash risk: - 1.29 times the crash risk of driving without being fatigued [1];

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heightened propensity for distraction [2]; reduced hazard perception [3]; and impaired lateral control [4]. A further complication is that fatigued drivers are more likely to believe that they can successfully "fight their fatigue" so may fail to stop driving when they become unsafe [5]. It is estimated that around 20% of European car drivers will have had trouble keeping their eyes open at least once in the past month [6].

1.2 Professional Drivers and Driver Fatigue

Multiple studies have identified that professional drivers are particularly vulnerable to driver fatigue e.g. [7, 8]. There is a complex relationship between fatigue and workplace safety. Unlike some other workplace hazards fatigue has both work and personal contributing factors [9]. For example, it has been reported in London bus drivers that work related factors including less than 11 h off duty time between shifts and working 6 or more days without a rest day predicts sleepiness at work [10]. In addition, personal factors such as poor self-reported health also predict sleepiness at work [10].

1.3 Aim of This Research

This work is part of the EC funded project PANACEA (grant agreement number 953426). The overarching aim of PANACEA is to develop a supportive coaching system that encourages trust and transparent communications between all involved parties. PANACEA is an abbreviation for PracticAl and Effective tools to moNitor and Assess CommErciAl drivers' fitness to drive. The overall aim of the project is to create a holistic monitoring and assessment system which detects professional drivers who are not fit to drive and support them and their employers to manage the situation and put measures in place to prevent it happening again. This paper specifically considers the research question: Do safety drivers of autonomous vehicles experience fatigue?

2 Method

2.1 PANACEA

The PANACEA system uses input from sensors in the vehicle, workplace depot and on the driver to evaluate fitness to drive. PANACEA takes into account a range of impairments which influence fitness to drive including: fatigue, drugs, alcohol and distraction. Project trials take place over three sites, use case (UC) A (UCA) in Sweden with autonomous shuttle safety drivers, UCB in Greece with taxi drivers and powered two-wheeler delivery drivers and UCC in Spain with truck and coach drivers. UCA was included because test sites with small autonomous buses (shuttles) in urban areas are becoming more common. For safety and regulation reasons all shuttles have a driver present ready to intervene if needed. In practice, this means that the safety driver is responsible for ensuring the safety of both passengers and surrounding road users. Therefore, driver health is as important as for any professional driver.

2.2 Design

Following a quasi-experimental design data were planned to be collected over a 4-week baseline and 4-week intervention period. Ethics approval was granted by Swedish Ethical Review Authority (ref 2022-06398-01). Data in this paper is from baseline only.

2.3 Participants

Eight autonomous shuttle safety drivers (mean age 47.8, SD = 8.2, 2 female, 6 male) who all work full time. They were shift workers, meaning that they could be expected to work during the daytime, evening and weekend. Participants had held a car driving license for an average of 25.4 years (SD = 9.4, range 13–40).

2.4 Procedure

Each participant completed an entry questionnaire including questions related to fatigue. Throughout the study a daily evaluation diary was completed. In the baseline period driving performance and impairment levels were monitored using the PANACEA system but support tools, alerts or feedback were not given to the driver. During the intervention phase drivers receive warnings about their fitness to drive and countermeasures are delivered through relevant support tools. Unfortunately during the spring/summer period of 2023 the project experienced significant delay. As such only data collected in the background questionnaire is presented.

2.5 Coaching Support Tools

One element of the PANACEA system is the cloud based coaching system (CCS). This component of the system will deliver countermeasures informed by data gathered from PANACEA sensors and interpreted through the PANACEA decision support system (DSS). The cloud based coaching system has a modular design with the potential to grow if additional countermeasures are added in the future. The CCS for drivers can be accessed through an application on their phone or through a web interface. Two fatigue countermeasures used are Daily Fatigue Briefing and Fatigue Questionnaire.

Daily fatigue briefing.

The daily fatigue briefing was delivered to drivers to the app on their phone at the end of each shift. It provided an estimation of their alertness throughout the shift. The report considers the proportion of time when fatigue was experienced using a traffic light system to indicate overall fatigue performance for the day.

Fatigue questionnaire.

Drivers received the fatigue questionnaire after one week of fatigue reports. This short questionnaire uses a self-reflection approach with a goal to help the driver subjectively assess and contextualize their fatigue and assist in raising any issues with their employer. The fatigue questionnaire included questions such as “how problematic did you find fatigue this week? And “which strategies did you use to combat fatigue?”.

2.6 Measures

Questionnaire: All drivers completed a background questionnaire, which included questions about previous experience of driver fatigue. Overall sleepiness was measured using the Bordeaux Sleepiness Scale (BOSS) [11]. The maximum BOSS score is 8, scores of 3 or higher have a positive risk of having sleep-related near miss or crash. Self-reported amount of sleep obtained and amount of sleep needed were recorded.

Subjective sleepiness: Participants used a 5-point Likert scale from 1 = Never to 5 = always to rate how often they had had trouble keeping eyes open while driving during the past 30 days. Sleepiness was reported once at the start and once at the end of shift using the KSS, a 9-point Likert scale from 1 = extremely alert to 9 = fighting sleep [12].

Intervention experience: During the intervention phase participants completed a daily diary rating their experience of each countermeasure. This included: how accurate the information was and how useful it was deemed to be. The closing screen of each countermeasure asks if participants wished to share with their employer.

2.7 Statistical Analysis

Descriptive statistics of means and standard deviation are reported. BOSS scores were calculated to identify sleepiness risk. Reported sleep obtained was compared to stated sleep need. Mean KSS scores at the start and end of shift for each participant were calculated and compared for statistical significance using a paired t-test.

3 Results

3.1 BOSS and Sleep

Using the BOSS scale, two drivers were identified as at positive risk of driver sleepiness, one scoring 3 and the other scoring 5. Participants reported needing an average of 6.9 h sleep and obtaining 7.1 h sleep. 5 out of 8 participants reported the same amount of sleep needed as sleep obtained. Two participants reported obtaining more sleep than they needed, and one obtained less sleep. Results are shown in Table 1.

3.2 Experience of Driver Sleepiness

Over the past 30 days, 6 out of the 8 safety drivers (75%) reported never having experienced difficulty keeping their eyes open. Of the two participants who had had trouble keeping their eyes open, one rated 2 and the other 3 out of a maximum of 5, the higher of which was the same participant rating 5 on the BOSS.

Daily KSS is presented in Table 2. There was no statistical difference between KSS at the start and end of a shift ($t(7) = -1.489$, $p = .18$). The greatest increase in KSS across shift was experienced by the same participant who scored 5 on the BOSS. Only six out of the total 148 shifts (4%) recorded ended up with a KSS of 7 (maximum reported) this was experienced by P5 and P7.

Table 1. BOSS, sleep need and sleep obtained

Participant ID	BOSS	Sleep need (h)	Sleep obtained (h)
P1	2	8	8
P2	2	6	6
P3	1	7	7
P4	2	6	6
P5	5	6	8
P6	2	7	7
P7	3	10	7
P8	2	5.5	7.5

Table 2. KSS at the start and end of shift

Participant ID	Number of shifts recorded	Mean KSS start shift	Mean KSS end shift	KSS change over shift
P1	16	1.50	1.50	0.00
P2	16	2.94	2.81	-0.13
P3	17	3.00	3.12	0.12
P4	13	3.31	3.23	-0.08
P5	22	3.50	4.64	1.14
P6	16	2.00	2.50	0.50
P7	24	4.54	4.96	0.42
P8	24	3.08	2.96	-0.13

4 Discussion

Although fatigue is a potential problem for professional drivers [7, 8], it does not appear to be a challenge for the shuttle safety drivers in the current study. The majority (75%) of participants reported never having difficulty in keeping their eyes open during the past 30 days. As a group this makes this small population of safety drivers notably different to other bus drivers in Sweden, where it has been reported that 19% have to fight to stay awake while driving the bus 2–3 times each week or more [13]. A likely factor influencing this finding is that all but one of the safety drivers reported receiving as much or more sleep than they need. This is very different than the experience of London bus drivers in a much larger survey, where 70% of the sample reported that they did not get as much sleep as they needed [10]. Safety drivers are a self-selecting group of bus drivers who have volunteered to learn a new skill operating a novel vehicle. It is likely that they are not representative of bus drivers in general. It is possible that these participants are

particularly conscientious about their fitness to work as all reported obtaining sufficient sleep, likely why there was little evidence of fatigue.

This study is one of the first to use the BOSS [11], identifying two safety divers at positive risk of driver sleepiness. These drivers were the only ones to experience a KSS of 7 at least once suggesting that this tool is a useful predictor of those most at risk.

There was no significant difference in KSS at the end of a shift compared to at the start of a shift. The KSS reported here is for baseline data collection only with no intervention. The mean KSS at the end of a shift was 3 which equates to alert. This suggests that any intervention will be realized by targeting rare occasions of feeling sleepy.

As with all studies there are limitations. Firstly, the sample size of 8 is small however, it represents 100% of the safety drivers employed at this location. Shuttle monitoring as a profession is in its infancy therefore sample size of all research will necessarily be small. If drivers feared for their job subjective sleepiness may have been underreported, however, findings were anonymizing and not shared with employers thereby likely increasing accuracy. Report. The BOSS was originally designed to evaluate the sleep-related risk of driving in patients with sleep disorders [11]. In this study we apply the questionnaire to participants without sleep disorders, it is not clear if the validity of the scale remains for healthy population.

Safety drivers of autonomous shuttles rarely experience self-reported sleepiness. This suggests that fatigue is not a regular workplace hazard for them. However, at times, some safety drivers experience sleepiness. Attentive monitoring without an active task (such as driving) is demanding, therefore, sleepiness should be avoided. Interventions aimed at managing sleepiness (no matter how rare its occurrence) have an important role to play in safety because sleepy drivers are at increased crash risk [1]. Professional drivers of all vehicle types should be supported to remain alert through their shift.

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Factors Affecting the Yielding of the Priority to Pedestrians

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Abstract. The safety of vulnerable road users is a key priority for road safety worldwide. One of the most vulnerable road users group on the road is pedestrians. Every user on the road is also a pedestrian at some point in the transport chain (vehicle access; transfer between vehicles). In everyday transport, designated pedestrian crossing point (vehicle-pedestrian interaction) is one of the road safety risk points for pedestrians. Previous research has shown that several factors can influence pedestrian priority, but most of this research has looked at the problem from the pedestrian's perspective. Our research aimed to investigate which factors increase the drivers' willingness to give priority to pedestrians the most. We developed a self-reported questionnaire for drivers. The questionnaire included questions on the socio-demographic characteristics and driving habits of car divers and infrastructure design. The results were analyzed using descriptive statistics. We identified two factors that increase the willingness to yield to pedestrians at signalized pedestrian crossings, both collectively and at the subgroup level. Our results can be used in several areas: infrastructure planning, transport education, and enforcement.

Keywords: road safety · pedestrian safety · yielding for pedestrian

1 Introduction

The safety of vulnerable road users is a key priority for road safety worldwide. One of the most vulnerable road users group is pedestrians. Every user on the road is also a pedestrian at some point in the transport chain (vehicle access; transfer between vehicles) [1, 2]. In everyday transport, designated pedestrian crossing point (vehicle-pedestrian interaction) is one of the road safety risk points for pedestrians. Because of the different speed characteristics, accident-free interaction requires a high awareness of vehicles and pedestrians and maximum compliance with traffic rules. [3].

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The factors influencing drivers' yielding the right of way to pedestrians can be divided into several groups. Driver behavior is influenced by pedestrian behavior [4], pedestrian socio-demographic characteristics [5], as well as traffic flow and infrastructure design [6]. The willingness to yield is increased by pedestrian confidence [7], police presence [6], pedestrian grouping [8], and pedestrian signals [9, 10]. Drivers' willingness to give priority is reduced by the increase in the speed of traffic [11] and the increase in the number of lanes crossed by pedestrians [12]. To travel safely, pedestrians and drivers need to be fully attention. However, several studies have shown that distraction can also reduce driver [13, 14] and pedestrian attention [15, 16].

The literature review shows that many factors influence the yielding of the priority to pedestrians, but only a few of these factors are related to the individual driver. Our research aimed to investigate which factors increase the drivers' willingness to give priority the most according to the drivers' self-report.

2 Methodology

We have examined how drivers yield priority to pedestrians. We prepared a questionnaire for drivers to see whether they reported that the factors under investigation increase, decrease, or do not affect their willingness to yield to pedestrians.

Our questionnaire also included the pedestrian's gender, age, mode of travel (alone or in a group), speed of the vehicle driven, traffic around the driven vehicle (whether there was a vehicle in front or behind), traffic density, the existence of yielding situations around the driven vehicle (whether there was a yielding situation in front or the opposite direction), time of day and the existence of a pedestrian refuge island. We also asked about the socio-demographic characteristics of the drivers (gender, age), as well as the most common mode of transport in a day. In addition, each driver was asked how he/she, as a pedestrian, asserts his/her right of way at a signalized pedestrian crossing. The questionnaire was distributed and filled in online. 94 people answered our questionnaire and we analyzed the data in Microsoft Excel.

In evaluating the data, we have made categories. These groups were gender, age, main daily transport mode, and behavior as pedestrians. We also evaluated the data in aggregate and grouped them by factors using the following function (Eq. 1).

$$I_x = \frac{I_{x_i}}{I_{x_s}} \tag{1}$$

where I_x shows the percentage of respondents who think that the given factor (x: e.g. pedestrian is a woman) is a factor that would lead to an increase in priority ratings I_{x_i} shows the number of respondents who selected factor x as a factor increasing pedestrian's priority, and I_{x_s} was the total number of respondents who evaluated factor x.

3 Results and Discussion

94 respondents (61 women and 33 men) filled our questionnaire. Respondents thought that 3 of the 27 factors increased their tendency to yield the right of way to pedestrians on their journeys. Drivers reported that they are most likely to give priority when a vehicle has already stopped to give priority in the opposite direction (73.9%). Second most likely to give priority to those under 14 years old (64.5%), and then when there is a high volume of pedestrian traffic at the crossing point (48.9%). Only a high volume of vehicle traffic was thought by drivers to reduce their willingness to give priority (39.1%). Other factors were not thought to influence their willingness to give priority.

We present our research results in a table for each subgroup. The data in the table show the three factors that most increase the willingness to prioritize in rank order, starting with the one that increases it the most.

We analyzed the preferences of female and male drivers separately (Table 1). The two groups ranked the same factor first and second, but there was a difference in third place. Women tended to think that the volume of pedestrian traffic increased their willingness to yield the right of way, while men tended to think that the behavior of the driver in front of them was a more influential factor. This result may suggest that for men, the behavior of other road users is more dominant than for women.

Table 1. Factors increasing willingness to give priority by gender of respondents

rank of the factor	female		male	
	factor	rate	factor	rate
1	a vehicle has given priority in the opposite direction	73,8%	a vehicle has given priority in the opposite direction	74,2%
2	under 14 years old pedestrian	63,9%	under 14 years old pedestrian	65,6%
3	high pedestrian volumes at the pedestrian crossing	52,5%	a vehicle in front of my car has already given way	43,8%

We analyzed the age-group data in two age groups (Table 2). We defined the two groups by age characteristics. Those aged 20–34 are considered young drivers with young families, while those aged 35 and over are considered middle-aged and experienced drivers. The oldest respondent in our survey was 65 years old. Like the gender groups, the same factor was ranked first and second. The third most important factor for young drivers was their own vehicle' speed, while for older drivers the volume of pedestrian traffic was a more important factor in giving way. This shows that young people focus on their quick journeys, while older people are more sensitive to other road users.

Table 2. Factors increasing willingness to give priority by age group of respondents

rank of the factor	20–34		35+	
	factor	rate	factor	rate
1	a vehicle has given priority in the opposite direction	73,1%	a vehicle has given priority in the opposite direction	75,0%
2	under 14 years old pedestrian	67,3%	under 14 years old pedestrian	61,0%
3	driving slower than the speed limit	51,0%	a high pedestrian volume at the pedestrian crossing	50,0%

For the main daily transport mode (Table 3), we could not find a different ranking for any subgroup. This shows that regardless of which mode of transport is the main transport mode chosen by road users in their daily lives, there is no difference in their compliance behavior and preferences.

Table 3. Factors increasing willingness to give priority by main daily transport mode of respondents

rank of the factor	vulnerable road user		car driver		passenger of public transport	
	factor	rate	factor	rate	factor	rate
1	a vehicle has given priority in the opposite direction	66,7%	a vehicle has given priority in the opposite direction	83,7%	a vehicle has given priority in the opposite direction	64,0%
2	under 14 years old pedestrian	58,3%	under 14 years old pedestrian	68,2%	under 14 years old pedestrian	64,0%
3	a high pedestrian volume at the pedestrian crossing	50,0%	a high pedestrian volume at the pedestrian crossing	51,2%	a high pedestrian volume at the pedestrian crossing	44,0%

We also examined the responses according to the behavior of the road user when participating as a pedestrian (Table 4). The responses showed no difference in the first two factors in the ranking, but the third factor differed significantly between subgroups. For those who enforce their right of way as pedestrians, we could not identify any other factor that increases their willingness to give way. For those who wait for their priority, the most influential factor is the volume of pedestrian traffic (if they are drivers). For those who cross when there is no vehicle nearby (most conflict avoiders), the most influential factor is slow vehicle speed. In addition to these, although not shown in the table, 7 other

factors were considered to increase priority for conflict avoiders as pedestrian crossers. The results show that there is a difference in the behavior of road users. Those who assert their will and intentions as pedestrians also tend to prioritize their transport as drivers.

Table 4. Factors increasing willingness to give priority by respondent's behavior as a pedestrian

rank of the factor	enforces the priority		wait for the priority		no vehicle nearby	
	factor	rate	factor	rate	factor	rate
1	a vehicle has given priority in the opposite direction	73,3%	a vehicle has given priority in the opposite direction	72,5%	a vehicle has given priority in the opposite direction	87,5%
2ő	under 14 years old pedestrian	53,3%	under 14 years old pedestrian	68,6%	over 14 years old pedestrian	62,5%
3	-	-	a high pedestrian volume at the pedestrian crossing	49,3%	driving slower than the speed limit	62,5%

4 Conclusion

As vulnerable road users, pedestrians are one of the most vulnerable users of our transport system. Their road safety is influenced by their and other drivers' behavior. Our research was therefore conducted on drivers' tendency to yield the right of way to pedestrians. For this purpose, we developed a questionnaire to investigate the behavior of drivers concerning pedestrians.

Our research results answer our initial research question, as we identified two factors that increase the willingness to yield to pedestrians at signalized pedestrian crossings, both collectively and at the subgroup level. The results showed that the willingness to yield the right of way is most dependent on the behavior of the driver driving in the opposite direction, according to both the aggregate and subgroup opinions of the respondents. This is an unfortunate fact, as it does not indicate voluntary compliance with the rules, but rather following the behavior of the other road user. Children were ranked second by respondents (both overall and subgroup) as the factor determining priority. This shows that most drivers consider the safety of children to be important and that they are the most cared for. For young drivers, driving more slowly increases compliance, but this was not the case for older drivers. We also found that pedestrians with conflict-avoidant behavior may also be more compliant as drivers.

However, our research also has limitations, which we plan to resolve in our future work. One of these limitations was the small sample size. The large sample size of the survey may affect the current results. Another limitation was that currently only pedestrian crossings with signage, and no refuge island were asked many of the questions.

The transport system has several other infrastructure improvements, and the results in these cases may be different. Thirdly, the results measured now are based on self-reporting, so they may be distorted towards real behavior. In the future, we plan to support our research with on-site measurements to determine the actual road user behavior.

Our results can be used to show which factors are the most important determinants of pedestrian safety for drivers. However, with the use of future extended research and results, pedestrian safety can be targeted for improvement.

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For the Price of Freedom – Perceptions of Car Use

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Abstract. This interview-based study seeks to gain insight into the varying motivations behind car usage across different societal groups, alongside their attitudes towards travel behavior and transportation options. Its overarching goal is to delve deeper into the factors and constraints that influences individuals' car use and mode choice. The research methodology involves collecting one-month travel data and considering individual characteristics while selecting a diverse cross-section of the Swedish population. The study is underpinned by the ontological viewpoint of time geography and the concept of "constraints", forming the foundation for the analysis. The findings suggest that the connection between individuals and their cars represents freedom of mobility but also a dependence to a varying degree between different life stages and level of car orientation. The primary influencing factor for modal choice appears to be individuals' perceptions of alternative transportation options and their practical viability. The outcome of the study indicates the value of analyzing individual and external constraints of different groups in order to further understand the perception of transportation options.

Keywords: Car use · travel behavior · constraints · sustainable transitions

1 Introduction

As the transport system faces the need for a transition from the personal car, the subject of behavioral change is put at the forefront. It is important to understand how cultures and attitudes affect the propensity for sustainable transitions (Sovacool & Griffiths 2020), as well as how people's everyday lives are structured in different life-stages (Berg et al. 2015). Therefore, any understanding of constraints must also consider the variations during different stages of life as well as car-orientation (Smidfelt Rosqvist & Winslott Hiselius 2019).

Segmentation based on travel behavior and attitudes has been used previously (e.g. Andersson et al. 2020), but with shorter time spans, hence not capturing the overall picture of travel on the individual level over time.

In addition, the constraints and preconditions for people need to be further understood in order to facilitate transitions to less car use. There are studies focusing on constraints e.g. (Berg & Ihlström 2019; Stjernborg 2014, 2021), however more studies

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are needed on different societal groups. The purpose of this study is therefore to deepen the understanding of the constraints and enablers present in different life-stages and how these affect the choice of travel mode. The study utilizes one-month travel data and information on individual characteristics in the recruitment of individuals representing a broad spectrum of the Swedish population. The concept of constraints forms a base for the analysis, especially in relation to age and occupation.

The paper is structured as follows. In the first chapter, the ontological perspective and theoretical approach used is outlined. Thereafter method and data collection are described. The result section starts with a description and analysis of the answers given with a following comparison of similarities and differences between studied groups. In the concluding section, the main results of the paper are pointed out.

2 Theory

For the purposes of this study, time geography is employed as an ontological perspective, centering on everyday mobility projects (Ellegård 2018; Hägerstrand 1970). The perspective is used due to the focus on the everyday life of the participants. All people exist in time-space and undertake mobility projects for which they rely on different strategies to complete (Hägerstrand 1970).

Mobility projects are sometimes hindered or abandoned. Hägerstrand (1970) breaks down these obstacles into different concepts of constraint – capabilities, coupling, and authority. Capabilities refer to constraints which concern the resources available to the individual. They can be physical as well as mental, economic, and transportation resources.

Scaling up, authority constraints concern the different forms of power relations present and how they hinder the individual in completing projects in everyday life. For example, restricting access to different spaces, as well as how regulatory or planning decisions affect the daily lives of citizens.

Between these two scales lie the coupling constraint, due to what is referred to in time-geography as coupling and de-coupling (Ellegård 2018). This refers to the act of bringing people or things together in order to complete a project. The constraint arises when coupling needs are not met, or when de-coupling is not possible. Constraints also interact with each other in different ways and reinforce or affect each other.

3 Methods and Data

This interview-based study seeks to analyze how people in different ages and car use habits reason about their travel behavior and perception of different travel modes. The participants were recruited from a project using travel survey data financed by the Swedish Energy Agency (Grant nr 51083-1). Within that project, travel survey data were collected during one month (autumn 2021) using a phone application. The total data set included 475 participants, 13 160 validated days and 55 272 trips. In the previous project, a cluster analysis was conducted to identify individuals exhibiting similar patterns of car usage. Based on the share of total car-milage and the share of total population, clusters were defined as being more or less car oriented.

Based on information on travel behavior and individual characteristics, 39 individuals were recruited and interviewed in this present study. The participants were recruited aiming for a spread in age, occupation, car use, gender and type of area of living. The interviews were carried out by phone during spring 2022. The interviews concerned three themes: the current travel behavior, views of car use and effects on personal life if reducing the use of cars.

Before the analysis of the stated answers, the participants were sorted into 4 groups based on occupation (working/retired) and high/low degree of car-orientation based on the cluster analysis previous described, see Table 1.

The material has been analyzed using thematic analysis (Braun & Clarke 2006), focusing on the themes of car use and travel behavior through the lens of time geography presented above. The analysis was conducted by an extensive reading of the material, followed by coding into themes using NVivo software for each group according to Table 1 to facilitate a comparison.

Table 1. Individual characteristics per studied group

Group	Participants, total	Women	Men	Living in urban area	Living outside urban area	Age span, mean
Retired and high car orientation (RHC)	10	5	5	7	3	65–74, 70.8
Retired and low car orientation (RLC)	7	5	2	5	2	68–75, 71.4
Working and high car orientation (WHC)	9	3	6	7	2	31–73, 53.7
Working and low car orientation (WLC)	13	7	6	12	1	31–62, 48.6

4 Results and Discussion

4.1 Retired and High Car Orientation (RHC)

Three of the participants in the group of retirees with a high car orientation live outside urban areas. They describe the car as the most convenient alternative for them. The car as a coupling tool is necessary for them to be able to live their life, and several participants

in this group strongly argue that the car could never be replaced by other options. Some point to the freedom it allows as paramount, while others pragmatically argue that they otherwise would not be able to reach the destinations they go to in everyday life. Here, a coupling constraint arises when time-constraints can't be overcome, and the car is therefore used as a tool to overcome this constraint.

4.2 Retired and Low Car Orientation (RLC)

Two participants in the group of retired persons with low car orientation live outside of urban areas. While both think the car is needed to reach some destinations, they describe using public transport when they can. They describe often combining journeys by driving to a bus- or train station. The distance to the station creates a constraint which needs to be solved using other forms of transport. It takes the form of an authority constraint, as the planning decisions limit their access to the public transport system.

Another participant from the retired low car-oriented group describes herself as a "public transport person" and explains that she lived most her life without a car. Similarly, another participant describe that she has always lived close to public transport and does not need a car. However, she also relates this to the capability constraint of not having the economic resources of owning a car.

4.3 Working and High Car Orientation (WHC)

Two participants in the group of participants that are working and have a high car orientation live outside of urban areas. Both describe their everyday life as car-oriented, and they view it as impossible for them to reduce their car use. The authority constraint arises from the lack of other transportation options, and they think it would be impossible to live where they live without owning a car.

The care of children contributes to a coupling constraint, and participants argue that the car is needed to overcome this. The coupling constraint can also take the form of an authority constraint, as the planning of public transport affect the ability to use it in their everyday life. The car is viewed as the solution which simultaneously has the capacity to overcome capability, coupling, and authority constraints.

4.4 Working and Low Car Orientation (WLC)

Only one person in this group of participants working and with a low car orientation lives outside an urban area. Several participants state that they have moved into urban areas in order overcome a coupling/authority constraint and to be able to commute and reach destinations by bike or public transport. While some do relate the car to a sense of freedom, most use a bicycle or car and avoid public transport. Participants often argue that public transport is too time-consuming or inconvenient, but unlike the group of individuals working and with a high car orientation, there seems to be a larger gravitation towards biking or walking instead.

Two participants in the working low car-oriented group do not own a car and as such need to use public transport for most of their transport needs, along with a bicycle.

They both find that a car would be too expensive, both for maintenance as well as paying for parking, which highlight an economic constraint of owning a car. Several other participants describe the car as expensive and troublesome, especially in terms of parking. Rather than being a symbol of freedom, the participants argue that the car imposes a constraint on them, mainly due to the cost of owning it.

4.5 Commonalities Among the Groups

A theme found irrespectively of life stage and car orientation is the notion that public transport is too burdensome to use in daily life. This poses a coupling as well as an authority constraint. Furthermore, participants in different life-stages as well as different car-orientations stated that they could not reach some of their everyday activities with public transport (authority constraint - access not planned for).

Another constraint for participants in all life-stages and car orientations was found regarding grocery shopping, as most used a car to shop for groceries. This constraint foremost related to two different factors: heavy bags and long distances to stores. This positions the constraint as a coupling constraint, as the carrying of heavy bags prevented the coupling with public transport. In addition, a participant explained that the stores she visited in the city center were more expensive than the larger ones in the outskirts. This is therefore also connected to the economic capabilities of the individual. The car can lower the cost of groceries, which therefore can serve as an argument for keeping the car.

In sum, at least some participants in each group, regardless of life-stage or whether car oriented or not, stated that it would be hard to give up the car. Most common were activities such as grocery shopping and trips to vacation homes.

4.6 Differences Between the Groups

While the participants in the group with high car-orientation mostly described the car as a source of freedom, their descriptions also reveal a dependence on the car. A failure of this coupling is detrimental to their mobility (coupling constraint). This symbol is of course also related to the provision of other kinds of transport available, however, as most participants in all groups live in urban areas, the constraint cannot be clearly derived from the lack of other forms of transport. Rather, the more important factor seems to be the perception of other forms of transport and the feasibility of using them. To encourage transitions to other forms of transport, breaking habits, or changing perceptions of other forms of transport might be just as important.

In the WLC group, participants stated that they had moved to an urban area to be able to use the car less, which indicate that people who want to reduce car use might relocate to where other forms of transport are more readily available. While the participants living outside of urban areas highlight the authority and coupling constraint provision of transport, many with access to transport still use the car a lot.

Contrasting the car as the symbol of freedom of mobility, the WLC group often describe the car as a financial burden. Instead, this group often view the bicycle as the enabler of freedom of flexibility. This can both be seen as a way to use available resources

(physically healthy) to ward off other forms of constraints, in a way that is not present in the RLC group.

The tension between the car as an enabler or as a dependency is evident both when contrasting groups as well as within them. It can especially be found when discussing future changes to driving habits. Most high car-oriented people view the car as a convenience, often describing that they don't have to wait, that they can go when they want, where they want. This notion of freedom includes the ownership of the vehicle, which meant that car sharing solutions and renting a car were not viewed as an attractive alternative by many participants. It also ties into the question of available resources and represents a potential capability restraint as it depends on the capabilities available to the individual (which is also structural). The high car-oriented groups use their resources (capability), to solve the coupling and authority constraint that public transport represents for them. Similarly, the WLC group are able to use their capability in order to overcome the same constraint by biking. However, the RLC group has comparatively lower capabilities, and therefore might be more vulnerable to all forms of constraints than the other groups studied.

5 Conclusion

The result indicates that the coupling of the car and the person represent a form of freedom of movement but also dependence to a varying degree between different life stages and level of car orientation. The result suggest that it can be partly attributed to a hesitancy toward changing habits, as well as the constraints experienced by different groups. The study further shows the importance of understanding the constraints and capabilities experienced by different groups in order to analyze the perception and use of travel modes.

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Revolutionizing Urban Safety: Multi-functional L7 Vehicles with Enhanced Safety

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Abstract. The REFLECTIVE project focuses on developing a versatile L7e heavy quadricycle designed for urban transportation of people and goods. Safety is a top priority, given traditional quadricycles' safety concerns. Weight limits imposed by the L-category classification pose a challenge, necessitating the use of sustainable materials to reduce weight, improve energy efficiency, and extend the vehicle's range.

Versatility is a key design principle, which is intended to meet a variety of use cases and requirements. However, due to current regulations, it is not possible to homologate the same vehicle for passenger and freight transport (L7e-CP $\leq$ 450 kg and L7e-CU $\leq$ 600 kg). The current type-approval only allows for one of the uses. However, the vehicle intends to give both options of use to explore what this would mean in terms of design.

L7e heavy quadricycles are gaining popularity for their economic and eco-friendly features. Yet, safety concerns persist, prompting action. The Euro NCAP campaign evaluated safety performance in heavy quadricycles, revealing significant disparities among models. In response, the REFLECTIVE project is enhancing safety by strengthening vehicle structures and improving occupant restraint systems. These measures address crash risks, reduce potential injury severity, and enhance overall occupant safety, making quadricycles safer for urban use.

Keywords: multi-functional vehicle · urban safety · L7 vehicle category · improved safety · type approvals for L7 type vehicles

1 Context of Challenges in Urban Environments for Vehicles

Cities must face the double challenge of regulating traffic and reducing congestion. The use of fleet-based business models for urban transport looks promising. Tailoring vehicles for specific purposes can reduce costs, but user acceptance, especially of L7 vehicles, depends on safety. Hence, the main objective of the project is to create safe and high-performance light electric vehicles.

Multifunctional fleet vehicles are a solution to urban congestion and the dominance of the private car. Their off-peak operation enables efficient distribution of goods and passengers, mitigating peak-hour congestion. Reliability, safety, energy efficiency and

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innovation are key factors in designing vehicles that meet the demands of fleet operators and facilitate new business models. The adoption of these vehicles advances sustainable urban transport, benefiting both residents and the environment.

2 Methodology

The process of the project:

- Conducting a State-of-the-Art analysis and Benchmarking for Safety
- Performing Feasibility Studies for Ergonomics, Comfort, and Safety
- Establishing Boundary Conditions
- Identifying Gaps
- Offering High-level Regulatory Recommendations
- Conducting Virtual CAE Simulations
- Evaluating Physical Crash Tests

Fig. 1. Subsystem Crash Frontal. Source: Applus IDIADA, 2023

The project aims to improve the vehicle's impact resistance, with the safety targets set to be close to the high-performance limits of consumer testing heavy quadricycle campaign, so far typical L7e quadricycles have received a maximum of 2 stars in Euro NCAP ratings (Fig. 1).

The crumple zone has been reduced to a minimum to maintain the small city car concept and at the same time improve the frontal structure to ensure adequate energy absorption in the event of a frontal impact.

There are no safety regulations for L7 vehicles, therefore the sources are based on the Euro NCAP campaign for Heavy Quadricycles performed in 2014 and 2016, we found limited references on the market. To address this, we designed and validated several tubular structures with different materials and thicknesses in parallel with virtual simulations to anticipate their behaviour in case of side and frontal impact.

The improved safety performance of the vehicles will be validated through a combination of virtual simulations and physical crash tests, all conducted according to up-to-date safety protocols.

These assessments will analyse the structural durability of vehicles, the effectiveness of occupant restraint systems and other critical safety-related factors. This includes

specialized restraint systems and steering wheels with airbags designed for the vehicle (Fig. 2).

Fig. 2. Vehicle tubular structure. Source: AUVETECH, 2024

3 Development of the REFLECTIVE Vehicle

The REFLECTIVE project focuses on designing and developing an L7 category vehicle from scratch. The design process follows a traditional methodology, starting with a concept phase where the volumes of various vehicle systems are allocated to make new requirements and user needs feasible for specific use cases. These vehicles include both plug-in electric and wireless inductive charging systems. They also plan to test an autonomous ADAS charging system, which is challenging due to limited space and positioning requirements. The concept phase involves space allocation and designing key systems like the powertrain, thermal management, charging, and suspension system (Fig. 3).

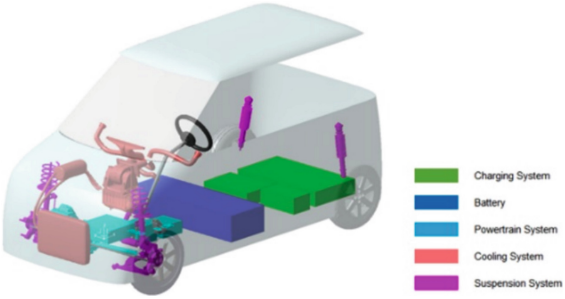

Fig. 3. REFLECTIVE Package of Main Systems, Source: AUVETECH 2022

3.1 Design and Features of REFLECTIVE

Currently, vehicles in the M-category are overly large, while those in the L-category lack safety and comfort. The project's objectives include achieving M-category comfort and

safety levels while maintaining L-category sustainability features. The primary focus is on minimizing dimensions without sacrificing performance (Fig. 4).

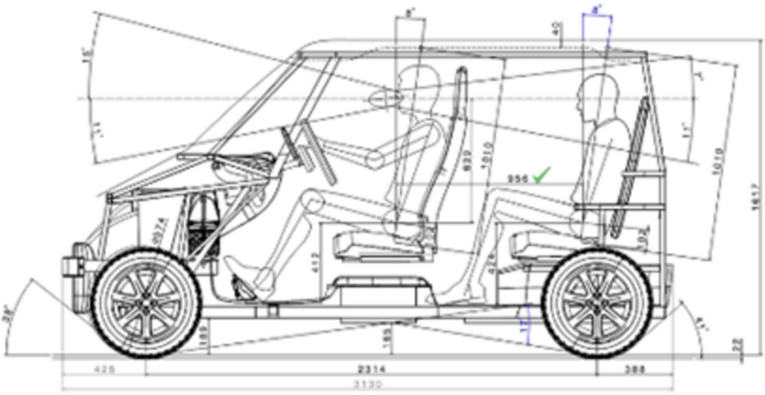

Fig. 4. Packaging and Feasibility Studies. Source: IDIADA, 2023

3.2 Adaptability to Various Use Cases

Creating a versatile multi-functional vehicle with adaptable interiors is essential to meet a range of usage scenarios. This vehicle is carefully crafted to serve both passengers and cargo, emphasizing accessibility, safety, and efficient space utilization. With a total load capacity of 400–450 kg, encompassing passengers and goods, we've identified specific use cases to guide our design process.

These use cases include accommodating individuals with reduced mobility, serving as a taxi, facilitating trips to grocery and hardware stores, enabling food and newspaper deliveries, supporting small clothing shop deliveries, and transporting gardening materials or cement.

The initial proposal includes two front and two rear seats, with a focus on accommodating either an 800*600 EUR-pallet or two washing machines in the goods delivery configuration. The accompanying images illustrate our initial concepts for each use case. Multi-functional vehicle design is geared towards meeting the diverse needs of transporting both people and goods. By carefully considering these specific use cases and incorporating features like accessible doors, robust safety structures, and flexible seating arrangements, we aim to provide efficient solutions for urban mobility and logistics. The versatile vehicle design meets urban transportation and logistics needs by accommodating both people and goods, with an emphasis on safety and flexibility (Fig. 5).

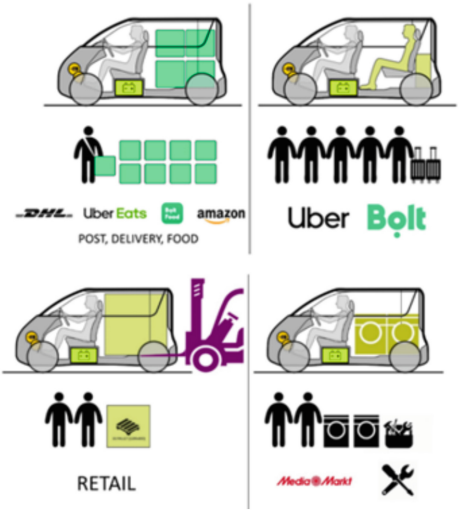

Fig. 5. Concept Study for different Use Cases. Source: AUVETECH, 2021

4 Conclusions and Challenges

The new fleet of vehicles would offer a solution to urban congestion caused by excessive private car use today, as it can provide adaptable off-peak services. This vehicle is designed to meet the diverse needs of customers and operate 24 h a day, 7 days a week, optimising transport operations and reducing congestion during peak hours.

Key factors such as reliability, safety, energy efficiency and innovative features are crucial in its design, making it a sustainable transport option. With the acceptance of these vehicles, cities can draft by-laws that allow prioritisation of road use according to the time of day, considering all that this type of fleet can offer to citizens.

But vehicle development still presents challenges that require attention for optimal production and functionality:

- Passenger safety systems require the implementation of restraint systems with airbags, seat belts and configured software which will also increase the cost.
- The tubular structure designed for frontal and side crash tests requires high-strength steel in some areas or safety-enhancing aluminium, but this has a high production cost, and it is essential to find cost-effective manufacturing techniques without compromising safety.
- Designing exterior and interior cladding with eco-sustainable materials involves several issues. A balance needs to be struck between cost, durability, assembly methods and material compatibility to find cost-effective and environmentally friendly solutions.
- Seating flexibility to accommodate passengers with diverse needs remains a challenge. Priority must be given to the inclusion and comfort of all users, especially the driver, who will spend most hours in the vehicle.
- Accessibility in small vehicles ensuring easy access and comfort for people with reduced mobility is vital to promote inclusion (Fig. 6).

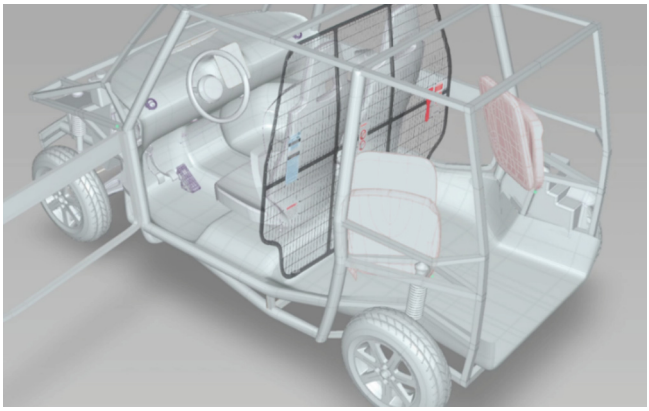

Fig. 6. REFLECTIVE Use Case with Cargo Separation. Source: AUVETECH 2023

Addressing these challenges can lead to multifunctional fleet vehicles that offer truly efficient, sustainable, and safe mobility solutions for urban environments. This means limiting weight-based usage, leveraging regulations for future designs, collaborating with suppliers to achieve compact and integrated systems, and leveraging sensor technology and connected vehicles to increase safety.

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Factors Modeling the Consumer Adoption of Electric Vehicles in Varanasi, India – An Extended UTAUT Model

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Abstract. It is known that Electric Vehicles substantially reduce transport fuel consumption and carbon emissions. Therefore, governments worldwide promote EVs. The Government of India (GoI) has also launched a series of policies and schemes to help promote the adoption of electric vehicles. The first national mission document, the "National Electric Mobility Mission Plan", was launched in 2013, followed by "FAME (Faster Adoption and Manufacturing of (Hybrid & Electric Vehicles)," in 2019. Other than this, different states have also produced different state policies to promote the adoption of electric vehicles. With different market players like TATA Motors and Mahindra producing electric cars for Indian consumers, it becomes essential to study the willingness of people to adopt this technology at the consumer level. To study this, we will apply the Unified Theory of Acceptance and Use of Technology (UTAUT) model and assess the factors involved in adopting the EV at the consumer level in Varanasi, India. The study will help in understating the willingness of people to adopt electric vehicles and also expand on the knowledge of how to promote these automobiles. It will eventually lead to identifying the needs of people in the sector of electric vehicles to form better sustainable transportation.

Keywords: Electric vehicle · Behavioral Analysis · UTAUT Model · Sustainable Transportation · India

1 Introduction

India is one of the fastest growing countries worldwide both economically and demographically. As expansion and improvement in road transport normally serve as a stimulus for socio-economic development, it also produces several negative environmental problems in India [1]. In the year of 2023, India has become the world's third-largest crude oil consumer as its imports dependency increases to 87.8% to meet the domestic demand, especially in transportation sector [2]. In the environmental sector, India has ranked 8th in the worlds most polluted country ranking for the year of 2022 with Mumbai being the most polluted city in India [3]. Currently the road transportation sector of India reports 12% of India's energy-related CO2 emissions and is also a significant source to urban air pollution [1]. Indian transportation sector is the largest oil user and second largest producer of CO2 emissions worldwide. As there have been rapid increase

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in automobile adoption since the last ten years, Indian transportation have reported for one-third of the total crude oil expended in the country, where 80% is for road transportation [4]. As India seeks to meet the increasing demand for transport sector, energy use and CO2 emissions from road transport could double by 2050 if necessary actions are not ensured [1].

This led to India making amendments and introducing new Electric Vehicle schemes and plans. The National Electric Mobility Mission Plan 2020, as notified by the Government of India, aims to augment the country's energy security, address the negative environmental consequences associated with road transport vehicles, and bolster the domestic manufacturing capacity for Electric Vehicles. Furthermore, the government has implemented Phase-II of the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, which aims to boost the electric vehicle (EV) market in the country. Additionally, they have deregulated the charging infrastructure industry and established guidelines and standards for EV charging infrastructure. This move has opened up opportunities for the development of public charging infrastructure and provided a clear roadmap for its growth. Moreover, the government has introduced several financial incentives to reduce the initial costs associated with EVs and charging infrastructure. As a result, EV usage has started to expand over the last five years due to legislative and regulatory backing [4].

These policies have led to the involvement of different market players like TATA Motors and Mahindra producing electric vehicle for the Indian consumers. Thus, it becomes imperative to study the willingness of people to adopt this newer technology at the consumer level. This can be assessed using The Unified Theory of Acceptance and Use of Technology (UTAUT). So, in this study we will apply the Unified Theory of Acceptance and Use of Technology (UTAUT) model and measure the factors involved in adoption of electric vehicle at consumer level in Varanasi, India.

2 Literature Review

This section will detail each factor under Unified Theory of Acceptance and Use of Technology (UTAUT) Model and the additional factor used in the study.

2.1 Unified Theory of Acceptance and Use of Technology (UTAUT) Model

In India, EV is a comparatively new technology. There have been a few researches done on the intentions to adopt EVs and to analyze individuals' acceptance and the consumers' intention to adopt regarding this developing technology [5]. In the past years, India has also been involved in promoting Electric Vehicles by introducing missions and schemes like The National Electric Mobility Mission Plan 2020, and Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme [4]. Even though Electric Vehicles are believed to be good alternative for conventional vehicles to help in reducing climatic change and energy security issues, the penetration of EVs is very low especially in the developing countries like India [6]. There have been studies done which highlight that consumer perception and behavior is just as important as factors affecting rapid adoption of Electric Vehicles [7, 8].

The consumer acceptance for Electric Vehicles adoption is decided by their individual decision-making. Therefore, it becomes important to classify the factors which not only enhance but also increase Electric Vehicles adoption at a personal level [9, 10]. This is where the use of Unified Theory of Acceptance and Use of Technology (UTAUT) Model is needed.

In the year of 2003, Viswanath Venkatesh, Michael G. Morris, Gordon B. Davis and Fred D. Davis came up with the behavioral model that was a combination of eight models i.e., "the theory of reasoned action, the technology acceptance model, the motivational model, the theory of planned behavior, a model combining the technology acceptance model and the theory of planned behavior, the model of PC utilization, the innovation diffusion theory, and the social cognitive theory" [11]. This model consisted of four core determinants and four moderators of key relationships. This was the first Unified Theory of Acceptance and Use of Technology (UTAUT) Model. In the future years many extensions of this model were created and one of them was UTAUT2 Model. It added 3 new constructs and three moderators [12].

Similar to the aforementioned study, this study involves the UTAUT2 Model which consists of the same seven factors which were "Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), Facilitating Conditions (FC), Hedonic Motivation (HM), Price Value (PV) and Habit (H)" with the moderators as age, gender, and experience [12]. To this, we will be adding the factor of Environmental Benefits (EB) as the major reason for this technological invention is to reduce the environmental impact of the transportation sector.

3 Methodology

The aim of this study is to assess the factors involved in adopting the Electric Vehicle at the consumer level in Varanasi, India. The study will not only help in understating the willingness of people to adopt electric vehicles at the consumer level in the city but also expand on the knowledge of how to promote these automobiles. It will eventually lead to identifying the needs of people in the sector of electric vehicles to form better sustainable transportation.

The objectives to identify the constructs, moderators, and models, to assess the behavioral intention at consumer level; to evolve and test an UTAUT2 model; to analyze impact of age, gender, and experience on the model; review the analysis to learn the constructs which effect the adoption of electric vehicle at consumer level.

For the study a questionnaire was developed survey was conducted in the campus of Indian Institute of Technology - Banaras Hindu University (IIT-BHU) Varanasi. Our target group were the residents at the college campus as they will be the upcoming primary users of this growing technology in India. The survey sample also showcases the willingness and excitement among the future generation in then technological spaces. A total of 184 samples were taken throughout the campus in a period of 6 months from January 2023 to June.

4 Results and Discussions

The following analysis was done on the results were produced as below. The model's fitness was assessed through confirmatory factor analysis (CFA). The results show that NFI = 0.76, CFI = 0.81,GFI = 0.84 and RMSEA = 0.054 (Fig. 1).

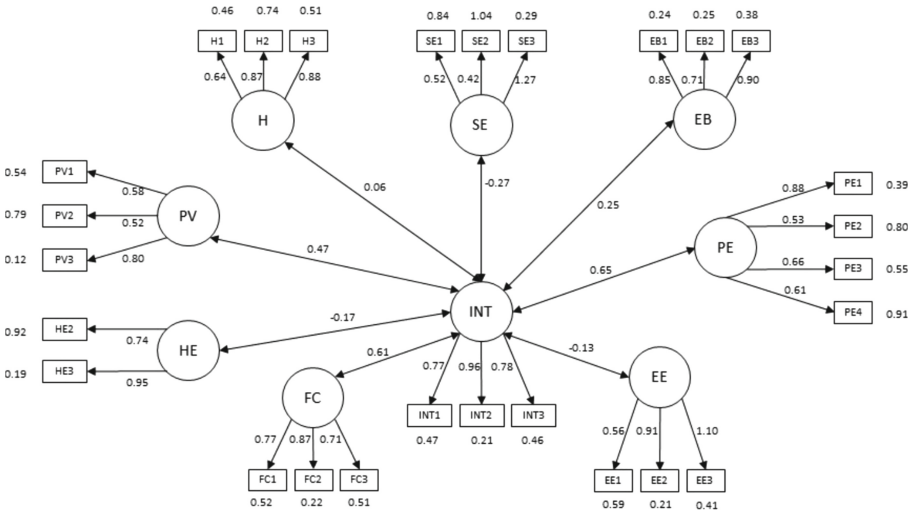

Fig. 1. Summary of the PLS-SEM results

The above analysis was done on the following factors, Intention to Adopt (INT), Performance (PE), Effort Expectation (EE), Social Effect (SE), Facilitating Circumstances (FC), Hedonic Incentive (HE), Price (PV), Habit (H) and Environmental Benefit (EB). These results indicate that factors pertaining to Performance (PE), Facilitating Circumstances (FC), Price (PV), Habit (H) and Environmental Benefit (EB) have a positive and significant while factors like Effort Expectation (EE), Social Effect (SE) and Hedonic Incentive (HE) have a negative and insignificant effect on impact on the overall intention to adopt and Electrical vehicle in the future.

In the above results, it is seen that three of the major features impacting the intention to adopt an Electric Vehicle for a consumer are its Performance (PE), Facilitating Circumstances (FC) and Price (PV) factors. These results show that the chances for a consumer to accept an electric vehicle will be greater if they provide a better or closer alternative to conventional vehicles in the aforementioned factors. While the performance of the vehicle is important for a consumer, it becomes equally vital to have its supporting infrastructure for it to function appropriately and if it's in their price range or compactivity priced compared to a conventional vehicle.

5 Conclusion

In India, the use and adoption of Electric vehicles have been an eminent topic of discussion for the last few years. Since 2011 when India took its first step into electric vehicle sector, the government have been introducing different national policies like, National Electric Mobility Mission Plan (NEMMP) 2020, Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles (FAME) – I and II, to encourage the use of electric vehicle. Other than that, a total of 29 States and Union Territories have proposed their State EV Policies out of which only 2 are in draft stage [13]. Due to this there has been a widespread knowledge of the Electric Vehicle at the consumer level. This is where the study helps in understating the willingness of people to adopt electric vehicles at the consumer level in the city and point towards the areas which we need to assess further to increase the acceptance of electric vehicles. With the use of UTAUT model, we could highlight the important factors that are lingering in the potential future user's mindset which they consider while accepting the emerging technology and adopting electric vehicle in the future.

The limitation of the study can be attributed to a relatively smaller sample size, and it is also to be noted that in India and its consumer market, Electric Vehicle is still an evolving technology and new factors may come up in future which may significantly impact the intention to adopt an Electric Vehicle.

There is a lot of scope for future studies in this area. The researchers recommend that assessment of each factor and its relationship with intention to adopt can be further explored using different analytical models. Also, dissemination of each factor and pinpointing the criteria under each of them that can hold a larger impact to the intention to adopt can also be researched upon through both qualitative and quantitative methods. These factors will prove invaluable to policy makers to formulate the new Electric Vehicle Adoption Policies in the country and can also contribute electric vehicle manufacturers into focusing on the factors which entice the potential burgeoning market.

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Public Transport Use and Challenges Faced by Immigrants, Refuges, and Roma Populations

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Abstract. Migration is a complex global phenomenon influenced by factors such as conflicts, economic crises, and climate change. This study focuses on the challenges faced by immigrant, refugee, and Roma (gypsy) populations in Western Greece when utilizing public transport. Western Greece is marked by increased migration due to agricultural and rural employment opportunities. Data were collected through collaboration with the Regional Asylum Office of Western Greece and accommodation facilities, involving the distribution of questionnaires to these specific groups. Initial findings reveal that 81% of respondents depend on public transportation for daily commutes with 60% using it on a weekly basis, even though the majority owns a private vehicle. Bus services are the preferred mode for both urban and interurban travel. A comparison between bus and train passengers shows differences in income levels and exposure to legal and ticket inspections. Challenges faced by these communities include dissatisfaction with ticket pricing and public transport reliability. Lastly, behavioral issues and discrimination also significantly affect passenger experiences.

Keywords: Public transport · train · bus · challenges · needs · migration populations

1 Introduction

Social and financial crisis assist in increase migration and refugee levels. Migration is a worldwide challenge that affects societies in terms of the economy, coherence, cultural diversity, and governance. Over the past five decades international migrants have been increased while in 2020 they were reached 281 million [1], while refugees rate the last year increased to 35.3 million [2]. Greece occupies a key strategic position through which a significant volume of migration transits. In 2022 Greece refugees were 34.36% increased from 2021 [3].

Literature have highlighted the challenges faced by immigrants and refugee populations regarding to Public Transport accessibility and use. Many factors that influence immigrants' travel behavior have been also studied [4], such as the affordability and transit accessibility [5]. A study in Minnesota USA find that immigrants are more likely to live in areas with high transit accessibility and are more likely to use transit [6]. Lastly,

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it is important to consider cultural and financial backgrounds of immigrant and refugee populations to develop policies for Public Transport planning [7].

The expected increase in immigrant and refugee populations globally the next years raises several challenges that demand attention. Regarding public transport utilization, addressing migration challenges and understanding their requirements and usage patterns in relation to public transportation presents a growing issue that needs to be faced. This paper aims to clarify the needs and challenges faced by immigrants and refugees in Achaia, Greece, and provide comprehensive solutions to facilitate their efficient integration.

2 Methodology and Results

This study examines public transport use by immigrant, refugee, and Roma (gypsy) populations in the region of Achaia, in Western Greece. The particular territory is characterized by increased number of immigrants and refugees because of the rural activities and farm works. Data were collected with the aid of the Regional Asylum Office of Western Greece and accommodation facilities, and the participants were refugees, immigrants, and gypsies (Table 1). Questionnaires were conducted to investigate the factors that influence public transport use among these groups. Initial findings indicate that a significant majority of the participants (81%) utilize public transportation and possess at least fundamental knowledge of the Greek language. Most of the passengers were within age group 26–40, and 41–60 years old. Notably, they exhibit a preference for bus services for urban or interurban routes (90%) over rail options (58%). Additionally, approximately 47% of them have private vehicle ownership (Fig. 1).

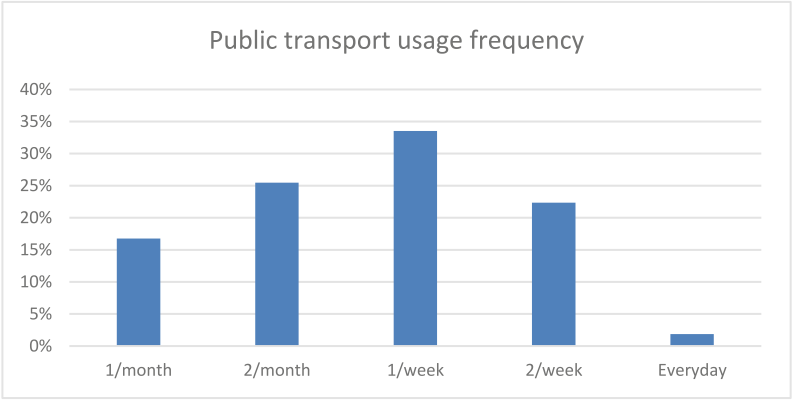

Fig. 1. Public transport usage frequency.

Regarding bus passengers, in the context of urban transportation, 44% have private vehicle ownership, while 60% of this group earn a monthly income below 500 euros, and 69% possess legal residence permission. Interestingly, similar results were observed for bus inter-urban transportation. Conversely, train passengers exhibit substantially lower

Table 1. Respondents' population categories.

	Immigrants	Refugees	Roma
Respondents	92	44	64
Proportion	46%	22%	32%

proportions, ranging from −12% to −29%, for the abovementioned characteristics. The examination of legal documents has a substantial influence on most bus passengers, whether they are traveling within urban or interurban areas. Train passengers, on the other hand, displayed lower percentages. Lastly, it is noteworthy that refugees are reported to be particularly vulnerable to the influence of inspections with an approximate rate of 30% (Fig. 2).

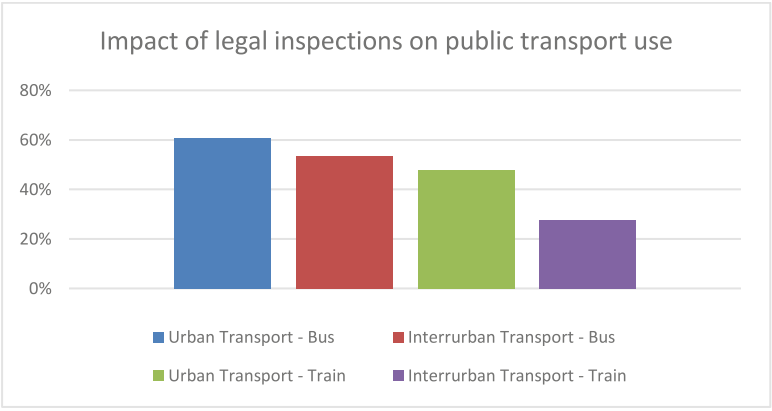

Fig. 2. The impact of legal inspections on public transport use.

Concerning their satisfaction with the Public Transport system, in line with literature [5], a notable portion of respondents expresses dissatisfaction with ticket prices and reliability. Train passengers, in particular, raise concerns about the accessibility of stations and the ease of route finding (Fig. 3). Furthermore, it's important to note that the behavior of both passengers and drivers as well as discrimination phenomena rates significantly contributes to their dissatisfaction (Fig. 4).

Regarding adjustments to public transport system, reliability and travel time of public transport are crucial determinants for all migration categories to opt for public transport for their commutes. Additionally, another contributing factor for their choice is comfort, while most of the respondents desire free of charge public transport tickets. A correlation analysis between age and some factors that determine public transport ridership was also conducted. A negative relationship between age and the frequency of public transport use, as well as the choice of buses as the primary mode of transportation is reported. Age exhibits a negative correlation with the inspection of tickets and legal documents.

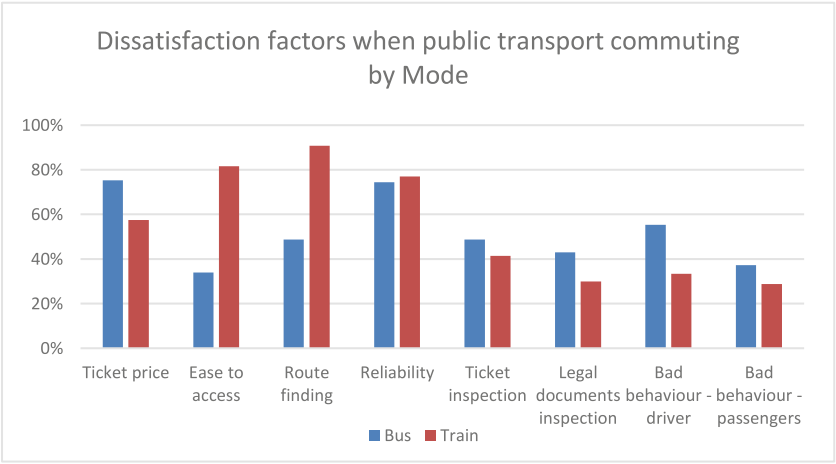

Fig. 3. Dissatisfaction factors when public transport commuting by Mode.

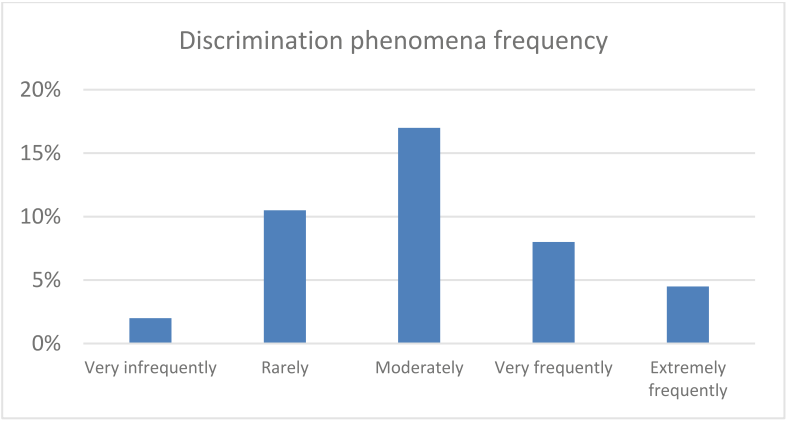

Fig. 4. Discrimination phenomena frequency when commuting with public transport.

Conversely, there is a positive correlation between age and instances of discrimination phenomena (Table 2).

Table 2. Correlation analysis.

	PT Use Frequency	Bus – Main Use	Ticket Inspection	Legal Inspection	Discrimination Incidents
Age	–	–	–	–	+

3 Conclusions, Future Work, and Recommendations

Migration is a worldwide phenomenon which is influenced by many factors such as war [8], financial crisis [9], climate change [10], etc. Consequently, migration rates are expected to be increasing the next years. Migration has a significant impact on societies, so the holistic integration of immigrants, refugees, and Roma populations on the societies is determinant. This paper's objective is twofold. Firstly, we need to understand the needs and habits of migration population of Western Greece in terms of commuting with public transport modes and secondly, address the challenges they face when commuting. For this purpose, questionnaires were distributed to targeted populations with the aid of Regional Asylum Office of Western Greece and accommodation facilities in order to collect reliable data.

The initial findings highlight that 81% of the respondents depend on public transportation for their commutes, whereas this figure stands at 46% for the general population [11]. Among those who use public transport, approximately 60% utilize it on a weekly basis. These results affirm the notion that there is an escalating reliance among such groups on public transport [6]. Notably, 47% of these individuals own a private vehicle, which could be attributed to the considerable operational expenses associated with private vehicles. A study conducted in Germany found that this percentage is approximately 40% higher than in Greece while the monthly incomes are higher in Germany [4]. Train passengers report higher percentages of legal residence permission. Interestingly, bus ridership experiences a greater impact from legal or ticket inspections, which are more commonly conducted within bus systems. Although trains are generally more reliable than buses, the increased accessibility provided by bus services often outweighs this factor. Concerning the challenges faced by the studied populations, dissatisfaction with ticket prices and the reliability of public transport persists across both modes. According to a recent survey [12] the dissatisfaction in pricing and reliability is found among Greek public transport users in general, suggesting a problem within the overall public transport system. Remarkably, behavioral factors play a significant role, with over 50% of bus users expressing dissatisfaction with passenger behavior, and approximately 30% of respondents reporting frequent incidents of discrimination. Additionally, train users encounter difficulties related to route finding and station accessibility. Train stations in Western Greece lack of timetables, which increase the need of reliance on station personnel for information. Lastly, various factors, including reliability, price, and travel duration, influence public transport use and can motivate passengers to select these modes more frequently. Last but not least, correlation analysis reveals significant relationships. These findings are in line with existing literature [6] and highlight the importance of addressing age-related factors when designing and improving public transport services to ensure accessibility and satisfaction across different age groups.

Overall, the challenges, the needs, and the habits of target populations when using public transport are studied in this paper. To enhance public transport accessibility and affordability for these populations, a comprehensive review of pricing structures and ticketing policies is recommended. Additionally, initiatives to promote awareness and sensitivity regarding behavioral issues are essential for improving the overall passenger experience. Future research should explore the long-term impacts of public transportation services considering the identified correlations between age and key determinants

of public transport utilization. This research should particularly focus on understanding how improved access to public transport, especially among older individuals who may face challenges related to location, language knowledge, and route finding. Lastly, a comparative analysis with other regions facing similar migration dynamics would provide valuable insights into best practices and policy recommendations for addressing transportation challenges in multicultural societies.

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Tactile Paving: A Comparative Analysis of Irish and International Approaches and Contexts

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Abstract. There are 296,601 people who experience blindness or vision impairment in Ireland of some form (Central Statistics Office 2023). To create a level of understanding of surroundings, and to support their independent mobility as a pedestrian and public transport user, various measures are adopted in streetscape design and implementation. These include wayfinding and sensory elements such as braille & audible features on pushbutton controls at pedestrian crossings and tactile paving, in differing arrangements to suit certain situations and obstacles, on a footway to complement their primary mobility aid. This is typically a long white cane or guide dog.

This paper will review international approaches to the design and implementation of tactile paving for pedestrians who are Blind or Vision Impaired (BVI) in a variety of different scenario types which aim to support independent mobility. Comparative analysis will establish what differences exist between the Irish context of tactile paving provision and international equivalence with a view to identify common approaches and best practice. A detailed review of existing different Design Guidance documentation in an Irish setting will discuss any contrasts in usage locally.

Keywords: Tactile Paving · Vision Impaired Pedestrians · Vision Impaired Public Transport Users · Transport Equity

1 Introduction

Due to the independence derived from its presence, it is widely accepted that vision is the most dominant of the human senses (Enoch et al. 2019). Nonetheless, there are at least 2.2 billion people globally with some form of vision impairment. Not only does this severely impact their quality of life, but the burden of eye conditions and vision impairment is not borne equally. Vision impairments vary significantly from person to person and, in an Irish context, just 6% of those with a visual impairment are fully blind. This varying nature of vision impairment creates disproportionate challenges and independence amongst this community who are less likely to engage in active employment and/or education (NCBI 2020).

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To date, there has been extensive research into autonomous vehicles. This industry is responsible for approximately 14% of total production and capital in-vestment in the European manufacturing sector (Ondruš et al. 2020). While BVI pedestrians with high levels of desire for independence have previously welcomed the prospect of travelling in Autonomous Vehicles, the health, equity and economic benefits of active travel, relative to motorised transport, are significant (Pérez et al. 2017). While Autonomous Vehicles operate by mapping their surroundings through sensors to transport occupants (Ondruš et al. 2020; Martínez-Díaz & Soriguera 2018), this paper aims to review the same logic by which pedestrians can navigate footways and streetscapes using Tactile Paving and associated standards.

Tactile paving allows vulnerable and BVI pedestrians to navigate with comfort and confidence (Delaney 2022). Provision of such paving allows a greater level of independence and mobility for vision impaired pedestrians while affording them the opportunity to move freely using a mobility aid such as a white cane (NSAI 2008). Tactile paving is also used to support safe and confident mobility in individuals who have low vision and don't necessarily use a traditional long white cane. While there have been technological enhancements to support and help the detection of tactile paving for wider navigation purposes using Smartphone Applications (Ghilardi et al. 2016), this paper seeks to review different approaches to tactile paving internationally and how they focus on independent navigation with traditional mobility aids.

2 Design Guidance in Ireland

The most used design standard used in Ireland for Tactile Paving originates in the United Kingdom: *Guidance on the Use of Tactile Paving Surfaces* (DfT 2021). Despite the many cultural similarities between Ireland and The United Kingdom (UK), utilization of design guidance from another jurisdiction has its challenges. Irish use and adoption of such international design standards effectively results in our community being a de facto stakeholder with no input in terms of how these standards evolve or are revised or indeed how they reflect local needs.

This document (DfT 2021), which will be discussed in further detail in Sect. 3, includes standard details for:

- Blister Surface for Pedestrian Crossing Points
- Corduroy Hazard Warning Surface
- Platform Edge (On-Street) Warning Surface
- Segregated Shared Cycle Track/Footway Surface and Central Delineator Strip (Ladder and Tramline)
- Guidance Path Surface
- Platform Edge (Off-Street) Warning Surface (only for use at the edge of railway and underground station platforms)

2.1 Transport Infrastructure Ireland Standard Construction Details

Transport Infrastructure Ireland (TII) Design Guidance includes standard construction detail for tactile paving across various contexts, including:

- Zebra Crossing Tactile Paving and Pole Position Detail: CC-SCD-05134 (Transport Infrastructure Ireland, 2021a)
- Puffin Crossing Tactile Paving and Traffic Signal Details: CC-SCD-05135 (Transport Infrastructure Ireland, 2021b)
- Tactile and Paving Details and Recommended Gradients at Uncontrolled Pedestrian Crossing: CC-SCD-05136 (Transport Infrastructure Ireland, 2021c)
- Tactile Paving Detail and Recommended Gradients - Controlled Pedestrian Cross-ing: CC-SCD-05137 (Transport Infrastructure Ireland, 2021d)

Some of these TII documents suggest referring to '*Tactile Paving Guidance Document*' which is understood to be the UK Design Guidance. It is noted that TII is primarily a roads authority for the Irish strategic/trunk road network. Additionally, TII Design standards also include maximum recommended gradients of 1:12.

2.2 Universal Access

The Building for Everyone: A Universal Design Approach – External Environment and Approach document (National Disability Authority, 2012) makes reference to tactile paving installation. This features the following:

- Blister surface for pedestrian crossing points: This includes warning paving for pedestrians using signalized (red colour blister paving) and unsignalized (buff colour blister paving) crossing points.
- Corduroy paving for hazards: This includes buff colour warning paving at the top and bottom of flights of steps, transitions between segregated footways/cycleways and shared space and edge of platform warnings.

2.3 Irish Building Regulations

Technical Guidance Document M (Department of Housing, Local Government and Heritage 2022), as a section in the Irish Building Regulations refers to tactile paving. This primarily pertains to stepped access routes, where corduroy tactile warning paving should feature 400mm back from top or bottom of a step riser. The Technical Guidance Document M also refers to '*Good Practice Guidelines on Accessibility of Streetscapes*' document details for controlled and uncontrolled crossings.

2.4 Good Practice Guidelines on Accessibility of Streetscapes

The Good Practice Guidelines on Accessibility of Streetscapes outline tactile paving design guidelines in an Irish context. It makes reference to the Disability Act 2005 and they were developed to enhance the Irish Traffic Management Guidelines. Design guidance, which references the Guidance on the use of tactile paving surfaces (UK) design guidance and the Irish Building Regulations Technical Document M includes:

- Signalized Pedestrian Crossings (with red colour blister paving) including staggered, signalized and Zebra crossings.
- Unsignalized Pedestrian Crossings (with buff colour blister paving) including in-line crossings, angled junctions, side road crossings and refuge islands.

2.5 Luas Accessibility

The Luas Tram system in Dublin has a prescriptive design for platform layout (LUAS 2016) including tactile paving. This includes:

- Edge of platform warning 550mm from edge of platform (charcoal colour lozenge paving).
- Top and bottom of stairs and ramp warning (charcoal colour corduroy paving).
- Pedestrian crossing (red blister for signalized or charcoal for unsignalized).

2.6 International Standards

The following are International Tactile Paving related standards to streetscapes and the built environment which may influence Irish design:

- ISO 23599:2019(en) Assistive products for blind and vision-impaired persons—Tactile walking surface indicators
- ISO 21542:2011 Building construction – Accessibility and usability of the built environment are adopted or used in a Republic of Ireland context.
- PAS 6463:2022 Design for the mind – Neurodiversity and the built environment.
- CEN/TS 15209:2008 Tactile Paving Surface Indicators Produced from Concrete, Clay and Stone

CEN/TS 15209:2008 has been ratified into an Irish context (NSAI 2008).

2.7 Summary of Irish Guidance

From the guidance available in Ireland, it is clear that there is similarities from different documents in terms of approaches to tactile paving provision in specific circumstances. There are however some contrasts in terms of provision for example the difference in colour adopted for unsignalized crossings of roads or rail tracks along Luas infrastructure. This outlines that there is not an explicitly uniform, coherent or systematic approach in an Irish context. There are also various international guidance documents which may be subject to varying levels of adoption in an Irish context.

3 International Design Guidance Review

3.1 United Kingdom

Various iterations of UK guidance in the Area of Tactile paving have been issued with the most recent being in 2021 (DfT 2021). This includes standard details for:

- Blister Surface for Pedestrian Crossing Points: This features the use of Buff colored blister paving, parallel to the kerbline, for un-controlled crossings. Red colored blisters are used for signalized crossings, including Belisha Beacons and Zebra Crossings.

- Corduroy Hazard Warning Surface: This features ridged corduroy type paving, buff in colour, predominantly used at transitions between segregated pedestrian/cyclist infrastructure and associated shared space surfaces, the top and bottom of flights of steps and the bottom of Light Rail platform access ramps. They are also used for at-grade level crossings to warn pedestrians before they reach level crossing gates.
- Platform Edge (On-Street) Warning Surface: This features lozenge type tactile paving, charcoal in colour, on platform edges, set at least 500mm back from the edge.
- Segregated Shared Cycle Track/Footway Surface and Central Delineator Strip (Ladder and Tramline): a segregating line between footways and adjacent cycleways.
- Guidance Path Surface: This features non-continuous warning tactile paving, in any colour other than red but generating a 'colour contrast' with surrounding material.
- Platform Edge (Off-Street) Warning Surface (only for use at the edge of railway and underground station platforms): This features blister type paving, typically different from that used for pedestrian crossings, in any colour other than red.

3.2 United States

Bentzen et al (2021), in a review of international paving standards, outline that US Tactile Paving Design Standards have evolved to the Americans with Disabilities Act Accessibility Guidelines (2010) standards. This pertains to all scenarios except public transportation facilities, which are subject to Department of Transportation (DOT) standards. The two standards are the same with regard to the dimensions of the truncated dome surface and the requirement for visual contrast, but the DOT standard re-quires truncated domes on curb ramps as well as at the edges of transit boarding plat-forms (Bentzen et al. 2021). Pedestrian at-grade rail crossings use blister tactile paving to warn pedestrians im-mediately before the pedestrian gates. High-level and low-level rail platforms feature a 600mm deep strip of tactile paving immediately along a platform edge. National standards for guidance path surfaces do not exist in the U.S (Bentzen et al. 2021). Detectable warning surfaces shall contrast visually with adjacent walking surfaces. Tactile paving at pedestrian crossings is not intended to indicate the direction of travel but just to indicate the crossing end (Bentzen et al. 2021).

4 Results

This assessment is not exhaustive globally. This preliminary study outlines that differences in standards both between different countries and within Ireland exist. It is clear from the review of Irish, UK and US approaches that different countries have different approaches in technical guidance. Adoption of different colours and types of paving used in differing situations represent the international variance. High level and low level rail platform approaches in the US feature tactile paving immediately adjacent to the platform edge, while Irish and UK guidance features tactile paving recessed back from the platform edge to give advanced warning and affording the pedestrian time to stop before the edge. This US approach also features similar blister tactile paving in differing scenarios, which may lead to confusion about the exact infrastructural feature encountered by a BVI pedestrian. Variability of lozenge type tactile paving with differing guidance in Ireland, specifically distance from platform edge, creates a designer discretion without appreciation on precise BVI user needs.

At grade level crossings require warning tactile paving in UK guidance but feature blister paving the US. Irish guidance suggests a charcoal colour corduroy hazard warning paving on Luas Light Rail platform ramps and adjacent steps, but UK guidance outlines the requirement for yellow warning tactile paving.

5 Discussions and Conclusions

Tactile paving use is not widespread globally. The Irish approach is somewhat fragmented and contradictory in terms of design standards across different organizations. Research by Bentzen et al. (2021) concludes that differing approaches to tactile paving within individual countries has historically resulted in varied local approaches. Japan for example, where the world's first tactile paving appeared in the 1960s, didn't have a formal design standard until 1985. Duncan-Jones (2015) outlines that even where there is a formal design standard, in that case The UK, varied installations of tactile paving with inconsistent configurations outlines a lot of misunderstanding. Many BVI pedestrians still have some residual vision allowing them to distinguish colour contrasts.

6 Limitations and Recommendations

This study is not exhaustive on a global/international scale and only includes certain countries. Further study should include an exhaustive literature review report on tactile paving using the ISO 3166 global list of countries. Such a robust level of detail will facilitate a greater level of comparing and contrasting of international standards relative to those from Ireland. Little research exists on the determinants for the adoption of standards (van de Kaa 2023).

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Towards Design Principles for an Accessible Autonomous Vehicle: Promoting Inclusivity, Independence and Well-Being

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Abstract. Lack of accessible transport for People with Disabilities (PwDs) negatively impacts access to work, social inclusion, and healthcare leading to adverse effects on overall well-being. The absence of access to autonomous mobility exacerbates these issues, presenting barriers for inclusion. Previous studies have provided important recommendations and while these represent important steps in the right direction, they often lack detailed principles to support design of accessible AVs. To address this gap a multi-study research, with the overarching aim to develop design principles for accessible AVs, was initiated by the Queensland Government Department of Transport and Main Roads (TMR) and conducted by Queensland University of Technology (QUT). This paper reports on an early study employing focus groups and workshops with five domain experts. Thematic coding resulted in five major themes: *COMMUNICATION, STRESS, INDEPENDENCE, SAFETY*, and *INTERFACE*, each consisting of multiple interconnected topics that contribute towards initial design principles. Later steps will involve developing an accessible AV concept using these initial principles. The concept will be refined into a prototype and tested with PwDs and reviewed by domain experts. By incorporating purposeful design principles it is anticipated that AVs will become more widely accessible alleviating barriers to freedom of movement for all.

Keywords: Accessibility · Disability · Autonomous Vehicles · Universal Design

1 Introduction

The cumulative disadvantage faced by PwDs has a detrimental effect on physical, financial, and emotional well-being. Barriers to freedom of movement for PwDs violate human rights and impact their dignity and inclusion in society and has been strongly linked to reduced access to work, social inclusion, and health (Australia & New Zealand Driverless Vehicle Initiative 2020; Rojas 2020; Sterkenburg 2020; Tabattanon et al. 2019).

This paper outlines the initial outcomes of a long-term study focusing on developing design principles for accessible autonomous vehicles following in the footsteps of previous research (Allu et al. 2017; Epting 2021). Findings revealed the following key Themes as important elements:

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- **COMMUNICATION**, including face-to-face, human-machine & human-environment;
- reduce **STRESS** for PwDs in accessing and using AVs;
- improve **SAFETY** throughout the transport experience;
- **INTERFACE** with the vehicle physically and digitally; and
- providing and considering **INDEPENDENCE** of PwDs

To address these themes, several topics were identified that represent impactful design opportunities, such as **seating**, **restraints**, **configurability**, **controls**, and **storage**. These design opportunities need to consider the following high relational topics: **anthropometrics**, **visibility**, **wayfinding** and **route navigation**, or **assistance** through automation. Several limiting factors seen to have a strong impact on the success of any accessible AV design include **infrastructure**, **barriers**, **risks**, **regulation**, and **cost**. As we move towards an autonomous future, effective access to future AVs has the potential to significantly improve mobility and transportation for PwDs, and these findings are a positive step in this direction.

1.1 Aim and Background

The overarching aim of this project is to develop design principles for an accessible AV. This study is part of a long-term multi-study research project consisting of 3 Phases spanning several years. Phase 1 includes thematic review of literature, data review, initial surveys with disability users, and focus-groups with domain experts. Phase 2 will involve a detailed benchmarking and expert analysis of existing autonomous vehicles as well as a concept development of an accessible autonomous vehicle. Phase 3 will involve the development of a prototype for testing by end users and domain experts leading to the final refinement of design principles for accessible AVs.

This paper reports on the focus-group with domain experts as part of Phase 1 of the overall project. The objective is to understand critical factors and develop initial recommendations that form the basis for a set of design principles from the perspective of domain experts. This will contribute to meeting the needs of the current and emerging public transport and private vehicles market, support PwDs and the ageing population, improve potential upstream value and benefits for national and state governments and ultimately place human rights and social inclusion as a cornerstone in the development of future transport and mobility planning.

2 Methodology

This study involved a focus-group between five experts to determine the potential opportunities and challenges of achieving accessible AV implementation within Australia. Table 1 provides an overview including an outline of the two Focus Group sessions. Two 2-h sessions were conducted across two weeks. Session One included four participants who returned the following week. Session Two included an addition participant who was not available for the first session.

Participants were contacted via email and provided a project protocol document outlining the nature of the research and logistic details. Researcher profile included expertise in (i) end user driven technology focusing on accessibility, (ii) automotive

Table 1. Focus Group Study.

Focus Group Overview	*Description*
Setting	Online via Zoom
Participants	5
Duration	Two x 2-h sessions
Study	Focus Group with Design Activities
Data Collection Method	Video and Audio Recording
Data Analysis Tool	Thematic Analysis
Session One Overview	*Description*
Induction: 20 min	Greet and introduction to Zoom software, troubleshoot connection and audio issues
Semi-structured Interview: 40 min	Have participants engage in a "round table" discussion with prompts
Break: 10 min	10-min break
Photo Elicitation: 40 min	Photo Elicitation activity in which AV concepts and production vehicles from different vehicle manufacturers are used to stimulate discussion
Session Two Overview	*Description*
Induction: 20 min	Greet and introduction to Zoom software, troubleshoot. Run through Miro features induction exercise
Reflective Task: 40 min	Review key findings and themes from Photo Elicitation activity. Identifying positive and negative features of different vehicles based on key findings and themes
Break: 10 min	10-min break
Design Activity: 40 min	Engage in a vehicle concept generation activity using a "dollhouse" approach in which images are used to assemble vehicles within Miro. Before having participants review and critique these concepts
Debrief: 10 min	10-min debrief

engineer, Australian Standards, Design Rules, regulations, and legislation, (iii) inclusion educator at primary and secondary schools, deaf community interpreter, with a current focus on children to young adults with autism, (iv) architect and accessibility advocate with lived experience, and (v) automotive engineer, accessibility vehicle modifier. A more detailed outline of the method and process is discussed in another paper (in press) but will not be presented here due to word limitations.

2.1 Data Collection and Analysis

The qualitative data collected included video and audio recordings from the session and visual data in the form of images. The session collected video and audio recording which

was later transcribed. Visual data from Miro was gathered through screen captures and image downloads.

The research team undertook several steps to analyse the data (Fig. 1). Otter.ai software was used to support analyses and generate an accurate transcription.

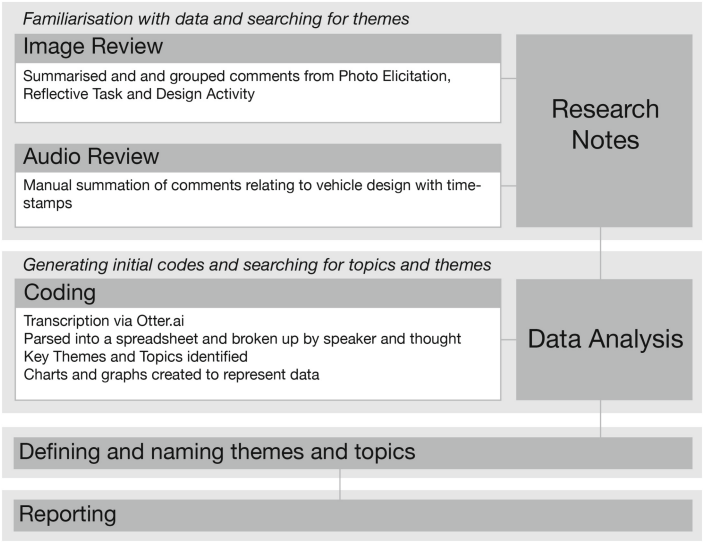

Fig. 1. Thematic analysis process

The coding process was used to generate a co-occurrence matrix. These results were analysed using Flourish Studio to highlight the frequency of the theme and topic occurrences, the relationship between key themes and underlying topics, and the relationship between the topics. A more detailed outline of the data analysis technique is discussed in another paper (in press) but will not be shown here due to word restrictions.

3 Results

Themes and Topics are discussed in relation to their relative frequency of occurrence, and the relationship between identified Topics are also discussed.

3.1 Key Themes

The five key Themes identified through the focus group session include **SAFETY** (29.9%), **COMMUNICATION** (27.5%), **INTERFACE** (19.2%) and **INDEPENDENCE** (15.6%), and finally **STRESS** (7.8%). Figure 2 also highlights the Topics (sub-themes) that were generated through the data analysis.

SAFETY refers to instances where safety is referenced (i.e. a safety risk) or where the idea of safety or safe practices were discussed. **COMMUNICATION** refers to communication between and within passengers, vehicle and infrastructure. **STRESS** refers

to emotional stress throughout travel (e.g. journey planning, entering/exiting vehicle, etc.). **INDEPENDENCE** refers to PwDs ability to live or operate without needing help. **INTERFACE** refers to instances of human interaction with digital or physical aspects of the vehicle.

3.2 Topics

There is a significant interconnection between topics, as seen in Fig. 2. The topics which appeared with the greatest relational frequency, that is, those topics with the strongest relationships to all topics of discussion across the focus group session are briefly outlined.

Seating: any form of seating incorporated into the vehicle design; **Regulation**: rules or directives made and maintained by an authority and includes design rules, regulations, standards and associated laws or statutes; **Restraints**: physical mechanisms or devices used to restrain or secure individual; **Design**: process or act of design or designing; **Configurable**: the capability of design elements to be configured/customisable/permitting rearrangement or adjustment.

Fig. 2. Topic frequency and relationships – authors' own work

Seating appeared with the greatest relational frequency to *Restraints* (21.6%), *Children* (13.7%), *Regulation* (13.7%), *Design* (11.8%), and *Configurable* (9.8%). **Configurable** appeared with the greatest relational frequency to *Seating* (23.8%), *Visibility* (19%), *Controls* (9.5%), *Manufacturers* (9.5%), *F2F Communication* (9.5%), and *Privacy* (9.5%). **Regulation** appeared with the greatest relational frequency to *Seating* (29.2%), *Stewards/attendants* (12.5%), *Risk* (12.5%), *Restraints* (8.3%), and *Technology* (8.3%). **Restraints** appeared with the greatest relational frequency to *Seating* (39.3%), *Design* (14.3%), *Children* (14.3%), and *Regulation* (7.1%). **Design** appeared with the greatest relational frequency to *Seating* (25%), *System* (25%), *Restraints* (16.7%), and *Comfort* (8.3%).

4 Discussion

Each topic mentioned did not occur in isolation but rather as part of a complex set of relationships. The rationale for these three domains is due to the complexity of the problem:

1. *High Frequency Topics*: topics with high conversational occurrence, such as **seating**, frequently emerged throughout the focus group session.
2. *High Relational Topics*: topics with low conversational occurrence but high topic relational frequency such as **risk**.
3. *Limiting Factor Topics*: topics without high conversational occurrence or high relational frequency but which were seen as limiting factors, such as **cost**.

Figure 3 shows a simplified visual representation of an autonomous AV with labels to assist in understanding general part/s of a vehicle identified as critical based on findings. These form the basis of the initial design principles developed.

Seating is a significant consideration for accessible AVs. Design, orientation during travel, and interface methods were often discussed alongside SAFETY. INDEPENDENCE would often focus on how PwDs could secure themselves without assistance (Ferati, et al. 2018).

The topic of **restraints** had clear connections to the theme of SAFETY and would generally centre around appropriate methods for restraining wheelchair users (Choi, et al. 2020).

How AVs interact with **infrastructure** was seen to promote or diminish PwD INDEPENDENCE, STRESS, and SAFETY during travel. AVs must also consider interaction with the surrounding environment and infrastructure (Porru, et al. 2020; van Vulpen, et al. 2021; Wolfgang, & Korydon 2011).

The topic of **configurability** and vehicle modularity as a design feature would require the user to either interact physically or through automated features with the vehicle. Experts argued that modularity can meet the needs of different PwDs.

The topic of **controls** related to the theme of COMMUNICATION between passenger and AV through appropriate interface design. Control systems should use multimodal sensory channels (i.e., audio, haptic, visual). A focus should be placed on control visibility, ease of use, and consistency across different vehicle types (Costa, et al. 2018; Ferati, et al. 2018; Fogli, et al. 2020; Wolfgang, & Korydon 2021).

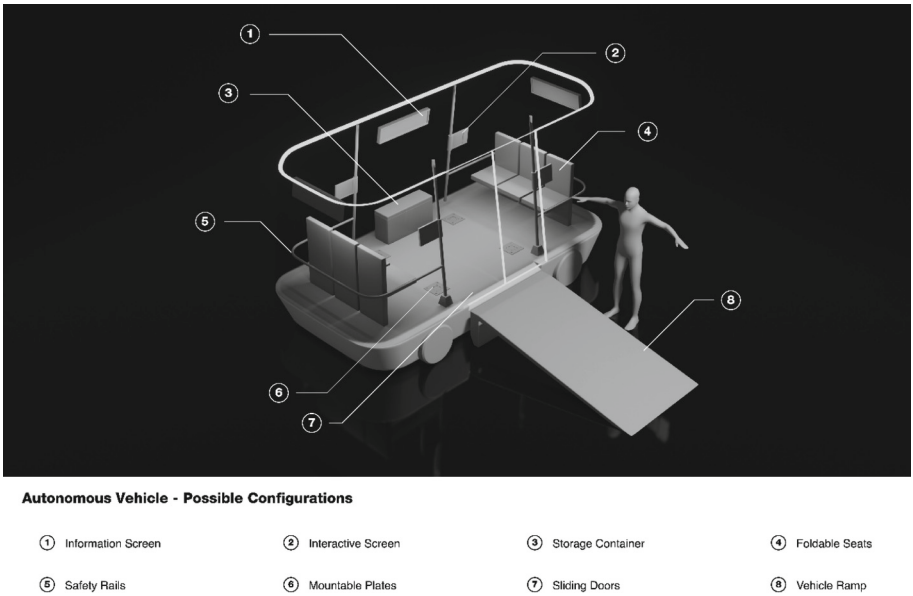

Fig. 3. Key design elements to consider for accessible AVs – authors' own work

An inability for PwDs to effectively communicate with an AV through different sensory channels was seen as a primary **barrier** to entry (Rojas 2020).

While reducing **risk** for passengers is an obvious goal, risk assessment and safety testing is a complex and cost-prohibitive process. For example, one expert highlighted that legislators do not always have data about how different wheelchairs will interact with passengers in the event of a crash.

Visibility was seen as a key factor in facilitating communication. There were also questions about how PwDs would effectively communicate with the vehicle's computer or AI; for example, could the HCI understand and generate AUSLAN for deaf users?

The topic of **wayfinding** would arise regarding what provisions there would be throughout the vehicle and surrounding environment to guide PwDs and enhance understanding and journey experience. **Route navigation** frequently emerged as an issue for PwDs within current transport. Effective wayfinding and navigation could help alleviate stress and encourage transport use (Rojas 2020; Dicianno, et al. 2021).

Storage design, provision and placement were often raised alongside INDEPENDENCE. Passengers may benefit from multimodal communication that indicate available storage locations.

The topic of **stewards** or **vehicle attendants** were seen as a method of providing useful services, functions and information to users but has the potential to reduced users' independence.

Experts reported several limitations within existing anthropometric data and vehicle standards when considering **anthropometrics** as they apply to vehicle design and safety testing.

The topic of **regulation** which included design rules, guidelines, and standards, would often focus on passenger safety. **Regulations** intersects with **risk**, **anthropometrics**, and **cost**.

While PwDs stand to benefit from the introduction of AVs, these vehicles come with considerable **cost**, which could limit ownership, access and features.

5 Recommendations

Based on the findings, it is proposed that an accessible AV should be designed to promote **COMMUNICATION**, reduce **STRESS**, improve **SAFETY**, consider **INTERFACE** issues and provide as much **INDEPENDENCE** as possible for PwDs. These are all interconnected elements as part of the journey experience but can be described independently.

To address these key themes, several elements were identified that represent impactful design opportunities. These include elements such as **seating**, **restraints**, **configurability**, **controls**, and **storage**. Any Accessible AV design should focus on these priority areas as they were connected to several user needs reflected and supported by prior research. Additionally, these design opportunities will need to consider additional elements including **anthropometrics**, **visibility**, **wayfinding** and **route navigation**, **stewards/attendants** or assistance through automation. Finally, several limiting factor topics were identified that were seen to have a strong impact on the success of Accessible AV design implementation, including Infrastructure, Barriers, Risks, Regulation, and Cost. The implementation of an effective design will therefore be dependent on how these factors are synthesised, managed, and mitigated.

6 Conclusion

Appropriate access to transport for PwDs has the potential to increase economic benefits, improved social inclusion and reduce the burden on healthcare systems. As we move towards an autonomous future, accessible and convenient AVs for PwDs which follow effective principles will be crucial to addressing existing barriers. Accessible AVs could help to increase safety when commuting, improve social inclusion and address issues around lack of access to work and healthcare allowing PwDs to be treated as equal citizens. The provision of seamless, personalised journeys will provide PwDs with greater independence.

This study has provided an understanding of the development of initial design principles for PwDs in accessing mobility options with recommendations for the design of accessible AVs. A focus group with 5 domain experts was conducted involving semi-structured interviews, photo elicitation, reflective task and design activity. Findings revealed the following key Themes:

- **COMMUNICATION**, including face-to-face, human-machine & human-environment;
- reduce **STRESS** for PwDs in accessing and using AVs;
- improve **SAFETY** throughout the transport experience;

- **INTERFACE** with the vehicle physically and digitally; and
- providing and considering **INDEPENDENCE** of PwDs

To address these themes, several areas were identified that represent impactful design opportunities, such as **seating**, **restraints**, **configurability**, **controls**, and **storage**. These design opportunities need to consider the following high relational topics: **anthropometrics**, **visibility**, **wayfinding** and **route navigation**, or **assistance** through automation. Several limiting factors were identified to have a strong impact on the success of any accessible AV design implementation, including **infrastructure**, **barriers**, **risks**, **regulation**, and **cost**.

The research outlined here is the initial step in a long-term study that will include a preference survey with PwDs, detailed data review, existing AV benchmarking, concept development, prototype development, porotype review with experts, and prototype testing with end-users. By conducting a detailed multi-method study, the objective is to have a refined and well-supported set of design principles that will lead to improved AV designs accessible to a large range of users with diverse needs.

It is suggested that if the factors outlined above are considered as the initial starting point for key design principles, the potential for accessible AV designs is possible, improving access to effective transportation solutions for PwDs and ultimately helping the entire community.

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Safe, Inclusive and Sustainable: Planning Future Transport in Thimphu, Bhutan

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Abstract. Thimphu, the world's only capital without traffic lights, has the population of 110,000 people, with forecasts of up to 190,000 inhabitants in the 2040s. It is a diverse capital nestled in the Himalayas, with linear city extensions planned along the Wang Chhu valley. Rapid population growth, combined with limited planning processes has meant that today's Thimphu is facing high car dependency, with a stigma attached to active travel and public transport. Therefore, disadvantaged groups suffer due to the expense of owning a car and poor active travel and public transport infrastructure. To help Thimphu to achieve its aspirations of becoming a greener and more equitable city, Arup's cross-cultural team delivered a Low Emissions Transport Master Plan (LETMP) for the city. The LETMP is delivered to the Ministry of Infrastructure and Transport (MoIT), Thimphu Thromde (TT) and the Royal Commission for Urban Development (RCUD) and it supported the delivery of Thimphu Structure Plan (TSP), prepared together with Prior+Partners, that will better integrate land use and transport in the city.

Keywords: Sustainable · Inclusive · Transport

1 Introduction

1.1 Background to the LETMP

Arup has worked for The Ministry of Infrastructure and Transport (MoIT) of Bhutan to develop Thimphu's Low Emissions Transport Master Plan (LETMP). The LETMP is one of the priority projects supporting the revision of Thimphu Structure Plan (TSP), developed in parallel by Prior+Partners. The TSP seeks to integrate land use and transport planning, and it follows the direction of 'good growth in the right places' that will cultivate balance, nurture community, create opportunity and inspire. This will enable accommodating the current and future travel demands of Thimphu, while improving access to sustainable mobility options.

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1.2 Approach to Delivering the LETMP

Throughout the process, Arup worked closely with MoIT, TT, RCUD and other key stakeholders, as well as the TSP team. This was to ensure that the LETMP would have a transformational impact on the sustainable and inclusive transport in the future of not only Thimphu, but the whole Kingdom of Bhutan.

Step 0: Early Planning, Mapping and Data Collection Activities. LETMP conducted Thimphu's first comprehensive traffic survey due to limited background data and information that would assist in providing a robust analysis of Thimphu's existing conditions. For capacity-building purposes, training was provided to the client organisations on undertaking traffic surveys as well as making use of open data to benefit current and future projects in Thimphu.

Step 1: Analysis of Context. Analysis of the current and future context for all transport modes included development of understanding Thimphu's travel demand. Thimphu's first-ever local area transport model was developed using SATURN to understand the current and future conditions of the network. Not only were the model outputs used to demonstrate the potential impacts of the strategy implementation and help the client understand the future performance of the road network but also assisted in gaining public acceptance that was key for the required substantial changes to successfully take effect.

Step 2: Establishment of Vision, Goals and Targets. The vision and goals for Thimphu's transport system were aligned with the Thimphu-Paro Regional Strategy, which also guided the development of the transport strategies. Further, the team developed targets and potential metrics to assess future performance against those goals.

Step 3: Development of LETMP Strategies. Clear and comprehensive strategies for each transport mode were developed, along with strategies on topics such as integration of land use and transport planning, and low carbon mobility. The strategies address the challenges and opportunities identified in Step 1 and align with the vision and goals set out in Step 2.

Step 3: Development of LETMP Strategies. This included a clear plan with timeframes, roles and responsibilities, and coordination with other infrastructure plans.

Step 5: Demonstration of Strategy Impact. This demonstrated the potential impact of the implementation of the LETMP against the vision, goals and targets. It included updating the traffic model to understand how the travel demand across the road network can change with delivery of the proposed interventions.

Step 6: Final LETMP Report Production. This step involved preparation of the LETMP report, building a clear case for investment in a sustainable transport system for Thimphu.

2 Vision and Principles

The LETMP was built upon the vision of delivering a sustainable transport system to the benefit of residents, visitors and businesses, that will connect people and places; help mitigate against climate change; and enhance the city's economy and attractiveness.

To guide the development of the subsequent LETMP strategies, the following overarching principles were set:

1. Prioritisation of people over vehicles to set out Thimphu's transport modal hierarchy, with pedestrian and other active travel first, followed by public transport, service and delivery, taxis and private cars being last.
2. Promotion of sustainable transport modes.
3. Integrated land use and transport planning.
4. Transition of vehicles to clean fuels.
5. Managing current and future travel demands.

3 Strategies

3.1 Introduction

A total of 11 strategies were developed for the LETMP, which were Active Travel, Public Transport, Vehicular Circulation, Car Parking, Freight & Delivery, Low Carbon Mobility, Mobility Hubs and Shared Mobility, Travel Demand Management, Transit Oriented Development, Placemaking and Wayfinding and Governance. However, this paper focuses on Active Travel and Public Transport to prioritise the transport modes that are safe, inclusive and sustainable.

3.2 Active Travel

Purpose
Prioritising active travel improvements so that people have easy access by walking, wheeling and cycling to employment, education, daily shopping and services. This in return will help reduce reliance on private cars. As the population grows in Thimphu, people will need to be able to choose to walk and/or cycle for short, local trips, contributing to better health, community interactions, and reduced impacts from traffic congestion.

Problem Statements
This strategy addresses the following challenges in relation to active travel in Thimphu:

- Narrow and inaccessible footpaths and disconnected pedestrian network;
- Inconsistent pedestrian facilities and network coverage;
- Lack of ancillary infrastructure along footpaths and key attractors;
- Limited provision of cycling facilities;
- Lack of affordable access to bicycles prevents the creation of a cycling culture;
- Formal dress (Kira) is restrictive for movement to comfortably ride bicycles; and
- No inclusive design guidelines and lack of standards for implementing active travel infrastructure.

Proposed Interventions
Infrastructure
Several infrastructure interventions are proposed for Thimphu to extend the coverage of the network for active travel, and to therefore enable everyone to safely walk, wheel and cycle easily to their destinations. These include the following:

- Prioritisation of improvements around local and neighbourhood centres within a five-minute walk, while sub-district centres within a ten-minute walk to/from the centre;
- Improvements to the walking network towards public transport stops and stations through provision of accessible footpaths with smooth surfacing within a 5-min walking/wheeling catchment of bus stops;
- Corridor-specific improvements to prioritise people over vehicles through road reallocation at key locations across Thimphu. This includes the pedestrianisation of Norzin Lam, the main street in Thimphu's city core (similar to Grafton Street in Dublin, Ireland);
- New facilities for walking and wheeling, which includes provision of new bridges across the two rivers in Thimphu: Wang Chhu and Ola Rong Chhu.
- Provision of a new north-south greenway along the Wang Chhu, to contribute to establishing a cycling culture in Thimphu;
- Provision of bicycle sharing infrastructure, which includes the implementation of e-bike sharing schemes to extend the catchment range and facilitate cycling on hillier terrains; and
- Provision of ancillary infrastructure for active travel, which includes bicycle parking, seating and urban street furniture, lighting and signage. This also includes the provision of end-of-trip facilities, such as changing rooms and showers for people to be able to change to their formal clothes (i.e. Gho for males and Kira for females).

Behaviour Change

A number of measures are recommended in order to provide the local community with the skills and confidence, and thus, reducing barriers, to travel by active modes in Thimphu. These measures included, for instance, active travel plans for workplaces, walking/cycling bus initiatives for primary school students, school streets to adopt temporary restrictions on cars, cycling classes for vulnerable groups, car-free days and behaviour change marketing campaign.

3.3 Public Transport

Purpose

A convenient, attractive affordable and integrated public transport system, that is accessible and connected to all major trip generators is a key priority to create a sustainable future for Thimphu.

Problem Statements

This strategy addresses the following challenges in relation to public transport in Thimphu:

- Circuitous bus routes, in part due to the lack of bridges/connections between certain areas;
- Lack of bus priority infrastructure that results to slower journey times and poor reliability around peak hours;
- Poor bus stop location/design and lack of associated facilities, including seating, shelters, lighting, timetable/route information and waste bins;

- Current fare payment and pricing structure as Smartcard payment options are limited and therefore cash is still the typical means of payment to locals;
- Lack of attractiveness and ease of use due to lack of funding issues for City Bus (operator); and
- Security issues at night with staff or female passengers feeling unsafe.

Proposed Interventions

Infrastructure

The public transport system is proposed to be overhauled to be simplified and be more reliable that will connect every neighbourhood centre. The interventions include, for instance:

- Provision of a core bus network with high-frequency routes with integrated interchanges between different routes;
- Provision of subsidised demand-responsive services (using taxis) in areas outside the immediate catchment of the core bus network;
- Provision of bus priority measures, which may include bus lanes at junction approaches, to be given priority over general traffic when at the stop line (through traffic signals or traffic police);
- Improvements to bus stop infrastructure to make them comfortable and accessible for all passengers. This includes provision of benches, shelters, lighting, kerbs for easy access at bus stops, passenger information and paving improvements;
- Main bus hubs to be in Chang Lam (one of the main north-south streets in the city core) and Olakha which will act as a terminus point for regional buses arriving from other regions in Thimphu. Olakha would also include a new park and ride to encourage people who live beyond these areas to park in this location and use the bus to travel to the city core; and
- Provision of tailored bus services to schools and other institutions that may lie outside the immediate catchment of the core services but have sufficient peak demand to justify them (e.g., school buses).

Behaviour Change

A suite of behaviour change measures is also recommended for implementation to complement the infrastructure interventions. The recommended measures include digital integration, bus service rebranding, disability consultation, disability equity training, driver training programme and fare incentives.

4 Conclusions

Development of an inclusive, safe and sustainable transport system is multi-faceted. Providing people with not only infrastructure and alternative modes but also awareness and skills are all vital in removing barriers to more sustainable transport. The LETMP has been carried out to enable this. The LETMP comprises of 11 strategies, including active travel, public transport and travel demand management. However, provisions for vehicle circulation, parking and logistics combined with balanced spatial planning form crucial parts of the development of a resilient city.

Given that many of the opportunities and constraints found in Thimphu are experienced by cities throughout the world, lessons from the LETMP and examples of the interventions, and findings from the stakeholder engagement process may be useful for other cities wishing to develop inclusive transport network.

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Human-Centred Systems Engineering Framework Approach for Defining and Enhancing Passenger Experience in Rail Infrastructure

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Abstract. A passenger's experience (PAX) is the culmination of interactions at all touchpoints within a station's infrastructure, encompassing the entire rail journey from ticket purchase to arrival at the passengers' destination. To successfully minimise stress for passengers and staff, managing expectations and understanding shortfalls in infrastructure could be incredibly beneficial for train operating companies.

Over half of the UK railway sector's income is from passenger fares. However, delays, poor experiences, and compensation payments strain its sustainability and deter future travelling. Companies that prioritise customer experience have been shown to outperform their competition tenfold.

This paper reviews passenger experience through a user-centred systems approach and considers journeys holistically rather than viewing them as an amalgamation of system requirements. The methodology broadens the understanding of systems engineering and encourages using human-centred systems engineering infrastructure design.

This approach represents a shift from traditional systems engineering, focusing on technical specifications, and instead places passengers at the core of engineering and design considerations. The matrices consider journeys as multifaceted entities, adding layers to the simplified journeys identified in systems engineering principles to comprehend passenger journeys as a holistic entity rather than fragmented, separate journeys to understand how passenger dissatisfaction in one journey may impact satisfaction on a following journey.

The study involves collecting user feedback, conducting ethnographic research, and using design thinking methodologies to create solutions aligned with passenger desires and expectations. This shift encourages considering customer satisfaction and contributes to the long-term sustainability of rail systems in an increasingly customer-focused world.

Keywords: Human-Centred-Bottom-Up Design · Journey Mapping · Inclusive Ergonomic Design

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1 Introduction

The act of travelling is seen, subjectively, as a 'necessary evil' [1]. Often, for passengers, it is not the travelling they enjoy but the destination they would like to get to [2]. Travelling is frequently seen as the required thoroughfare to reach a destination, and inconvenience in an already frustrating experience further contributes to a passenger disliking the necessity to travel [3–7]. The current comprehension of a journey in the eyes of the railway is a system-centric top-down understanding [8], focusing primarily on system operations, regulations, and system identification and significantly less on the customer [9]. However, with a better understanding of customer expectations, recognition of potential irritations in a journey could be addressed much earlier, reducing staff stress, and shifting the mindset of passengers to a neutral or even positive outlook [10].

In aviation, passenger experience (PAX) is defined as '*the interactions between the airlines and the passengers, from booking tickets to baggage claims at destinations*' [11]. A prominent consideration in air travel [10–13], successfully understanding a passenger's experience in a railway setting should mirror successful journey attributes in aviation, considering a journey from when a customer leaves their origin station to when they arrive at their destination.

Over half of the UK railways income is received through ticket revenue from passenger journeys [14]. Yet, due to delays, poor experience, or infrastructure inadequacies, over five per cent of this is paid back to customers in compensation [4, 5]. Research conducted by Mark Van Hagen [17], shows that a poor passenger experience can result in customers developing a negative outlook on the infrastructure, becoming unwilling to use the service again, and even discourage others. This can ultimately lead to decreased demand and lower expectations from customers for a good experience. Therefore, investing in improving the passenger experience may be crucial to ensure the sustainability of passenger rail usage in a post-pandemic world and encourage more people to choose rail transport over private modes.

Human factors and customer experience are fast becoming prevalent features in the railway industry [18–20] with the implementation of '*everyone home safe every day*' [21], '*putting passengers first*' [22], and '*put passengers at the centre of rail design*' [23] initiatives paving the way for a human-centric perspective to railway transportation. Comprehension of passenger experience and satisfaction have been explored in railways since railways started running public services [24], and the satisfaction of a customer through their journey is typically mapped as a customer experience *rose and bud* diagram (see Fig. 1), which illustrates the frustrations and delights in a journey [25–27].

Despite this, a system's definition of a journey and a customer-centric definition of understanding journeys sit siloed from one another, making it complicated to identify where issues in infrastructure are, how a setting may impact a passenger or the common problems of rail transportation.

Adopting a design approach centred on the wants and needs of rail passengers could enable operators to provide genuinely satisfying experiences for their passengers. To gain deeper insights into this approach, Dutch rail operator Nederlandse Spoorwegen (NS) [29] formulated a hierarchy of customer requirements to identify what *good* looked like for their customers. Their research showed that factors such as the travel duration, safety, and user-friendliness within their evaluation were deemed "acceptable" and "expected",

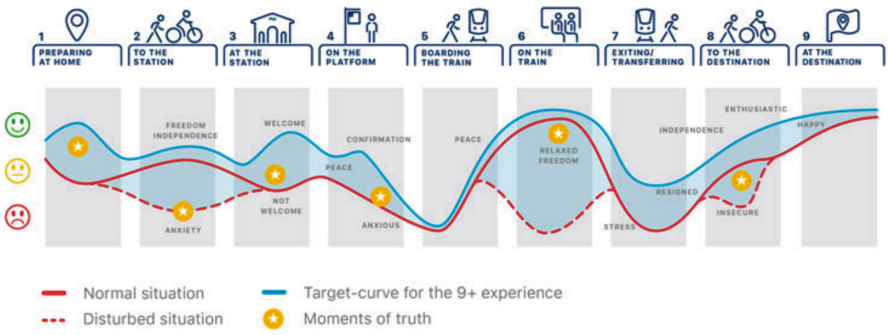

Fig. 1. Customer experience of positive and negative emotions throughout a journey [28].

not necessitating a large contribution to customer satisfaction. Achieving customer "delight," on the other hand, necessitates offering practical amenities like power outlets and Wi-Fi, maintaining above-average standards of comfort and cleanliness, and fostering interactions with approachable staff [30].

Transport for London adopted a similar methodology in its "*Strategy for Improvement*," [31] incorporating elements known as "*Delighters*"—customer service enhancements that elevate overall satisfaction, such as offering localised information or personalised assistance for persons with reduced mobility (PRM). National rail operators collectively map customer journeys using heartbeat data (the variability in heart rate to determine a person's stress levels) and map those against journey maps (the numerical time vs happiness score, or Rose and Bud diagram) [26, 32], and most supplement this with their own data sources to understand their customers [33]. The caveat with doing this is that external factors such as whether the participant has had caffeine, the heart health of the participant, and whether their heart rate increases significantly during walking between trains lead to inaccurate representations of stress during a journey. When creating these types of journey map, certain factors such as the participant's current mood, ongoing stress, and interruptions (such as phone calls or text messages) during the journey may not be considered. Although these factors may not directly affect the stress levels associated with the journey itself, they can still have an impact on the participant's overall stress levels and increase their heart rate. An increased heart rate can also be a symptom of various emotions, including stress, excitement, joy, or anxiety, making it difficult to rely solely on heart rate data to determine the stress levels of a journey.

Examples of design thinking focused on passengers might involve user-centric technologies like Citymapper [34] or electronic ticketing via smartphones, enhancing the passenger experience through station design like King's Cross/St Pancras station or even smaller-scale endeavours like displaying Olympics medal news on station screens to uplift weary commuters.

Despite these initiatives, very little research has been done across multiple train operating companies (TOCs) to comprehend the holistic passenger experience across multiple TOCs. A poor experience in one leg of a journey may have lasting effects on the latter half, creating a subpar customer experience. Without adequate identification of the journey type and its characteristics, train operating companies are unlikely to be

able to pinpoint lulls in customer satisfaction, no less act on improving it. Unfortunately, these substantial enhancements in customer-centric services remain elusive in the rail industry, leading to a 10-year low in passenger satisfaction [35].

This paper proposes a new methodology framework for identifying holistic customer experience mapping across multiple TOCs, and multiple transport options to be able to locate where commonalities of shortfalls in railway satisfaction lie.

Historically, customer satisfaction and needs have come secondary to systems engineering. Retrofitted to pre-existing infrastructure and rolling stock, wheelchair ramps, stair lifts, and elevators create a non-inclusive and unwelcoming space for those who rely on railways as a means of transportation due to out-of-date design specifications which do not represent the 21st-century passenger [36]. Furthermore, the use of different definitions by customer information hubs and systems definitions to identify service issues leads to a mismatch in understanding the hot spots for passenger dissatisfaction. This fragmented perspective of a passenger journey makes it difficult to improve the overall experience of railway passengers [37, 38].

While operational system definitions are critical for reducing ambiguity and upholding the safety and dependability of rail systems, they often prove inadequate in addressing passengers' intricate needs and preferences, especially if a passenger changes services. This can leave the rail operators unaware of a prior issue in a passenger journey that an earlier journey on a different service could cause.

This paper builds upon a growing body of research in passenger experience (PAX) within transportation [39] and the broader field of customer experience and service design for demand. Although passenger journeys are identified using operational scenarios, and holistic journeys are defined using heartbeat data and journey maps, there is little to bridge the two together to form human-centred systems engineering idealisms across multiple operating companies. This paper adds to the existing literature in this space, combining systems engineering definitions with start-to-end journey maps to create a more genuine representation of a passenger journey, fostering inclusive design practices to understand passenger demographics, reasons for travel and the wants and needs of a vast array of passenger personas [40–43].

The paper acknowledges previous studies [26, 28, 44–49] highlighting the importance of managing passenger expectations, the impact of poor experiences and delays on the UK railway sector and emerging trends of human-centric perspectives of the railway industry. This methodology positions passengers at the forefront of engineering and design deliberations. It encompasses the collection of user feedback, undertaking thorough ethnographic research, and utilises design thinking methodologies to formulate matrices that closely align with passengers' desires and expectations. Human-centred engineering elevates customer satisfaction and substantially contributes to rail systems' long-term sustainability and adaptability in a progressively customer-focused world. The new approach comprehends the passenger journey holistically, pushing past traditional siloed systems engineering system requirements and investigating the multimodalness of a passenger's intricate journey.

2 Methodology

When a complaint is registered from a passenger, the journey's system degradation mode is often captured, rather than the entire passenger's journey. The current approach to understanding passenger journeys is inherited from a systems-centred engineering concept [50]. In this context, journeys are split into four operational scenarios: '**Normal operations'** describing how the railway was designed to operate, including planned peak periods. '**Abnormal operations'** arise from extreme loading on a part of the railway system, for example, due to severe weather or delays to a train service impinging on others**. 'Degraded operations'** occur when part of the railway system continues to operate in a restricted manner, for example, after the failure of signals. '**Emergency operations'** include an unforeseen or unplanned event with life-threatening or extreme loss implications and usually requires immediate attention, such as a fire or an obstruction on a line." [51–53].

Conversely, understanding passenger satisfaction in a journey is typically performed using passenger satisfaction and heart rate analysis, focusing on the passengers' feedback, their psychological stress and heart rate variability in different scenarios of infrastructure [54–59]. This method focuses more on the passenger and their needs, distinguishing that all passengers and their needs differ, and their personal-level measurements encourage a granular approach to understanding travel.

This paper suggests a new human-centred systems engineering approach, merging both methodologies into a unified framework for comprehending passenger narratives in different settings. Passenger journeys are defined in many ways, with inconsistencies in their descriptions [32, 60, 61]. Some refer to journeys with multiple 'legs' as numerous, separate journeys, with one journey representing one train trip [62], whereas others determine a journey from a broader perspective that encapsulates the entire journey from the moment the customer thinks about purchasing a ticket [61].

Passenger journeys have been defined for this research as simple, complex, and multimodal journeys where:

- Simple journeys involve direct routes using a single railway line.
- Complex journeys are more intricate, requiring multiple transfers or connections within a railway network.
- Multimodal journeys involve the integration of various modes of transportation, such as trains, buses, planes, or trams, to reach the intended destination—for example, London Victoria to Gatwick Airport to Rome.

For this research, journeys are identified as encompassing all 'legs' holistically, considering all aspects from the passenger's initial boarding station to their destination.

To define the passenger journey settings, a combination of operational scenario identification and journey types were placed into a matrix to create 12 different journey settings (see Table 1).

Once titled, the journeys were defined further and considered from a customers' perspective, where the new twelve journey settings are expanded and defined in Table 2.

Table 1. Journey type versus operational scenario matrix

Journey type	Operational scenario			
	Normal	Degraded	Abnormal	Emergency
Simple	Simple, normal	Simple, Degraded	Simple, Abnormal	Simple, Emergency
Complex	Complex, Normal	Complex, Degraded	Complex, Abnormal	Complex, Emergency
Multimodal	Multimodal, Normal	Multimodal, Degraded	Multimodal, Abnormal	Multimodal, Emergency

The matrices describe potential scenarios for a journey, outlining possible outcomes and hypothesised passenger satisfaction. They start to underpin the methodology for capturing holistic passenger experience across different operational scenarios and journey types for this work.

2.1 Participants

Thirty-four participants were randomly selected from the School of Engineering at the University of Birmingham to trial this ideology, better understand different journeys and how journeys vary, and test the rationale using a sample group and their effects on passenger satisfaction.

The trial group comprised a wide range of ages from 18 to 64, with 32% identifying as female and 68% identifying as male. Of these participants, 12% identified as Autistic, 9% with a physical disability, 3% with a mental health condition, 9% with attention deficit hyperactivity disorder (ADHD), and 3% with a visual impairment not helped by corrective glasses (e.g. partial blindness).

After gathering all participants through anonymous flyers, the participants were screened to reduce bias in the journey data. To understand how biased the data could be, the participants were given a Myers-Briggs test [63], which was underpinned with statistical backing to determine how optimistic and pessimistic the participants felt they were and how statistically they were written down to be [64, 65] (see below).

The MBTI screening allowed researchers to understand the personality types of the candidates, capturing their perceived optimism (the optimism they think they are), against the optimism calculated by Myers-Briggs' statistical data. The screening was done before the journey, on the same day, to capture the Myers-Briggs Type Indicator (MBTI) as it stood on the day of travelling (Table 3).

Participants were also asked to note any additional requirements and anonymously write them alongside their candidate number (a four-digit randomly assorted number which they used for the entirety of the trial), which was submitted online via a confidential computer. The statistics showed that several members identified with characteristics affiliated with persons with reduced mobility (PRM). People with reduced mobility (PRM) may have difficulty boarding/alighting/using trains or their infrastructure. The varied nature of PRM identification can adversely affect the journey a person with

reduced mobility may have and add additional layers of complexity to the trip. PRMs included in current designs for railway includes the following categories (Fig. 2):

As these are identified in the People with reduced mobility technical standards of interoperability (PRMNTSN) [67], these persons should be able to access infrastructure in a similar way to non-PRM people. As such, it was deduced that this was not a biased attribute to the data but something to acknowledge when understanding the satisfaction of the participants.

Using these PRM identifiers, a matrix was drawn to develop a framework for understanding where passengers may need more assistance and where operational scenarios may impede their journey further than what we already know they need. This table helped

Table 2. Journey type versus operational scenario

Operational scenario					
Journey type		Normal The rail schedule runs as it is supposed to	Degraded The rail schedule is still in operation but restricted due to the failure of one or more parts	Abnormal Rail schedule is disrupted due to extended delays, extreme loading or part of the service impinging on another	Emergency Rail schedule is disrupted due to unforeseen or unplanned events which are life-threatening or require immediate attention
	Simple A journey that uses one mode of transport, with no changes	Simple, normal These journeys consist only of one mode of transport to get to a destination, all schedules running as the timetable suggests	Simple, Degraded These journeys require one mode of transportation to reach a destination, but the service runs in a restricted manner. Delays possible	Simple, Abnormal These journeys consist of only one service, but the timetable has been disrupted due to an abnormality, such as a football game, a marathon or external weather conditions	Simple, Emergency These journeys require only one train but are inhibited by unforeseen circumstances caused by an emergency. Delays and alterations are probably

(*continued*)

Table 2. (*continued*)

Operational scenario					
	Complex A journey that uses rail, but passengers have to change to get to their destination	Complex, Normal These journeys consist of the passenger changing trains, but both trains are running to schedule. Delays unlikely	Complex, Degraded These journeys require the passenger to change trains, but the service on one or both trains is altered. Delays are possible; changeover could made more difficult	Complex, Abnormal These journeys require a passenger to change trains, but one or all of the trains are disrupted by abnormal timetabling, such as a football game. Delays possible	Complex, Emergency These journeys require the passenger to change trains, but one or both trains have an altered service due to an emergency. Delays likely, crossover time potentially reduced
	Multimodal A journey that has rail transportation but also uses alternative types of transport to reach a destination	Multimodal, Normal These journeys require trains as one component of the journey and other forms of transportation to get to the destination. Services on all are running as planned	Multimodal, Degraded These journeys require passengers to use trains to reach their destination, but the train portion has been altered due to degraded conditions. Delays possible	Multimodal, Abnormal These journeys require train travel as part of the journey to reach a destination, but abnormal amounts of people travelling disrupt the train portion	Multimodal, Emergency These journeys require passengers to use trains as part of their journey, but an emergency inhibits the train timetable. Delays possible

identify where the shortfalls for passengers with reduced mobility could be, who may be most likely to be affected by significant changes in infrastructure and timetabling, and where improvements could be made to make infrastructure more inclusive.

2.2 Data Collection

Participants were asked to take the same journey from Loughborough station to Birmingham New Street station, which consisted of one change at Leicester station, two train operating companies (EMR (East Midlands Railway) and Cross Country), and a 66-min journey.

Table 3. Optimism and pessimism from MBTI type. Adapted from [64, 65].

TYPE	I/E	N/S	F/T	J/P	OPTIMISM	PESSIMISM
INFJ	Introverted	Intuitive	Feeling	Judging	0.5	0.5
ENFJ	Extroverted	Intuitive	Feeling	Judging	0.75	0.25
INFP	Introverted	Intuitive	Feeling	Prospecting	0.75	0.25
ENFP	Extroverted	Intuitive	Feeling	Prospecting	1	0
INTJ	Introverted	Intuitive	Thinking	Judging	0.25	0.75
ENTJ	Extroverted	Intuitive	Thinking	Judging	0.5	0.5
INTP	Introverted	Intuitive	Thinking	Prospecting	0.5	0.5
ENTP	Extroverted	Intuitive	Thinking	Prospecting	0.75	0.25
ISTJ	Introverted	Observant	Thinking	Judging	0	1
ESTJ	Extroverted	Observant	Thinking	Judging	0.25	0.75
ISFJ	Introverted	Observant	Feeling	Judging	0.25	0.75
ESFJ	Extroverted	Observant	Feeling	Judging	0.5	0.5
ISTP	Introverted	Observant	Thinking	Prospecting	0.25	0.75
ESTP	Extroverted	Observant	Thinking	Prospecting	0.5	0.5
ISFP	Introverted	Observant	Feeling	Prospecting	0.5	0.5
ESFP	Extroverted	Observant	Feeling	Prospecting	0.75	0.25

Wheelchair users (persons who, due to infirmity or disability, use a wheelchair for mobility)
Other mobility impaired, including:

- people with limb impairment;
- people with ambulant difficulties;
- people with children;
- people with heavy or bulky luggage;
- elderly people;
- pregnant women.

Visually impaired.
Blind people.
Hearing impaired.
Deaf people.
Communication impaired (persons with difficulty communicating or understanding the written or spoken language, including foreign people with a lack of knowledge of the local language, people with communication difficulties, and people with sensory, psychological, and intellectual impairments).
People of small stature (including children).

Fig. 2. Definition of PRM [66]

Participants took the 09:32 from Loughborough, changed at Leicester at 09:42, and had an 8-min transfer time to the Birmingham train at the same station. They boarded their second train at 09:50, arriving in New Street at 10:38.

Under the operational scenario definition, the journey is 'normal', with no external factors affecting the journey service. Using the new methodology, this journey is determined as a 'Complex, Normal' journey where passengers have to change services, but both run on time.

Before the investigation, a presentation was delivered to the delegates to reduce any ambiguity. There, they were told how to access their online forms, how to enter their data, how to capture their satisfaction scores from 1 (being very unsatisfied) to 10 (being very satisfied), and how to record qualitative data regarding why they scored the way they did. A structured metric was shown to them, including an automatic time stamp when participants entered their data to remove the risk of participants entering all the data after their journey and thus not being representative of their journey at the time.

Whilst travelling, participants were asked to record how they felt every 5 min of their journey via their online forms, which were made individually for each participant. This data was compiled into a dataset for all 34 participants, which allowed researchers to analyse participants individually (to see whether their data was entered correctly and at the right time), and all together to identify peaks and troughs in the dataset.

3 Results and Discussions

The matrices of journey types and their derivatives create a set of ideal and non-ideal scenarios that help develop a comprehensive understanding of a passenger's journey. In practice, those in the trial mentioned that their ideal scenario was a journey that required no changes, was on time, and was over quickly. 94% of the participants agreed that the new way of assessing journey characteristics was truer to their journey than the operational scenario identification was and helped them understand their journey better. By assessing the journey characteristics, which include normal, simple, multimodal, and abnormal scenarios, a more complete picture of the trip can be obtained.

To better understand passenger journeys, 34 participants with varying levels of mobility, ages, and backgrounds embarked on a journey from Loughborough to Birmingham New Street Station. Every 5 min, they were asked to assess their satisfaction levels independently, without consulting their fellow travellers. Figure 3 provides an overview of their combined experiences.

Analysing the journey collectively revealed its peaks and troughs, highlighting moments of comfort and discomfort shared among the group. The first, initial high, may have been met with general excitement for travelling, with many noting that they were 'inquisitive about the new station' that they had started at. Before the first satisfaction peak and arrival at the station, a base reading was taken before the journey began to decipher how their happiness changed versus a control variable.

The journey's map is divided into multiple segments, with the first base reading recorded prior to the journey start, readings taken during the initial leg of the journey, then the dwell, the second leg and a base reading collection at the end of the journey. Despite the first half of the journey being the shortest, the spikes in happiness were significantly higher than the following segments of the journey at 7.07 on average. During the dwell, participants were happier when they knew their next train was coming, before being significantly less satisfied when the second leg of the journey began, and satisfaction scores dropped to an average of 5.83.

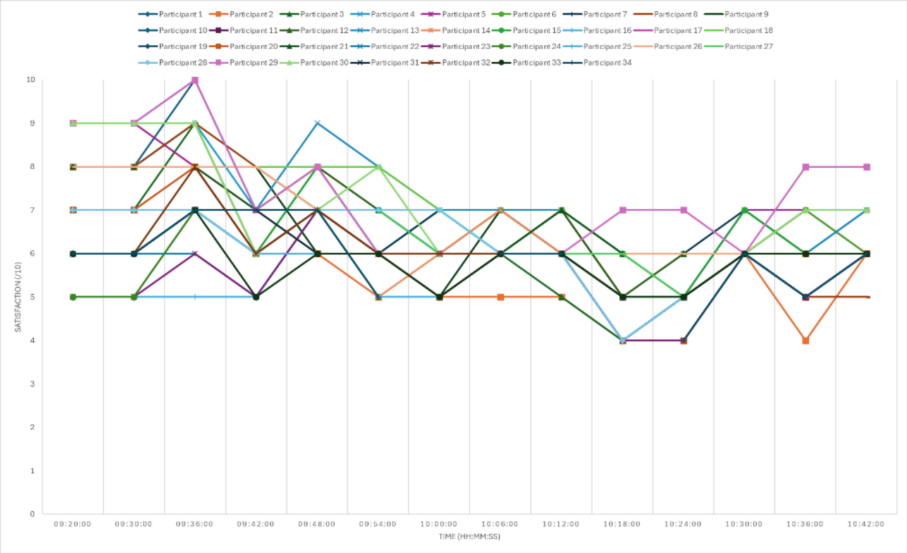

Fig. 3. Satisfaction over time periods for all 34 participants.

During the latter part of the journey, participants noted that the train was notably crowded, leaving passengers standing with nowhere to sit. They remarked on the noise levels, outdated décor, and the frustration of paying for a ticket yet not being able to find a seat. PRM passengers were able to board and alight in both instances with station staff assistance but were not comfortable about 'squeezing into the carriage' when it was already busy. Despite the satisfaction levels being significantly lower during the second leg, the higher satisfaction reported earlier in might be attributed partly to the anticipation of the journey itself and the excitement of participating in the experience.

Within the diverse groups, there were clear differences in the satisfaction scores. Notably, those with ADHD had a predominantly larger standard deviation compared with all other groups, potentially due to the neurodivergent conditions' variability in satisfaction generally. The fluctuations in satisfaction levels could be due to noise levels, crowded spaces, and sudden changes in environmental impacts such as smells and surroundings or growing impatience during the change time (see Fig. 5) (Fig. 4).

The differences in satisfaction between the genders was negligible, with an average satisfaction score of around 6.31, and both dropped, on average, one point in satisfaction scores for the latter half of the journey.

For the participants with reduced physical mobility, one member was unable to finish their sheet, quoting that they felt rushed through the trial and, in the thick of trying to muster up the ability to get through their journey, submitted their time stamps outside of the time bracket allocated. Despite this, their standard deviation was minimal, meaning low variability in results and, perhaps, a similar satisfaction score throughout the journey despite the change. The passenger mentioned that their satisfaction score, and ability to complete their sheet would have been made even more complicated if their next train was departing from a different platform.

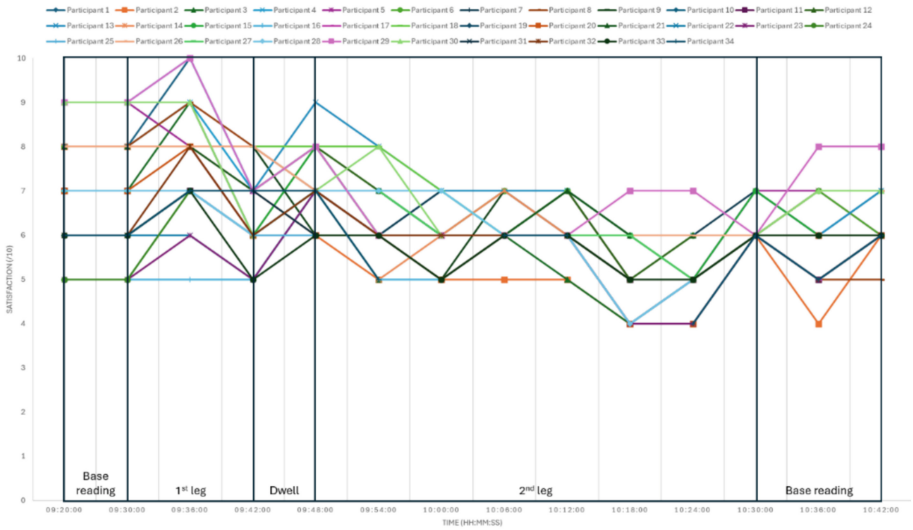

Fig. 4. The different segments of a journey.

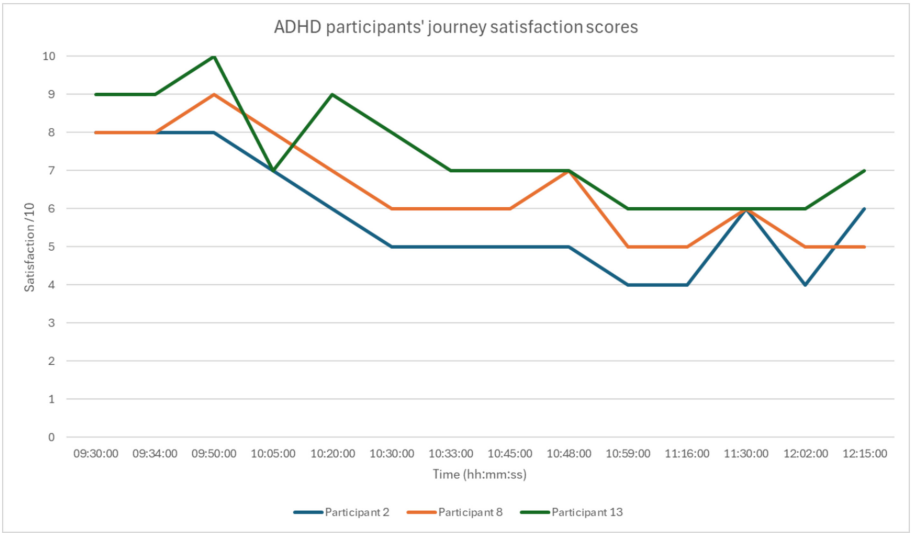

Fig. 5. ADHD participants' journey satisfaction variation.

Those with Autism had similar satisfaction scores as the rest of the group, not moving down much on the journey's second half. The only participant to continue with a higher-than-average score was participant 29, who was not fussed about the change of rolling stock or the wait for the next train. In their notes, they mention that the pause in their journey let them relax and listen to music, and the added knowledge that the train would

arrive on the same platform put them at ease. They were also an abed train spotter and enjoyed the experience.

The chart displays scores coded by colour. Blue scores are more than two standard deviations from the group average, green scores are one standard deviation from the group average, orange scores are one standard deviation below the group average, and yellow scores are more than two standard deviations below the group average. The red areas indicate where participants left the form blank. In all cases, bar participant 29 showed decreased satisfaction on their second journey compared to their initial journey.

Despite the trial unintentionally doing so, the participants were, for neurodiverse statistics, relatively consistent with statistics as they stand for neurodivergent people in the UK (around 15–20% [68]). However, the gender differences in this study are not characteristic of the UK population, and the trial simulates one possible journey scenario. The trial could not account for the lack of seating, the weather, or the business of the service.

Despite this, the research shows the complexity of the journey experience and the effects of a poorer service on passenger satisfaction resulting in a lower satisfaction score post journey. Should there have been another section to the journey, it may have been possible for satisfaction to drop further. The approach enables us to see journeys holistically and encourages a shift towards a user-centric approach in design and operation. Instead of prioritising system requirements, focusing on passengers' needs first could lead to more tailored and satisfactory experiences. By adopting a holistic perspective, encompassing all aspects of the journey, from minor details to overarching goals, designers may be able to mitigate customer complaints and gain valuable insights into passenger preferences.

Further, broader studies involving diverse participant pools and varying scenarios can refine the framework, directing investments towards enhancing passenger satisfaction and optimising travel experiences.

4 Conclusions

This study aimed to comprehensively understand passenger journeys by looking beyond standard system definitions. External factors such as travel purpose, mode of transportation, and passenger requirements, including PRM status, contribute to the complexity of passenger journeys and are not captured in the current operational scenarios. This ambiguity creates difficulty in identifying where passenger dissatisfaction may lie.

The study resulted in developing a framework that systematically contextualises passenger journeys. The framework aims to identify where passenger experiences differ and how multi-leg journeys impact overall satisfaction, particularly among diverse demographics. The approach used in this study was human-centred and went beyond just operational scenarios to conceptualise experiences from a bottom-up perspective.

Central to this methodology was the desire to differentiate between "good" and "bad" passenger journeys, considering the entirety of the passenger experience from initial station arrival to destination. The Passenger Journey Matrix Framework achieves this by adopting a holistic approach to passenger experiences, urging transportation companies to understand pre-service boarding scenarios from the passenger's viewpoint whilst

simultaneously using terminology adopted by the industry to ease the implementation of this new framework. This perspective enables the identification of pain points and opportunities for system-wide enhancement.

Furthermore, by integrating operational scenario analyses with passenger experiences, the framework enables proactive addressing of challenges and complaints, thereby strategically enhancing service quality. The framework's significance lies in promoting a holistic passenger experience and aligning with the industry's human-centric transportation ethos. It addresses infrastructure shortcomings and acknowledges the economic repercussions of poor passenger experiences on railway companies.

In conclusion, this study advocates for a structured approach to understanding and improving passenger journeys. Organisations can deliver better service and foster a more human-centric transportation system by anticipating customer complaints and tailoring responses to different scenarios.

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Measuring Vulnerable Road User Volumes After Mobility Interventions in the Metropolitan Center of Athens

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Abstract. In today's rapidly urbanizing world, the surge in urban population has led to heightened transportation demands and intricate mobility patterns. However, the pursuit of efficient mobility must not compromise the safety of Vulnerable Road Users, including pedestrians, cyclists, children, elderly individuals, and those with disabilities [16, 17]. The "Predictive Approaches for Safer Urban Environment" (PHOEBE) project addresses this pressing concern by employing predictive techniques to enhance safety measures for Vulnerable Road Users. This study focuses on investigating parameters influencing pedestrian, cyclist and scooters movement in the center of Athens. Three Multiple Linear Regression Models were deployed, with the number of pedestrians, cyclists and scooters as dependent variables. Field measurements data were collected before and after the implementation of interventions under the Athens Great Walk framework. The results underscore the positive impact of Athens Great Walk: reducing traffic lanes and expanding sidewalks led to significant increases in pedestrian and cyclist numbers. Subsequent interventions increase road user counts. Road type, traffic lanes, and pavement width were identified as statistically significant factors contributing to the rise in vulnerable users. These findings offer valuable guidance for policymakers and stakeholders striving to create secure environments for road users, forming a crucial foundation for pedestrian-friendly urban spaces. This research not only fills a crucial gap in understanding urban transformation in metropolitan areas but also provides practical insights for promoting cycling as a viable transport mode in Athens, aligning with the global shift toward sustainable urban mobility.

Keywords: Vulnerable Road Users · Pedestrians · Cyclists · Scooter Riders · Regression Analysis · Road Interventions · Athens Great Walk · PHOEBE

1 Introduction

In contemporary highly motorized societies, cities are experiencing an increasing concentration of population, leading to increased transportation demands and complex mobility patterns, especially in highly congested urban centres. However, the need for efficient mobility should not come at the expense of compromising the safety of VRU's.

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Pedestrians, cyclists, scooter riders, children, elderly individuals, and individuals with impairments or disabilities are particularly susceptible to crashes and injuries in the urban environment [16, 17]. Such Vulnerable Road Users (VRUs) lack the protection that motorized vehicles provide, and often lack the means of perception or headway management to address the aggressive course of vehicles, whether moving legally or illegally.

To ensure the safety and well-being of vulnerable road users (VRUs), it is crucial to have a thorough understanding of their interactions with the built environment and transportation systems. Additionally, evaluating the effectiveness of mobility interventions designed to enhance conditions for VRUs is imperative. One approach to assess the impact of these interventions on the safety and convenience of VRUs is by measuring the volumes of VRUs before and after their implementation. This allows policymakers and urban planners to analyze the effects of such measures and make informed decisions regarding the improvement of safety conditions for VRUs [8].

The metropolitan center of Athens, like many other major cities worldwide, has experienced a notable increase in mobility interventions designed to meet the growing needs of its residents while prioritizing the safety and accessibility of VRU's. These interventions, ranging from pedestrian-friendly pathways to cyclist-oriented infrastructure enhancements, represent a response to the evolving challenges posed by urbanization. However, in the pursuit of creating mobility solutions, it is paramount to assess the efficacy of these interventions concerning vulnerable road user safety.

This study aims to investigate the effect of mobility interventions in the metropolitan center of Athens on the volumes of vulnerable road users. By quantifying changes in pedestrians, cyclists and scooterists volumes before and after the implementation of specific interventions, insights are gained into the effectiveness of these measures in promoting safer and more accessible urban environments. Such findings can inform future planning and policy decisions, allowing for evidence-based interventions that prioritize the needs and safety of VRUs in highly congested urban areas.

Existing academic research has extensively examined the effectiveness of sustainable urban transport policies in improving road safety and encouraging active modes of transportation. However, there is a notable gap in the literature regarding a comprehensive analysis of the specific impact of interventions such as the introduction of alternative greenways (AGW) on the mobility of pedestrians, cyclists, and scooter riders in densely populated metropolitan areas. This study aims to fill this gap by employing regression modelling techniques to provide valuable insights into whether the implementation of AGW initiatives influences the mobility patterns of these user groups. By investigating the relationship between AGW interventions and the mobility behaviors of pedestrians, cyclists, and scooter riders, this research contributes to a deeper understanding of the implications of these interventions on sustainable urban transport and road safety [3, 12].

The EU PHOEBE project ("Predictive Approaches for Safer Urban Environment") aims to advance the application of traffic simulation tools and road safety assessment to enable transport planners and managers to fully understand and address the safety implications of changes in road conditions, mode choice, new modes, road user behaviours and other factors as well as their impacts on safety. The project, which includes three

pilot city use-cases—Athens, Valencia, and West Midlands—focuses on investigating the impact of specific interventions and more precisely for the Athens Use Case of the AGW on pedestrian, bicycle and scooter trips in the central area of Athens. To that end, the aim of the present study is to examine and investigate whether the parameters that affect the movement of pedestrians and cyclists in the center of Athens have been adequately affected by the interventions of the AGW.

Following the introduction, the structure of this paper is as follows: Section two outlines the methodology used to fulfill the research objectives of this study, including the relevant background information. Section three presents the findings of the analysis, while section four provides a summary of the conclusions derived from this research and section five presents a discussion by proposing possible directions for future investigations.

2 Methodology

2.1 Interventions Background – Athens Great Walk Implementation

The City of Athens introduced the Athens Great Walk, a project reshaping the cityscape and putting pedestrians and cyclists at the forefront of urban mobility [7]. This transformative endeavor, reclaims public spaces, prioritizes pedestrians and cyclists, and promotes sustainable transportation methods. Beginning in June 2020, the pilot phase involved road surface enhancements, easing traffic regulations, limiting traffic, extending sidewalks, and creating bicycle lanes, Key city landmarks, including Omonia Square, underwent restoration and reactivation. Notable interventions, as planned from 2nd July 2020 to 6th August 2020, included the creation of bicycle paths, bus lanes, and wider sidewalks. Precisely, the interventions implemented and examined in this paper, is the renovation of Panepistimiou Street with a new bike path, 3 lanes for cars and a bus lane in the same direction.

Recent research emphasizes the importance of multimodal approaches that cater to diverse commuters, including pedestrians, cyclists, and scooter riders [3, 6]. By integrating cycling lanes, expanded pedestrian pavements, and scooter-friendly zones within the urban fabric, cities create a comprehensive and inclusive transportation network. Wider sidewalks not only encourage more people to walk but also facilitate the integration of urban amenities [14], dedicated cycling lanes has revolutionized cycling in urban environments [12] and allocating specific spaces for alternative modes of transport, including scooters, has positively influenced urban mobility [14]. These interventions not only create safer environments but also encourage the adoption of active transportation modes, contributing to the overall sustainability and livability of urban areas.

2.2 Methodological Background

Regression analysis is a statistical technique used to model the relationship between a dependent variable and one or more independent variables. It allows researchers to quantify the effect of independent variables on the dependent variable and make predictions or draw inferences based on the model. In this specific case, Poisson regression

is employed to analyze count data, which is commonly encountered in fields such as transportation. Poisson regression is particularly suitable for modeling count outcomes, as it assumes that the counts follow a Poisson distribution [2].

The Poisson regression model is based on the Poisson distribution, which is a discrete probability distribution used to model the number of events occurring in a fixed interval of time or space[1]. The probability mass function (PMF) of the Poisson distribution is given by the equation:

$$P(Y = y) = (e\text{^}(-\lambda) * \lambda\text{^}y) / y! \tag{1}$$

Where Y represents the count variable, λ (lambda) is the average rate or intensity parameter, and y is the observed count value. Poisson regression extends this concept by introducing explanatory variables to model the relationship between the count variable and the independent variables.

In Poisson regression, the logarithm of the expected count (λ) is assumed to be a linear combination of the independent variables. The equation for the Poisson regression model is:

$$log(\lambda) = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p \tag{2}$$

Where log(λ) is the natural logarithm of the expected count, β_0, β_1, β_2,…, β_p are the regression coefficients, and X_1, X_2,…, X_p are the independent variables.

Generalized Linear Models (GLMs), used in these analyses, provide a flexible and powerful framework for modeling a wide range of response variables that may not adhere to the assumptions of ordinary linear regression. GLMs extend the linear regression paradigm by allowing for different types of response variables, including binary, count, and non-normally distributed data. The key idea behind GLMs is to model the relationship between the response variable and the predictors through a systematic component called the linear predictor [9].

However, instead of assuming a linear relationship between the predictors and the response, GLMs introduce two additional components: the link function and the error distribution. The link function connects the linear predictor to the response variable, enabling the model to capture the underlying relationship. The error distribution characterizes the variability of the response and can be chosen based on the nature of the data. For example, the Poisson distribution is commonly used for count data, while the binomial distribution suits binary outcomes. GLMs allow for modeling the mean and variance of the response variable separately and can accommodate various forms of non-constant variance. Estimation of the model parameters in GLMs is typically done using maximum likelihood estimation [2, 5].

In order to analyse the results of the generalized linear model regression there is a number of factors to understand. Firstly, in regression analysis, the coefficients represent the estimated effect of each independent variable on the dependent variable. For a linear regression model, the equation is:

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + \varepsilon \tag{3}$$

Where Y is the dependent variable, X_1, X_2,…, X_p are the independent variables, β_0, β_1, β_2,…, β_p are the coefficients, and ε is the error term. The coefficients measure the

change in the dependent variable associated with a one-unit change in the corresponding independent variable, assuming all other variables are held constant [10]. Additionally, standard errors provide an estimate of the precision of the coefficients. They quantify the variability of the coefficient estimates across different samples. The standard error (SE) is calculated as:

$$SE(\beta_i) = sqrt[Var(\beta_i)] \tag{4}$$

Where Var(β_i) represents the variance of the coefficient estimate. Smaller standard errors indicate greater precision and reliability of the coefficient estimates [4]. Furthermore, the significance level, or p-value, assesses the statistical significance of each coefficient. It indicates the probability of observing a coefficient as extreme as the one estimated, assuming the null hypothesis is true (i.e., no relationship between the independent variable and the dependent variable). The p-value is typically compared to a predetermined significance level (e.g., 0.05) to determine statistical significance. A p-value less than the significance level indicates statistical significance [15]. Finally, goodness-of-fit measures evaluate how well the regression model fits the data. One commonly used measure is R-squared (R^2), which represents the proportion of the variance in the dependent variable explained by the independent variables. R-squared ranges from 0 to 1, with higher values indicating a better fit [15].

3 Results

The data of this study stem from the implementation of Panepistimiou Street, and span for a day per month, six months before the implementation of the pilot phase of the Athens Great Walk for the pedestrians, cyclists and scooter riders at morning hours from eight o'clock till three 'clock and for six months after the implementation of the interventions. More precisely, after creating a new bike path, three lanes for cars and one bus lane.

In this paper, separate regression analyses are performed for three types: Pedestrians, Bicycles, and Scooters. For each type, the independent variables used in the regression model are the day of the week, the month, and the hour of the day. These variables are believed to have an impact on the traffic volume.

The regression models presented in Tables 1, 2 and 3 for pedestrian, cyclists and scooter drivers correspondingly, provide us with valuable information on the significance and magnitude of the interventions effects, in this way better understanding the impact of the implemented interventions on different modes of transportation.

Based on the results of the log-linear regression analysis for pedestrians as shown in Table 1, the day of the week variable shows a significant association, with a coefficient of 0.5893. The confidence interval [0.355, 0.823] suggests that we can be 95% confident that the true coefficient lies within this range. As for the hour of the day variable has a modest but still statistically significant relationship, with a coefficient of 0.1179. Lastly, the coefficient for the variable "Month" is 0.3416, indicating that the traffic volume of pedestrians increases by 0.3416 units for each incremental month. This coefficient is highly significant with a z-value of 12.451, indicating a robust relationship between the

month and pedestrian traffic volume. The confidence interval [0.288, 0.395] suggests that the true coefficient is likely to fall within this range with 95% confidence.

The regression analysis results indicate that all three predictor variables, namely 'DayOfWeek,' 'Month,' and 'HourOfDay,' exhibit statistically significant relationships with pedestrian traffic volume. Notably, the variable 'Month' demonstrates particularly strong statistical significance. This finding is particularly important in the context of the study's design, which compares pedestrian traffic volume six months before and six months after the implemented interventions. The small standard error (0.027) associated with the 'Month' coefficient suggests a precise estimate, and the large positive z-score (12.451) indicates that the coefficient is approximately 12.451 standard deviations above the mean. Furthermore, the extremely small p-value provides overwhelming evidence against the null hypothesis, indicating that 'Month' significantly influences pedestrian traffic volume.

Table 1. Generalized Linear Model Regression Results for Pedestrians

	Coef	Std. Err	z	P > |z|	[0.025	0.975]
DayOfWeek	0.5893	0.119	4.938	0.000	0.355	0.823
Month	0.3416	0.027	12.451	0.000	0.288	0.395
HourOfDay	0.1179	0.055	2.150	0.032	0.010	0.225

The results of the regression analysis for bicyclists indicate that the day of the week variable does not show a significant association with bicyclist traffic volume, as the coefficient of 0.5116 is not statistically significant. Similarly, the hour of the day variable also does not exhibit a statistically significant relationship with bicyclist traffic volume, with a coefficient of −0.1462. However, the coefficient for the variable "Month" is 0.2578, suggesting a positive relationship between the month and bicyclist traffic volume. While the coefficient is not statistically significant at the conventional 0.05 significance level, it is worth noting that there might be some suggestive evidence of a relationship. The confidence interval [0.030, 0.546] indicates that the true coefficient may fall within this range with 95% confidence.

In summary, the analysis reveals that, among the predictor variables considered, only the month variable shows some indications of a relationship with bicyclist traffic volume.

Table 2. Generalized Linear Model Regression Results for Bicyclists

	Coef	Std. Err	z	P > |z|	[0.025	0.975]
DayOfWeek	0.5116	0.637	0.804	0.422	−0.736	1.759
Month	0.2578	0.147	1.754	0.079	−0.030	0.546
HourOfDay	−0.1462	0.403	−0.363	0.717	−0.935	0.643

The results of the regression analysis for scooter drivers indicate that the day of the week variable does not show a significant association with scooter traffic volume. The coefficient for 'DayOfWeek' is 0.9519, but it is not statistically significant ($p = 0.424$). Similarly, the hour of the day variable also does not exhibit a statistically significant relationship with scooter traffic volume, with a coefficient of -0.8370 ($p = 0.261$). However, the coefficient for the variable "Month" is 0.6287, indicating a positive relationship between the month and scooter traffic volume. The coefficient is statistically significant with a z-value of 2.353 ($p = 0.019$), suggesting a robust relationship. The confidence interval [0.105, 1.152] suggests that the true coefficient is likely to fall within this range with 95% confidence.

In summary, among the predictor variables considered, the month variable shows a statistically significant relationship with scooter traffic volume. The coefficients for the day of the week and hour of the day variables are not statistically significant, indicating that they have less influence on scooter traffic patterns. These findings highlight the importance of considering the month variable when analyzing and predicting scooter traffic volume, while the day of the week and hour of the day variables may have relatively less impact.

Table 3. Generalized Linear Model Regression Results for Scooter Drivers

	Coef	Std. Err	z	P > |{z|	[0.025	0.975]
DayOfWeek	0.9519	1.190	0.800	0.424	−1.381	3.285
Month	0.6287	0.267	2.353	0.019	0.105	1.152
HourOfDay	−0.8370	0.744	−1.124	0.261	−2.296	0.622

4 Discussion

The regression analysis conducted on the data reveals compelling insights into the effects of the Athens Great Walk interventions on various modes of transportation. In terms of pedestrian traffic volume, the results indicate a significant impact resulting from the implementation of the interventions. The coefficient associated with the variable "Month" demonstrates a strong statistical significance, suggesting a positive relationship between the month and pedestrian traffic. This finding demonstrates the success of the measures employed, such as the expansion of sidewalk widths, which have effectively facilitated increased pedestrian activity. These findings lend substantial support to the efficacy of urban planning initiatives in fostering pedestrian-friendly environments and promoting the use of active transportation modes.

However, when examining the impact on bicycle traffic volume, the regression analysis results suggest that the Athens Great Walk interventions did not yield as statistically significant effects for the cyclists as for the pedestrians. The coefficients for both the day of the week and the hour of the day variables were found to be statistically insignificant,

indicating that these factors had limited influence on bicycle traffic patterns. Nevertheless, there are indications of a potential positive relationship between the month and bicycle traffic volume, which suggests the need for further investigation to comprehensively understand the factors influencing cycling behavior. Additionally, this warrants the exploration of potential interventions that can effectively encourage cycling as a sustainable mode of transportation in the context of the Athens Great Walk initiative.

On the other hand, the regression analysis reveals that the interventions had a statistically significant impact on scooter traffic volume. The coefficient associated with the variable "Month" exhibited a high level of significance, indicating a positive relationship between the month and scooter traffic. This finding suggests that the implemented interventions, such as the establishment of dedicated scooter lanes, effectively stimulated the utilization of scooters. The observed increase in scooter traffic volume underscores the potential of micro-mobility solutions in addressing transportation needs and alleviating congestion within urban areas.

In summary, the regression analysis outcomes emphasize the significant role played by the month variable in influencing traffic volumes for pedestrians, cyclists, and scooter drivers. These findings underscore the importance of considering seasonality and temporal factors when designing and implementing transportation interventions. The noteworthy increase in pedestrian traffic volume, the suggestive evidence of a relationship for cyclists, and the statistically significant impact on scooter traffic collectively affirm the effectiveness of the Athens Great Walk interventions in promoting sustainable transportation options and contributing to the creation of a more dynamic and accessible urban environment.

5 Conclusion

Findings form the current research can provide valuable guidance and evidence-based recommendations for policymakers and stakeholders working to create a secure environment for VRUs. The results indicate that the interventions of the AGW have had a significant positive effect on pedestrian traffic volume, as evidenced by the strong relationship between the month and pedestrian activity. The expansion of sidewalks and pedestrian-friendly measures have successfully encouraged increased pedestrian movement, highlighting the effectiveness of urban planning initiatives in promoting active transportation.

In summary, the findings of this study highlight the positive impact of the Athens Great Walk interventions on pedestrian traffic volume, while indicating the need for further investigation and tailored interventions to enhance cycling behavior. The study contributes to the understanding of sustainable transportation initiatives and underscores the importance of considering factors such as seasonality, infrastructure, and user preferences when designing and implementing transportation interventions.

Further areas of investigation should focus on understanding the specific factors that influence cycling behavior and developing interventions tailored to promote cycling as a sustainable mode of transportation. This could involve initiatives such as improving cycling infrastructure, implementing bike-sharing programs, and raising awareness about the benefits of cycling.

While the results demonstrate the effectiveness of the Athens Great Walk interventions in the specific context of Panepistimiou Street, further research is needed to assess the applicability of these interventions in other urban areas. Conducting similar studies in different cities or regions with distinct traffic patterns and infrastructure would allow for a more robust assessment of the generalizability of the findings and the effectiveness of the interventions in different contexts. The study provides a foundation for future studies to replicate and validate the findings in different cities and regions.

It is important to acknowledge the limitations of this study. The analysis focused on a specific time period before and after the interventions, and other potential confounding factors may not have been fully accounted for. Additionally, the study only examined the impact of the interventions on pedestrian, bicycle, and scooter traffic volume, and other aspects such as safety and user satisfaction were not thoroughly explored.

To address these limitations, future research should consider expanding the dataset to include a more extensive and diverse range of driving scenarios, encompassing different seasons, days of the week, and times of the day. This would provide a more comprehensive understanding of the impacts of the interventions across various temporal and environmental factors. However, further investigation and additional data may be needed to establish a more definitive understanding of the relationship between month and bicyclist traffic patterns.

To conclude, to optimize the effectiveness of transportation interventions, it is recommended to consider a holistic approach that takes into account the needs of different modes of transportation. This includes ensuring adequate infrastructure for pedestrians, cyclists, and scooter users, as well as promoting multi-modal transportation options and integrating various modes seamlessly.

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Abbreviations

AGW: Athens Great Walk
PHOEBE: Predictive Approaches for Safer Urban Environment
VRU's: Vulnerable Road Users

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