Simulation of Heterogeneous Motorised Traffic at a Signalised Intersection

Puspita Deo[1], Heather J. Ruskin[1]

[1] School of Computing, Dublin City University, Dublin9, Ireland
{dpuspita, hruskin}@computing.dcu.ie

Abstract. The characteristics of heterogeneous traffic (with variation in vehicle length) are significantly different from those for homogeneous traffic. The present study describes an overview of the development and validation of a stochastic heterogeneous traffic-flow simulation model for an urban single-lane two-way road, with controlled intersection. In this paper, the interaction between vehicle types during manoeuvres at the intersection are analysed in detail. Two different motorised vehicle types are considered namely cars and buses (or similar length vehicles). A two-component cellular automata (CA) based model is used. Traffic flow data, captured manually by Dublin City Council at a local intersection, are analysed to give a baseline on how the distribution of short and long vehicles affect throughput. It is anticipated that such detailed studies will aid traffic management and optimisation strategies for traffic flow.

1 Introduction

Studies of road traffic characteristics are necessary for planning, design and operation of road facilities, in addition to regulation and control of traffic. In Western countries, specifically Ireland, car and heavy goods vehicle (HGV) traffic volumes have increased dramatically over the past 30 years [1], and this trend is likely to continue, at least in the short term.

Field observations of traffic flow can be difficult and time consuming to obtain. Frequently, such experiments in the field must cover a wide range of traffic volume and composition to provide practical benefits. Computer simulation models offer a viable alternative for in-depth study and a practical tool for understanding traffic dynamics.

There are three different conceptual frame works for modelling traffic. A fluid dynamical model [2], the car- following model [3], [4] and [5] and cellular automata models [6],[7] and [8] for modelling traffic on both highways and urban networks. These cellular automata (CA) traffic models represent a single lane road as a one-dimensional array of cells of certain length, with each cell either empty or occupied by a single vehicle. Vehicle movement is updated according to a given rule set, which applies to all constituent units.

Typical urban roads support mixed traffic with a variety of motorised vehicle types, using the same right of the way. As an extreme case, traffic composition in South Asian countries specifically India is mixed both with motorised and non motorised vehicles and with e.g. little or no lane discipline [9], whereas traffic in Western European countries consists of a mix of mainly motorised vehicles of different length. The features that characterise mixed traffic systems, otherwise known as *heterogeneous traffic*, mainly reflect the wide variation in size, manoeuvrability, and static and dynamic properties.

Much of the work on heterogeneity in traffic flows has been done in India for widely diverse units [10], [11], [12] and [13]. As such, these include motorised and non-motorised flows. These models cannot be used for a comprehensive study of mixed motorised traffic flow characteristic in a "single-lane", due to different patterns of road usage, e.g. multiple occupations of cells. The work presented thus aims at the development of an appropriate traffic simulation model for Western Europe roads. Western Europe model is a simplified model, which excludes multiple and shared occupation, which more nearly reflect Indian characteristic road-usage pattern. We propose and developed a simplified and novel heterogeneous *two-component cellular automata* model that allows for two classes of vehicle, long and short. The model was designed to describe stochastic interaction between individual vehicles and is independent of headway distribution [14]. In this heterogeneous model is used space mapping rules for each vehicle type, namely long and short vehicles, where the former equal a multiple of two of the latter. The detailed description of the update rules of the different vehicle types is given in the following section.

2 Methodology

To describe the state of a road using a CA, the street is first divided into cells of length 7.5m [8]. This corresponds to the typical space (car length + distance to the preceding car) occupied by a car in a dense jam. Each cell can either be empty or occupied by exactly one car. A speed say, v=5, means that the vehicle travels five cells per time step or 37.5 m/s or 135 km/h.

In our model each cell is occupied by one particle per cell corresponding to a standard car of length less then or equal to 7.5metrs. Long vehicle (LV) are taken, for simplicity, to be double the length of a standard car i.e. two cells are required for one LV. A short vehicle (SV) is understood to be a car of length 1, while a LV is of length 2. Both SV and LV will move exactly one cell in the next time step if the cell in front is vacant.

The update rules are as follows.

C_n^t designates the state of the nth cell at time step t. If $C_n^t > 0$, there is a vehicle in nth cell at time step t. The updates of the cells are on a vehicle by vehicle basis i.e. if the C_n^t =1 (SV) in this time step and the cell in front is vacant then the SV will move one cell otherwise the SV will stay in the same cell in the next time step. Similarly, if $C_n^t = C_{n+1}^t = 2$ (LV) in this time step and the cell in front is vacant then the LV will move one cell in next time step otherwise the LV will not move.

The algorithm is:

Step1: If $C_n^t = 1$ and $C_{(n+1)}^t = 0$, then $C_{(n+1)}^{(t+1)} = C_n^t$ and $C_n^{(t+1)} = 0$

Step2: If $C_n^t = 1$ and $C_{(n+1)}^t > 0$, then $C_n^{(t+1)} = C_n^t$

Step3: If $C_n^t = C_{(n-1)}^t = 2$ and $C_{(n+1)}^t = 0$, then

$$C_{(n+1)}^{(t+1)} = C_n^t \text{ and } C_n^{(t+1)} = C_{(n-1)}^t \quad \text{and } C_{(n-1)}^{t+1} = 0$$

Step4: If $C_n^t = C_{(n-1)}^t = 2$ and $C_{(n+1)}^t > 0$, then $C_n^{(t+1)} = C_{(n-1)}^{(t+1)} = 2$

2.1 Traffic light Controled Intersection (TLCI)

In Fig.1 roads are labelled road-1, road-2, road-3, road-4, with major and minor as indicated. The shaded area is the intersection area and the junction is control by traffic light and a pre-determined cycle of green, yellow and red lights, with the yellow light occurring twice per cycle. This is common in most European countries including Ireland.

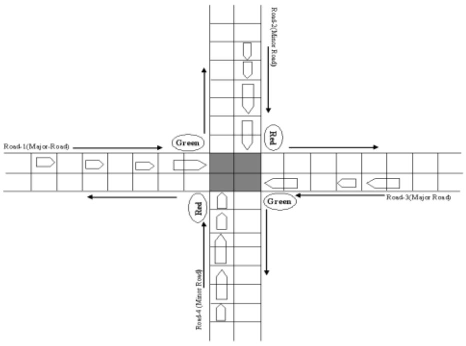

Fig. 1. A schematic traffic flow at a single-lane two-way signalised intersection

Signalisation of Traffic light: Fixed Time Scheme. In this scheme, the traffic flow is controlled by a set of traffic lights, which are operated in a *fixed cycle* manner. Fixed-cycle intersections operate with a constant period of time T= 100 seconds for fixed cycle, where this is divided into a green, yellow and red periods for each phase.

For road-1 and 3 Green= 55 seconds, yellow= 4 seconds and Red= 41 seconds where as road- 2 and 4, Green= 37 seconds, yellow= 4 seconds and Red= 59 seconds.

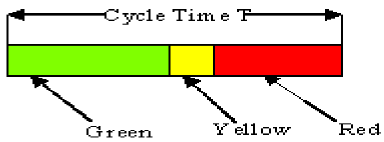

Fig. 2. Break down of a single fixed cycle

In our model we consider two phases for controlling the four roads. In *phase-1* the traffic light is green for major road-1 and road-3 (simultaneously red for road-2 and road-4). In the second part, the lights change colour to yellow for major road-1 and road-3 and simultaneous by changes to red for road-2 and road-4. Phase-2 the cycle repeats i.e. road-2 and road-4 become green and road-1 and road-3 red and the light changes colour to yellow for road-2 and road-4 and simultaneously red for road-1 and road-3.

Vehicle Manoeuvring at the Intersection. Fig. 3 shows the requirements in terms of free cells for right turning vehicles from both major and minor road in a controlled intersection. Right turning short vehicles and long vehicles require 2 marked free cells for manoeuvring. “0” means that the cell is free or vacant. Where as left turning (LT) and straight through vehicle need one free cell before entry into the intersection. In previous works [14], we note that it is insufficient only to consider conditions to commence a manoeuvre. The manoeuvre must be completed otherwise throughput of all vehicles is seriously affected by incomplete RT vehicle manoeuvre. In the situation when two vehicles, travelling in the opposite direction, have entered the intersection to turn right, both vehicles wait for an indefinite period of time i.e. there is a deadlock condition. In this paper we present an improved version of our previous model, which should be more realistic where intersection controls are observed.

CA models have considerable flexibility in terms of modelling urban road feature and a *one-dimensional two-component deterministic automata model*, can be used to simulate the interactions between types of vehicles. The speed of the vehicle is taken simply to be either 0 or 1.

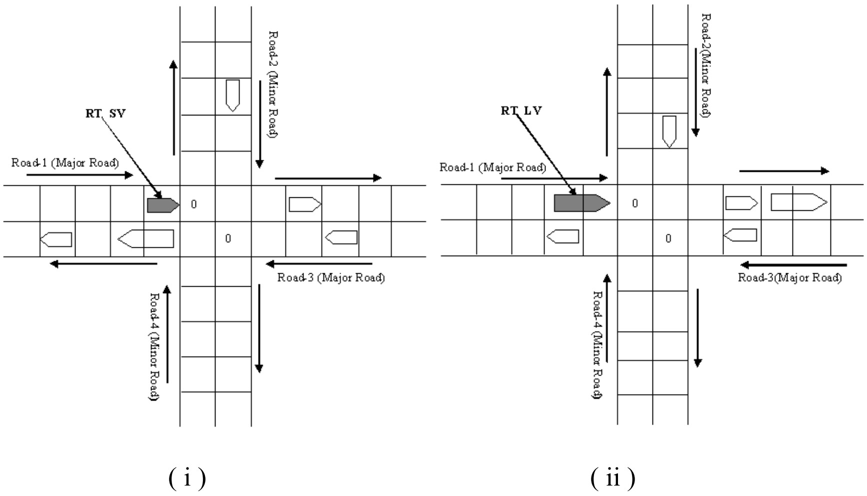

Fig. 3. A right turning (RT) vehicle from major road (i) SV (ii) LV

3 Simulated Results

Simulation was carried out for 36000 time step (equivalent to 10 hours) for a road length of 100 cells for all approaches and under different values of traffic parameters, such as arrival rate, turning rate and proportion of short and long vehicle in each of the four roads. The basic inputs that are necessary to underpin and validate the simulation are given in Section 3.3. This is a base line we would expect to vary base line values underpin the sensitivity analysis, enabling us to determine how robust the model is to different assumptions and values. The intersection chosen for developing the model in this study is a single lane two-way signalised intersection. Based on the assumptions given in Section 2 we studied *throughput* (the number of vehicles, which cross the intersection in a given time) and *entry capacity or capacity of the intersection* (the number of vehicles passing from an entrance road on to the intersection per unit time). In each of these scenarios the simulation ran for 10 hours and we have averaged the result over 10 independent runs of the program unless otherwise specified.

3.1 Overall Throughput of the Intersection

Table1illustrates effects of different SV: LV proportions on overall throughputs. In each scenario, the turning rates of all approaches are based on analysis of the field data. For road-1, left turn (LT): straight through (ST): right turn (RT) =0.1:0.85:0.05, for road-2, LT: ST: RT=0.16=0.65:0.19, for road-3, LT: ST: RT=0.03:0.09:0.07 and for road-4, LT: ST: RT= 0.23: 0.71: 0.06. The arrival rate of the two major roads and minor roads are taken to be equal and vary from 0.1 to 0.3 (equivalent to 360 vph to

1080 vph). It is found that the average throughput of the intersection increases when arrival rate increases both in homogeneous (100 percent SV) and heterogeneous (SV+LV) traffic. In contrast, heterogeneous traffic throughput decreases with increased proportion of LV in the traffic mix.

Table 1. Avg. throughput Vs. arrival rate and long-vehicle proportion

$AR_{(1=2=3=4)}$	Vehicle types proportion (SV: LV)					
	1:0	0.9:0.1	0.8:0.2	0.7:0.3	0.6:0.4	0.5:0.5
0.1	14405	14249	14031	13984	13793	13707
0.2	28744	28143	27352	26171	24905	23855
0.3	38411	36308	34509	32865	31327	29624

3.2 Capacity of Major Road

Right-turning vehicles from the major-road in a shared lane,(where RT, ST and LT vehicles are on the one lane), can block ST and LT vehicles behind and on the same road. RT rates (RTR) of the major-roads thus have great impact on capacities of the major-roads. In order to examine the capacity of the major road, we varies major-road1 right turning rate (RTR1) from 0.1 to 0.2, with major-road3 RTR3=0. Arrival rates of AR1 = AR2 =AR4 = 0.15 (equivalent to540 vph) were used initially, with the arrival rate of major road 3 varied from 0.05 to 0.55 (i.e. equivalent to 180 vph to 1980vph).

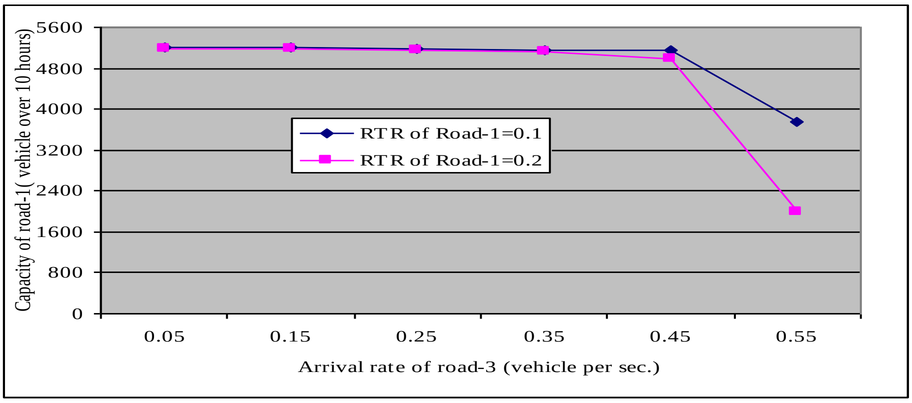

Fig.4. Capacity of major road-1, there is no RT vehicles of major road-3

Fig 4 shows unsurprisingly that the capacity of the major-road 1 declines as RTR of road-1 and arrival rate of conflicting major-road-3 increases. Here we conclude that capacity of the major road declines when the percentage of RTR increases and /or the arrival rate of the opposing major road deviation increases.

4 Validation of the Model with Real Data

4.1 Field Data

Table 2. Field Data collected by Dublin City Council 1997, total for 10 hours.

Road number ⟶	Road-1	Road-2	Road-3	Road-4
Totals (SV+LV) for 10 hours	4937	2428	4941	2138
Averages per seconds	0.14	0.07	0.14	0.06
Total SV	4703	2391	4678	2111
Total LV	234	31	263	27
Left turning (LT) SV	523	378	137	497
Straight through (ST) SV	3941	1545	4173	1504
Right turning (RT) SV	239	468	368	128
Left turning (LT) LV	9	9	3	2
Straight through (ST) LV	219	24	254	22
Right turning (RT) LV	6	4	6	3

The data for SV: LV ratios are studied for one local single lane two-way intersection (Rathgar Road/ Frankfort Avenue) in Dublin, Ireland. The intersection is controlled by signals, with basic characteristics and composition of the intersection as detailed given in Table 2. The traffic flow data were collected on 17th December 1997 by Dublin city council, Ireland over a 10 hours period at every 15-minute intervals; weather was fair.

4.2 Comparison of Simulated Data with Field Data

The model developed needs to be validated against real life situations (field conditions). Accordingly, while the simulation model may attempt to replicate directly the mixed traffic flow on a given single lane two-way control intersection, for which we have observed data, this is clearly one possible realization only. The field data represents an average day's traffic and so it makes sense to validate our model using an average run. For 50 runs of ten hours, and the parameter values observed, the average results are presented in Tables 3 and 4 and Figure5. The model was run 50 times to ensure convergence of the average and this average was used in validation.

Table 3. Comparison results of our model and field data.

Road Number	Turn	Short vehicle (SV)		Long vehicle (LV)	
		Obs Data	Avg. Sim. Data	Obs . Data	Avg. Sim. Data
Road-1	LT	523	478.12	9	21.42
	ST	3941	4057.68	219	184.9
	RT	293	240.8	6	10.34
Road-2	LT	378	395.04	9	7.74
	ST	1545	1596.74	24	29.66
	RT	468	464.34	4	9.32
Road-3	LT	137	149.32	3	6.48
	ST	4173	4458.44	254	203.98
	RT	368	163.02	6	7.7
Road-4	LT	497	510.1	2	5.06
	ST	1504	1578.06	22	14.68
	RT	128	49.24	3	0.32

Obs.= Observed, Avg. Sim= Average simulated

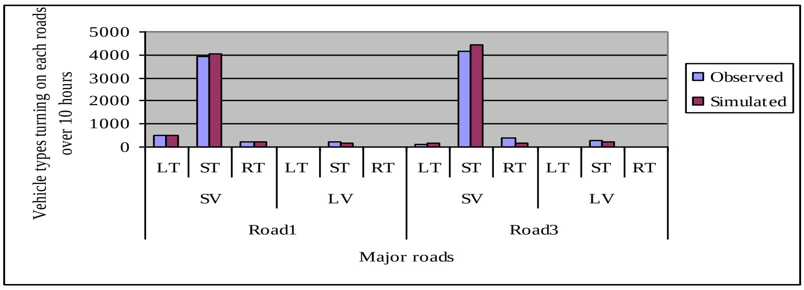

Fig.5. Model validation (comparison of observed and simulated turning data of SV and LV from two major roads)

From the Figure and table, it appears that the simulation model reproduces accurately observed behaviour at the intersection.

Table 4. Comparison of observed and simulated entry capacity or capacity of the intersection over 10 hour.

Intersection entry capacity (vehicle in 10 hours)			
Road number	Obs. Data	Avg. sim. Data	% Error
Road-1	4937	4993.26	+1.13
Road-2	2428	2502.84	+3.08
Road-3	4941	4988.92	+0.96
Road-4	2138	2157.46	+0.91

Table 4 presents the comparison of observed and average simulated entry capacity or capacity of each approach of the study intersection. Simulated capacity matches the corresponding observed value with low % error. The highest relates to road2, it may be due to variation of cycle time with respect to real time situation.

5. Conclusions

In this paper, we have described a prototype two- component cellular automata model, which attempts to simulate heterogeneous motorised traffic flow at a single-lane two way signalised intersection. Importantly, we consider vehicles of different length, (true to real life situations). In order to model a realistic microscopic simulation, vehicle arrival, turning rate, vehicle type are built into our model.

On investigating the throughput of mixed (SV+LV) traffic and comparison with the homogeneous (SV or LV), our model clearly reproduces the decrease in throughput observed when traffic is mixed (proportion of LV increases).

Secondly, the major road capacity is clearly shown to depend on the arrival rate of the opposing major road and RT rate of the major roads as well as LV proportion. Finally, our model of vehicle manoeuvres at an urban road configuration has been validated using field data. The simulation results show good agreement between simulated and observed data. Future work will examine other features such as delay time, queue length and congestion period for both simple and complex intersections.

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