Estimating Vehicle Emissions from Road Transport, Case study: Dublin City

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ABSTRACT

Air pollution is becoming a very important issue for the transportation sector, particularly car emissions in urban areas, and there is much interest in evaluating the actual level of emissions. In this paper, a case study of a standard driving cycle in the urban area of Dublin city is presented. On-road, speed-time data was extracted by an on-board diagnostic tool, and saved into a data acquisition package. Firstly, the driving cycle was established for the urban area of the city; one car travelling different routes has been employed to implement this research and some representative results have been achieved. The second part of the project was to estimate the emissions from the same car using the driving cycle obtained and compare the results with those obtained by a gas analyzer attached to the car simultaneously in order to validate the methodology used in this paper. A representative driving cycle reflecting the real-world driving conditions is proposed and estimated vehicle emissions were compared with measured results. The method is easy to follow and the results are in a good fit to the estimated values.

Keywords: Vehicle emissions, Driving cycle, On-board diagnostic system, Gas analyzer.

1. Introduction

The transport sector is one of the major contributors of hazardous emissions to the environment in recent years. In 2005 40% of NOx emissions (about 119kt) and 25.6% of CO2 emissions (about 55.6 Mt) originated from the transport sector in Ireland [1]. Various approaches to help decrease these emissions by; using new technologies, where fuel consumption has been minimized using dynamic optimization [2]; applying new legislation standards for newer cars; using alternative fuel systems, such as using liquefied natural gas or biofuels in heavy duty vehicles [3-5]; applying new strategies, such as a road transport system based on renewable resources [6], or developing an eco-driving strategy of a passenger vehicle based on the least fuel consumption, have been proposed [7]. Moreover, the design of 100% renewable energy systems has been discussed in literature with the analyses and results that includes the transport sector [8].

Since emission estimation from road transport can assist researchers in evaluating the air quality in urban area, many projects have validated modeling methods in order to represent accurate results [9]. Car testing includes pre-test vehicle certification on chassis dynamometer emissions test equipment as manufacturers should prove that their vehicles comply to emissions standards (type approval tests) [10], therefore making the vehicle valid in terms of emission limitations over a period of time. Thereafter, a vehicle should pass a compulsory vehicle inspection test in order to ensure that the vehicle’s emissions are under a certain limit.

On-board diagnostic (OBD) systems built into cars can identify faulty parts in the car [11]. Results from regulatory measurement methods are not sufficient, and chassis dynamometer testing must be carried out. This can be done by either instantaneous or model emissions in parallel with the aggregate bag measurements required for certification [12].

Using drive cycles in chassis dynamometer testing is not always representative of real-world driving cycles [13-15], they only cover a limited number of driving modes [16], and it can be seen as a weak point of emission estimation, as vehicles could conceivably be tested differently depending on their performance levels and usage characteristics [17]. In this regard, many researchers have developed real-world driving cycles [18-19], and compared them by showing differences in measured emissions. Using on-board emission monitoring for measuring instantaneous emissions gives data quickly, reducing the cost of testing and providing the driving cycles and emission factors to be evaluated [20-23]. Comparisons between measured and estimated emission data have been found to be within 5% for carbon dioxide (CO_2) and nitrous oxide (NOx) [24], and within 10% for hydrocarbon (HC) and carbon monoxide (CO) [25].

In conjunction with recent advancements, many software packages have been utilized to estimate vehicle emissions. The advantages of using these software techniques include cost and time savings. Good correlations between the predicted results of the software packages and the actual data obtained by direct measurement are still maintained. In order to estimate vehicle emissions, driving cycles in a city are analyzed by researchers using the same approach in many other countries; many projects have been conducted to establish the drive cycle of a specific area/city. When validating these estimates, significant differences between measured and modeled emission rates have been found [26]. Sometimes, tunnel studies have been conducted in order to validate the emission estimations [27]. In Edinburgh, for instance, the driving cycle was obtained from recorded data in actual traffic conditions, using the car chase technique, and compared with the European driving cycle [28]. In Athens, emissions and fuel consumption measurements showed significant variations between Athens driving cycle and the European driving cycles [29]. Outside of Europe, i.e. Hong Kong, a systematic and practical method for developing representative driving cycles has been developed with a focus on the cost effectiveness for continuous refinement of the driving cycle [30].

Some research has been done using emission analyzers in order to calculate the instantaneous emissions; for example, Ayala et al. identified the different hydrocarbon species emitted from the tailpipe [31]. In the following experiments, a gas analyzer has been used in order to evaluate the results obtained from the calculated method, and the possibility of finding the correlations between the experimental and calculated results is discussed.

2. Emission Modeling

Many modelling methods have been developed to estimate the emission factors in the transport sector. National emissions inventories of areas, such as a country or a state, are important to assess the emissions levels to identify the air quality and further contribute in this field to reduce the hazardous emissions affecting human health and the environment. Much research has been done in developing these modelling methods to estimate the emission factors such as CO, CO2, HC, NOx and particulate matters (PM) [32]. Other factors such as evaporative emissions and PM emissions of brake dust have also been investigated [33].

2.1 Modelling Approaches

2.1.1 Average Speed Model

The average speed approach is commonly used to estimate emissions from road traffic. This approach is based on aggregated emission data for various driving patterns and driving patterns are represented by their mean speeds alone [34]. The average speed is combined with vehicle class, size and year and a speed dependant emission function is derived. This fails to take into account the fact that different cycles with different driving behaviors and vehicle dynamics can yield the same average speed, resulting in different emissions and fuel consumption factors for the same average speed [35]. The standard method in Europe and US is average-speed models, and the most useful data sets of this work are COPERT (Computer Programme to estimate Emissions from Road Transport) [36], or TRL (Transport Research Laboratory) emissions factors. Both can describe emissions in terms of grams per kilometre travelled [g/km] and are functions of vehicle speed [37].

2.1.2 Instantaneous Emissions Model

The instantaneous emission model was introduced to overcome the limitations of the average speed model. This model measures emissions continuously from the exhaust during chassis dynamometer tests and stores the data at a particular time interval, usually every second [34]. An averaged emission value is assigned to every pair of instantaneous speed and acceleration values measured simultaneously. The emission function can then be defined as a two dimensional matrix of speed and a product of speed and acceleration.

In this paper, COPERT methodology has been applied [38] using hot emission factors as in the following equation:

$$EF_{i,\ m,\ n} = \left(\frac{\alpha + \gamma\chi + \varepsilon\chi^{2} + \zeta\chi^{-1}}{1 + \beta\chi + \delta\chi^{2}} \right) \cdot \left(1 - RF\right) \qquad (1)$$

Where, $EF_{i,\ m,\ n}$ is the emissions factor, in grams per kilometre travelled [g/km] for a given species i, of age m, and engine size n. x is the average vehicle speed in kilometres per hour, and α, β, γ, δ, ε, ζ are related to the legislative emission factors for that car i.e. Euro1, 2, 3… RF are coefficients specific to a given engine size n, and technology level m.

CO and NOx has been calculated individually for each time step using equation (1), and then accumulated in order to extract the average EF:

$$\text{Ave EF} = \sum \text{EF (n)} / \text{N} \qquad (2)$$

where EF (n) is the emission factor each time step, N is the number of time steps.

The total EF would become:

$$\text{EFtotal} = \text{Ave EF} \times \text{Distance travelled} \qquad (3)$$

NOx emission has been calculated by the same steps mentioned above.

3. Exhaust Emission Analyzer

During the experiments, a portable Gas Analyzer, Fig.1, has been used for evaluation purposes. This is a portable device with software which can be run on any Windows PC. It is designed to be used in an environment where both high durability and excellent accuracy are critical to diagnosing vehicle problems. The analyzer can measure five separate types of gas HC, CO, CO2, O2, NOx as well as Lambda and Air/Fuel ratio. It also has excellent performance requirements for measurement specifications such as ASM/BAR 97, OIML, and BAR90 [39]. The analyzer is mounted in a case that keeps all connections safe from accidental dropping.

Fig.1. The Gas Analyser attached to the test car.

4. Experimental Work

The use of on-board monitoring techniques is recently very common [40-41]. An On-board Diagnostic (OBD II) reader, Fig.2, has been configured to extract the data and record it in a built-in data acquisition package in order to estimate the instantaneous emissions produced from a vehicle. This type of tool is not compatible with all car makers, so only few cars have been tested such as a NISSAN Micra, FORD Focus, FIAT Marea, TOYOTA Camry, HYUNDAI Verna...etc. The programme utilized can show and record vehicle parameters such as engine speed, vehicle speed, coolant temperature, and engine load. It also shows accelerations and decelerations of the car during the trip.

Fig.2. OBD scan tool connected to both car and laptop

The test was carried out on a passenger car with the following specifications: car maker is Fiat Marea, model year 2001 with engine specifications mentioned in Table 1 and the legislative standard is Euro3.

Table2: Engine specifications of the car tested.

Fuel type	**Gasoline**	**Fuel system**	**Normal**
Bore x stroke	80.50×78.40 mm	**Catalytic Converter**	Y
Bore / stroke ratio	1.02	**Max. output**	76kW@ 5750 rpm
Displacement	1596 cc	**Max torque**	145Nm@4000rpm
Compression	10.5	**Coolant**	Water

Two persons were on-board; the driver who has been trained to drive naturally as if there were no control on his car and the second person is the technician who monitored the two devices while working to ensure normal results have been taken. Fig.3 describes the methodology used in the experiments.

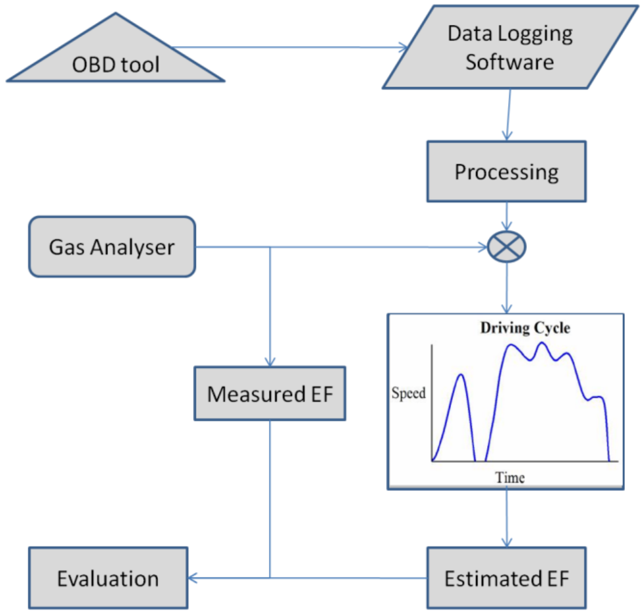

Fig.3. Flow chart of development of Driving Cycle

The tests were performed over three different time periods by focusing on the most important rush hours times: the first test was performed between 8.00 and 10.00, which covers the time period required for most of people to go from their home to work. The second test was run between 16.00 and 18.00, which covers the time period during which most people to return home from their work. Finally, for comparison purposes, the last test runs were performed between 21.00 and 22.00, which is at night time and consequently the traffic would be significantly less. These tests were performed on two main routes on two major roads, which link Dublin City University (DCU) with Dublin City Centre. Route I, starts from DCU main gate towards Upper Dorset Street through Botanic Road with a distance of 5 km as shown in Fig.4. Whereas route II starts from Upper Dorset Street towards DCU main gate through Drumcondra Road with a distance of 4 km. In total, eighteen test runs were performed on three nonconsecutive days as presented in Table 2. An OBD connector was used to extract the data from the OBD system in the car. Data acquisition software installed in a laptop was used to obtain the following test data: engine speed, vehicle speed, acceleration, deceleration and coolant temperature, all versus time per 400msec which was the timestep of each data logging. In order to compare the results of the software and the actual emissions, a gas analyzer model Autologic was used, which measures emissions directly from the exhaust pipe.

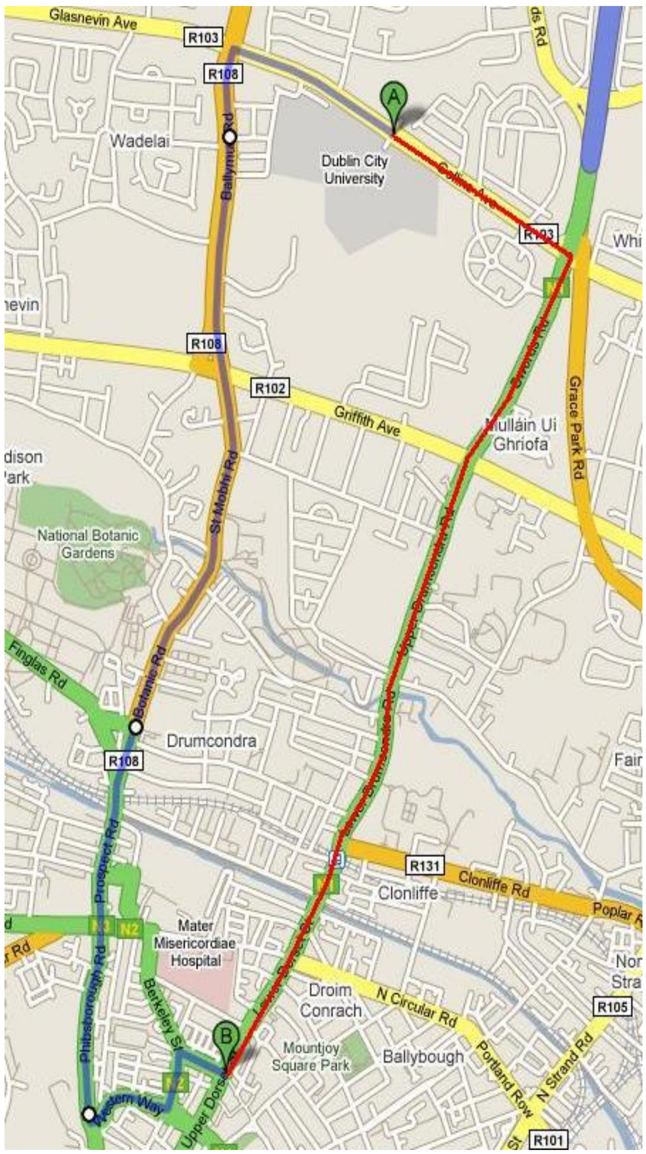

Fig.4. Routes that were employed during the tests.

Table2: The total number of tests.

	By routes	By periods of time	By days	Total
No of tests	2	3	3	18

5. Results

Two trips were completed during the same time period. The car was driven from DCU to Upper Dorset Street via route I, then stopped to save the recorded data, before being driven back via route II. It was noticed after tests had been carried out that going to the city centre in the morning and returning from the city centre in the afternoon took more time regardless of the route taken, Table 3.

Table3: The average time taken by each route of the tests.

Time	8:00 – 10:00hr	16:00 – 18:00hr	21:00 – 22:00hr
Route I [min]	33.9	20.77	10.68
Route II [min]	13.65	33.45	12.92

On testing, some errors had occurred, therefore, 18 tests were performed to achieve a representative driving cycle for Dublin city and estimate vehicle emissions from this driving cycle rather than using the European driving cycle (EDC).

Fig.5 shows one of the eighteen driving cycles obtained from the tests. It can be seen that the driving cycle obtained between 21:00 – 22:00hr was faster than the other two periods (morning and afternoon), due to higher speeds, up to 55km/hr and less stops at the night time period.

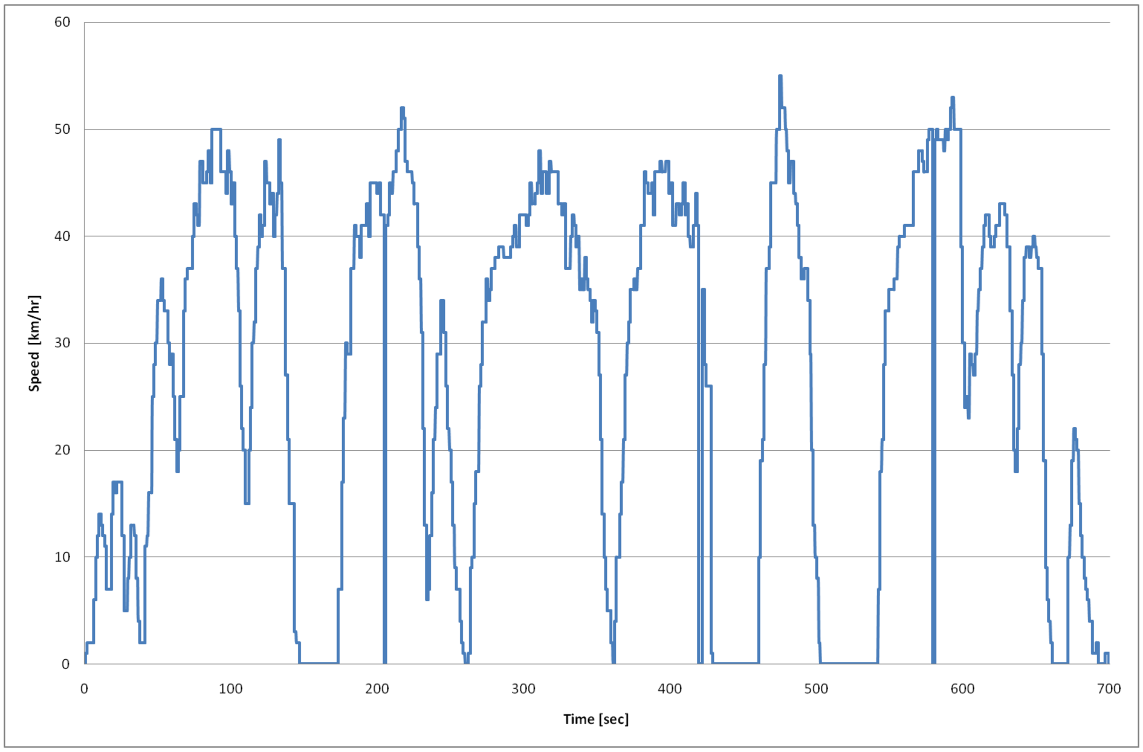

Fig.5. Dublin Driving Cycle (DDC)

Fig.6 and Fig.7 shows the emission factors extracted from the Dublin driving cycle by applying equation (1) and using the parameters for each emission factor from COPERT4. Hot emissions were only considered in the calculation as the engine was running for a period of time enough to eliminate cold emissions from the estimation.

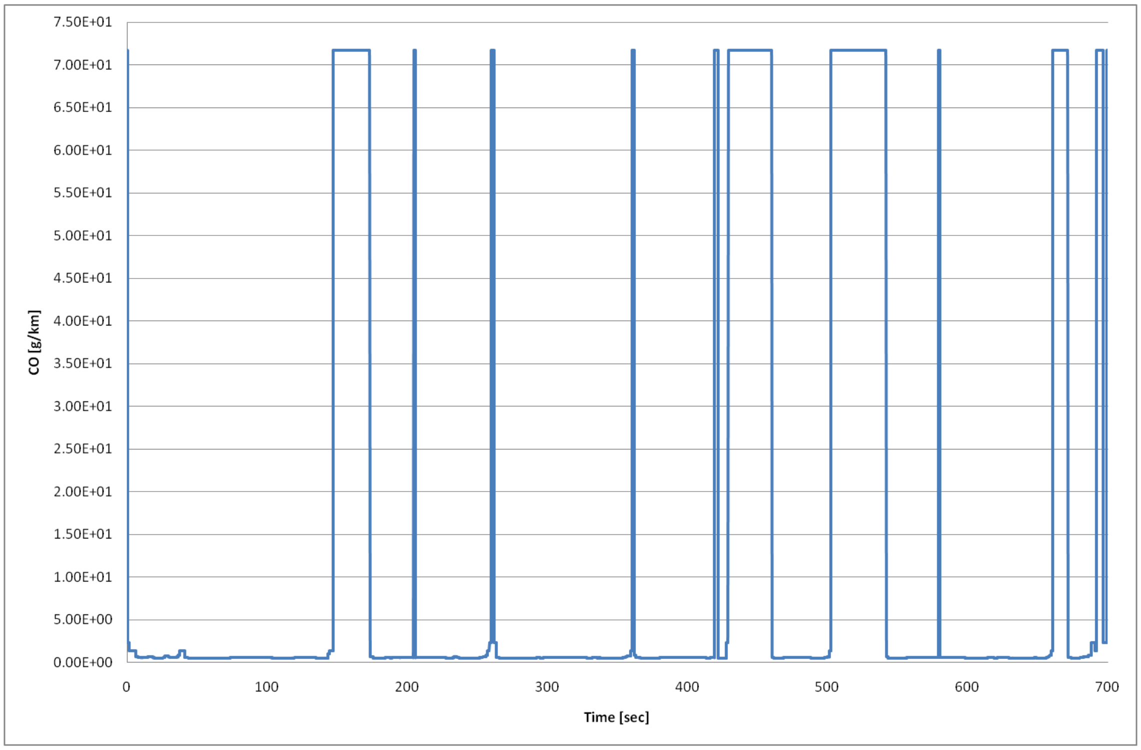

Fig.6. CO emissions estimated from DDC

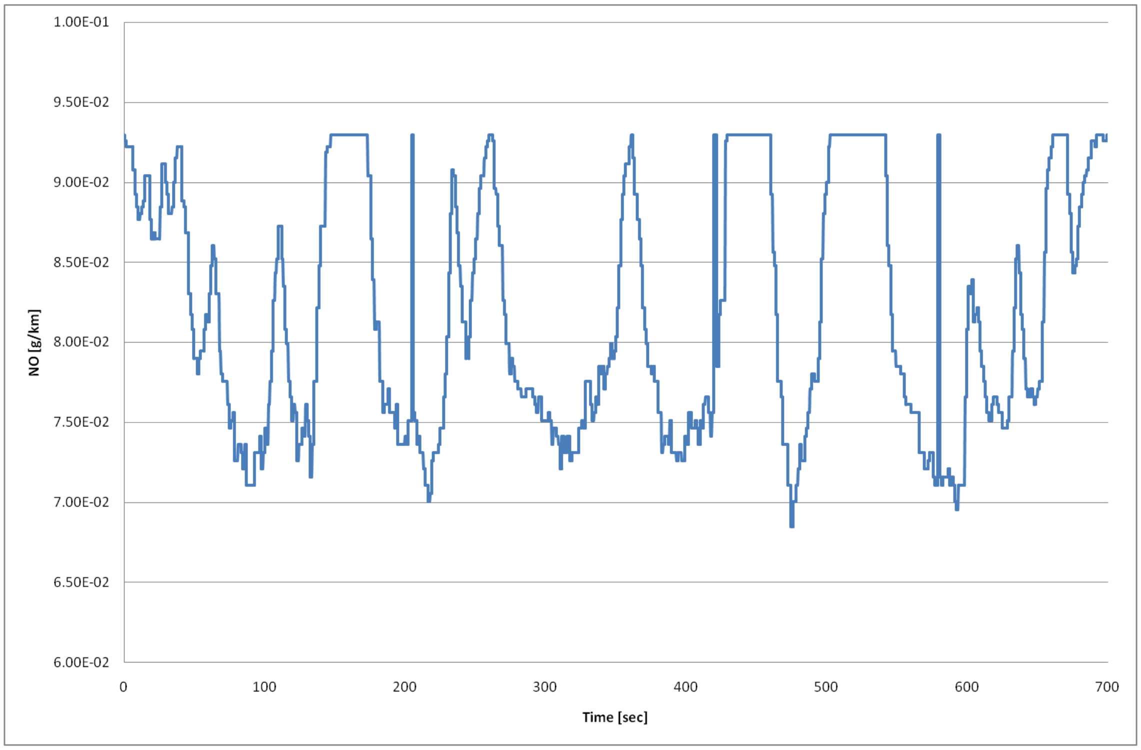

Fig.7. NO emissions estimated from DDC

At the same time, a Gas Analyzer was in the car with a separate pocket PC screen that monitored and recorded the data every second in an Excel file. This device stores the data for a maximum of 20mins, after which the device is restarted to save a new data set. For this reason, a short trip (less than 20mins) was recommended for getting accurate measurements.

The gas analyser stores the emission factors in two different ways, either in volume percentage (Vol%) and part per million (ppm), or in gram per mile. Fig.8 and Fig.9 show the emission factors after converting them into gram per kilometre.

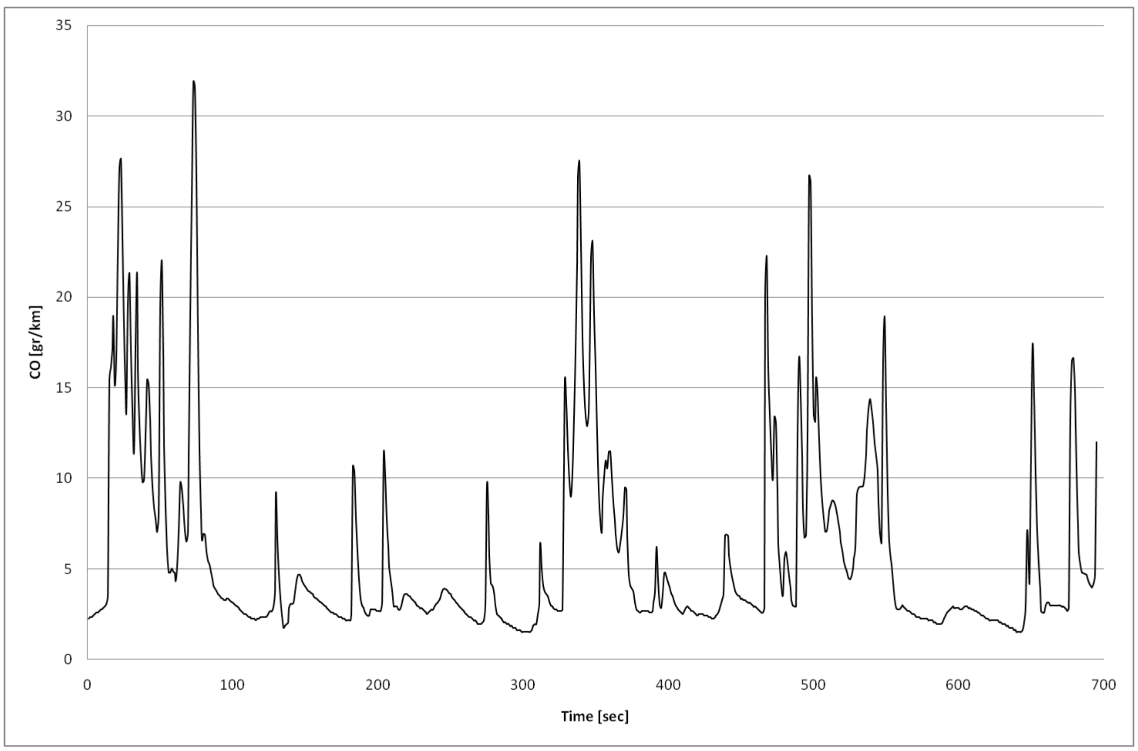

Fig.8. CO emissions from gas analyser

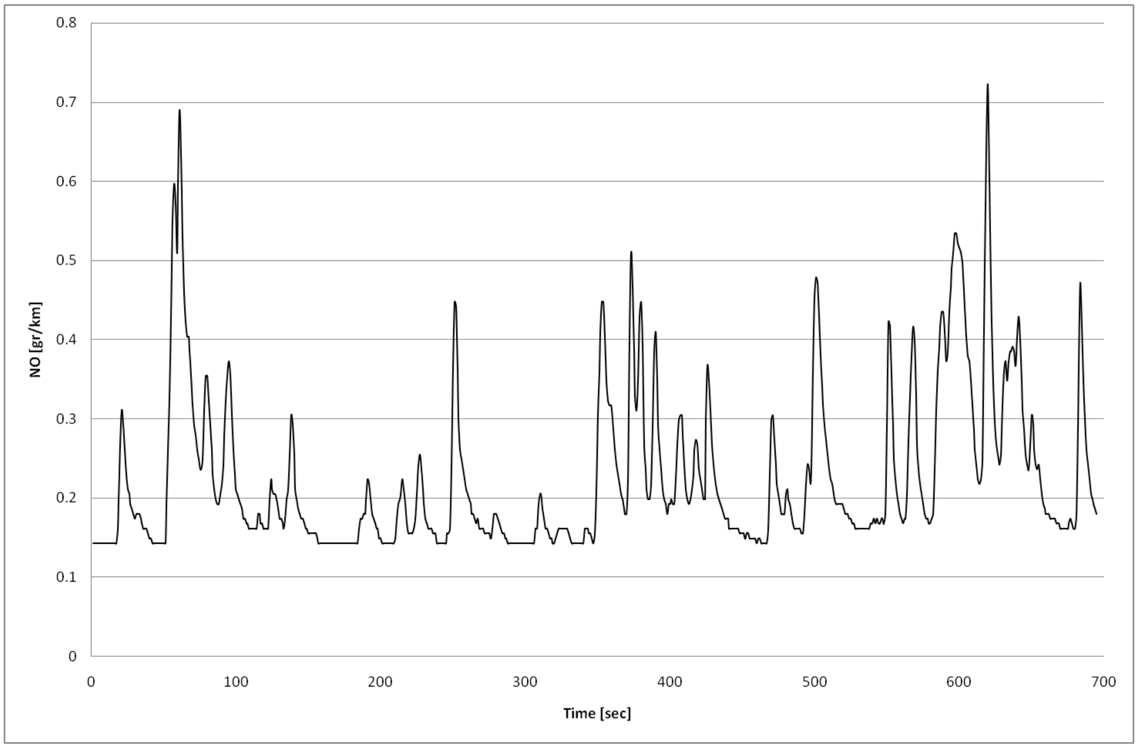

Fig.9. NO emissions from Gas Analyser

6. Comparison & Discussion

Table 4 shows the comparison between the estimating and the measuring methods. The results obtained in this experimental study have shown a noticeable deviation between the COPERT 4 theoretical CO and NO emission factors calculated and the actual values. It has been found that COPERT 4 overestimated the CO emissions while NO emissions were underestimated. For this reason, the emission variations have been investigated versus vehicle speed using equation (1) for a Euro 3 legislative standard car which has the coefficients set up for the tested car by COPERT methodology.

Table4: Comparison between measured and estimated emissions.

	Measured	**Estimated**
NO [gr/km]	1.136	0.420
CO [gr/km]	28.66	66.48

Fig.10 and Fig.11 show the emission factor variations for vehicle speed from zero to 100km/hr. It has been found that CO emission has a significant emission level when the car is at idle (zero speed) which was 17% of the total time of the test. That led to a remarkable difference to the real emission. In relation to NOx emissions, the variation was slightly different among speed steps including idle time.

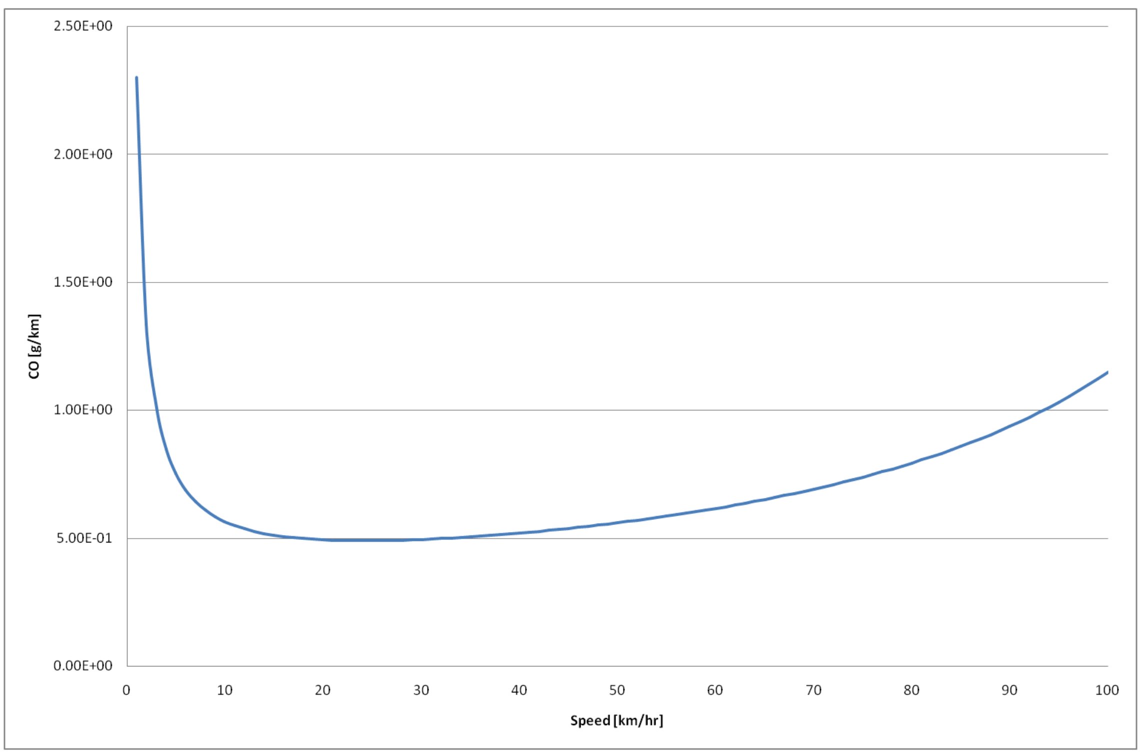

Fig.10. CO vs speed in COPERT methodology.

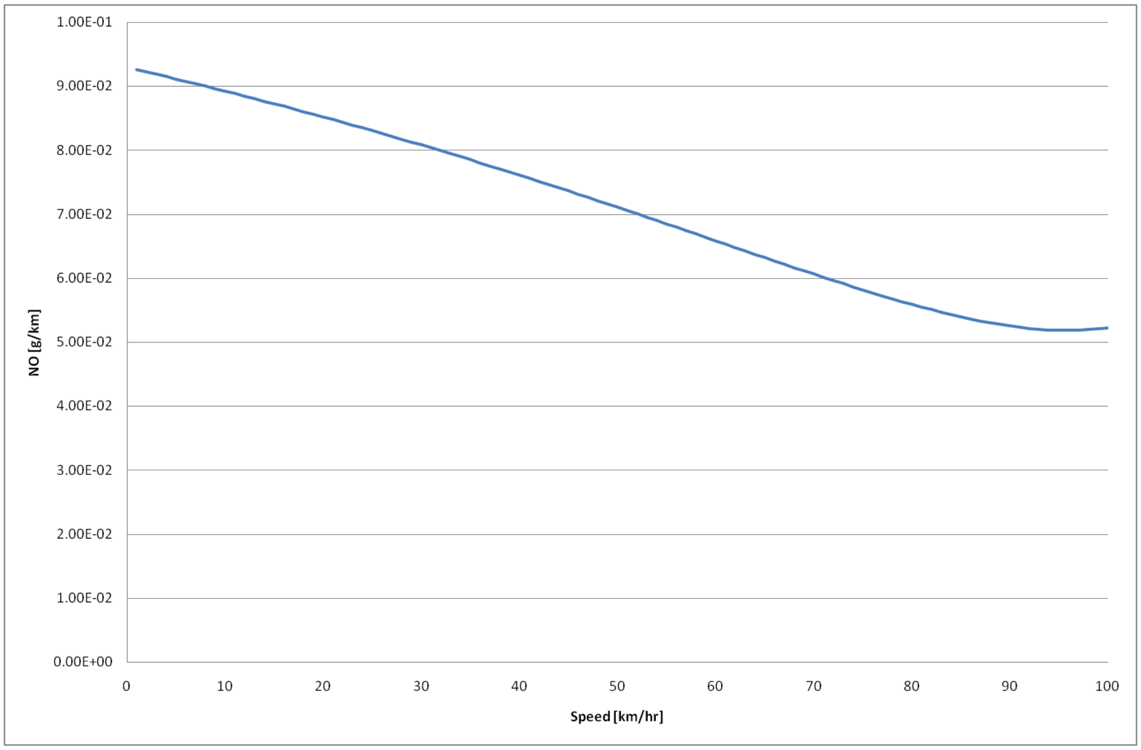

Fig.11. NO vs speed in COPERT methodology.

Table 5 shows the critical car speeds for CO and NOx variations. In relation to CO, if idle time was excluded from the total time, CO emission would be underestimated.

Table5: The critical car speeds for CO and Nox variations.

Speed [km/hr]	**0**	**1**	**25**	**96**	**100**
CO [gr/km]	71.7	2.3	0.49	-	1.15
NOx [gr/km]	0.0929	0.0926	-	0.0518	0.0523

7. Conclusions

- The presence of the high factor considered in COPERT methodology for Euro 3 legislative standard passenger cars during idle time might be leading to the noticeable effect on the amount of emissions being considerably overestimated compared to the actual on-road emissions. Therefore, some kind of correction factor should be designed for representing the real-world vehicle emissions in order to improve the inventories used in different applications.

- As each country has a unique driving cycle which represents the characteristics of the driving and the real amount of emissions from vehicles, individual testing is necessary for each region. A case study on the estimation of the emission values taken from a passenger car has been carried out. A representative driving cycle reflecting the real-world driving conditions was proposed and estimated vehicle emissions were compared. This method is user-friendly and the results were shown to be accurate, as real data from Dublin city was used.

8. Acknowledgments

Author would like to thank the technician Mr. Cian Merne for the use of his car in the tests and Dr. Khaled Benyounis and Ms. Evelyn Campbell for English proof. Finally I would like to thank Aleppo University for their financial support.

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