Gender-linked disparity in vehicle exhaust emissions? Results from an activity-based survey

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Abstract

This study explores the relationship between the vehicle exhaust emissions caused by a trip and the characteristics of the driver involved. The hypothesis formulated is that certain 'groups' of individuals produce more emissions (per kilometre) than others and therefore should be treated differently when aiming vehicle emission reduction. To support this hypothesis an activity-based survey collected speed profiles and driver characteristics of different car drivers. The speed profiles of the individual trips served as input for the emission model VeTESS (Vehicle Transient Emissions Simulation Software), to calculate the instantaneous emissions made by a single vehicle. This paper reports on the differences in vehicle exhaust emissions between trips made by men and women.

Introduction

Policy measures to reduce vehicle exhaust emissions often include campaigns to induce efficient trip chaining, environmentally friendly driving behaviour or reduced car use. When applying these soft measures it isn't just important to assess the potential benefits but also to determine the proper target group for each of these actions to obtain the most efficient results. People displaying different travel behaviour will for example respond to different policy measures.

To gain an insight into the travel behaviour of people travel surveys can provide useful information. A travel survey generally starts with standard questions about the person and then questions his/her travel behaviour. As a result the travel behaviour can often be classified according to certain personal characteristics like age, education and household structure.

A recently developed travel survey is the activity-based (AB) survey, asking people to fill in an activity diary during several days. The data collected through this AB survey can then be used to develop an AB transportation model which aims at predicting the trips and the activities conducted by people [1]. To acquire this kind of information more detailed but still taking into account the respondent’s burden, new data collecting technologies are being developed [e.g., 2]. Accurate information on facets like activity, location and route choice, for example, are nowadays often obtained through the use of a Personal Digital Assistant (PDA) with built-in GPS receiver.

Methodology

This section describes how the database with details on emissions and driving behaviour was obtained and how the data were processed.

Data collection

Data were obtained in a small scale AB survey collecting activity diary data using self-reporting of activities and trips by respondents in a paper activity diary. A Personal Digital Assistant (PDA) with built-in GPS receiver was used to acquire information about the exact location of activities and to provide more accurate information on the reported trips (route choice, trip distance, driving speed, etc.).

This study was actually intended as a pilot survey preceding a large scale AB survey (2500 households) for the development of an AB transportation model. Therefore the original data set from this small scale survey contained only information of 32 respondents, 15 men and 17 women, varying in age, education, income, etc. They all filled in the activity diary for a period varying from two days to one week. In total 1014 trips were reported in the paper activity diaries of which 303 trips were made as a car driver.

Data processing

After data collection, data were organized and converted into usable formats. Trips were classified according to different variables like trip purpose, gender of the driver, age of the driver, number of accompanying persons, etc. The GPS logs, consisting of second-by-second information on location, time, speed and date were downloaded from the GPS receiver. Next, these NMEA GPRMC sentences were converted into formats usable for further analysis. The following step in the data processing was linking the activity diary data and the GPS logs based on the trip departure and ending times. A manual check was finally performed to ensure that all the GPS records associated with vehicle trips were included in the analysis and, if necessary, trip timings were adjusted. After this processing procedure 235 vehicle trips remained.

Emission modelling

Within the EU 5th framework project DECADE (2001-2003) a vehicle level simulation tool was developed for the simulation of fuel consumption and emissions of vehicles in real traffic transient operation conditions [3]. A specific task in the project was to develop and validate a method for calculating very accurately dynamic emissions, and thereby reaching higher accuracy than traditional emission simulation modelling. The final simulation tool, which is called VeTESS (Vehicle Transient Emissions simulation Software), calculates emissions and fuel consumption made by a single vehicle during a defined ‘drive-cycle’ [3]. The VeTESS emissions model uses new methods based on experimental characterization of engines and aims to provide a more realistic simulation by incorporating transient engine behaviour [4]. Together with the associated speed profiles, the actual power demands allow a detailed calculation of emissions.

VeTESS calculates the emissions per second for CO_2, CO, NO_x, HC and PM, but for the moment detailed engine maps are only available for three types of passenger cars: a Euro II LGV, a Euro III diesel car and a Euro IV petrol car. Since all the participants in the survey drove a diesel car and, moreover, most vehicle kilometers in Belgium are covered by diesel vehicles, this study was limited to the EURO III diesel car, described in Table 1. The other assumptions used in the model include flat terrain, ‘normal’ driving and gear change assumptions and no air conditioning or additional payload carried by the vehicle.

Speed profiles, based on the instantaneous speed data from the GPS receiver, were composed for every detected vehicle trip and used as input for the VeTESS tool. The model output consisted of second-by-second emission data, total emission data and emission factors for every trip.

Table 1. The EURO III diesel car in the VeTESS emissions model [4]

Make of car	Skoda Octavia 1.9 Tdi
Engine size	1896 cm^3 diesel engine
Fuel system	Direct injection
Euro class	EURO III certified
Max. power	66 kW at 4000 rpm
Max. torque	210 Nm at 1900 rpm
Engine aspiration	Turbo + intercooler
Exhaust gas recirculation	Yes
Emissions control device	Oxidation catalyst

Driving behaviour

A set of driving parameters was calculated based on the speed and acceleration profiles from the GPS receiver. The driving parameters applied in this study include average speed, average positive acceleration, relative positive acceleration (RPA) and the percentage of stop time (PST) (see Table 2). RPA is calculated from the power that is needed for all vehicle accelerations in the cycle, divided by the distance driven. It gets high when the driving pattern includes a lot of high power-demand accelerations and is found to increase exhaust emissions and fuel consumption [5]. RPA is calculated as:

$\frac{1}{x}\int_0^T va^+ dt$, where T = total cycle time (s), v = speed (m s^{-1}), a^+ = positive acceleration (m s^{-2}) and x = total distance (m).

Table 2. Driving pattern parameters for the study

Driving pattern parameter	Denotation	Unit
Average speed	v_{avg}	km h^{-1}
Average positive acceleration	a^+_{avg}	m s^{-1}
Relative positive acceleration	RPA	m s^{-1}
Percentage of stop time	PST	%

Analysis

Vehicle trips were classified according to the characteristics of their driver. The analysis aimed at answering the following question: Is there a relationship between the ‘type’ of the car driver and its driving behaviour and/or amount of vehicle emissions caused per trip? To answer this question, the calculated emission factors and driving parameters had to be linked with the trip driver information. Since the trip number was attached to every calculated value, each driving pattern and emission estimate could be coded with information concerning the driver of the vehicle trip. In this study, due to the small scale, trips were classified either as made by a man, or as driven by a woman. An analysis was then performed to find out if there was a gender-linked disparity in vehicle exhaust emissions.

Results

This section presents the results from the small scale survey where 32 respondents participated in an AB survey with GPS tracking technology. Both the results from the emission estimates and the driving parameters are presented for the trips made by men and the trips made by women. In total 235 trips were analyzed.

Emission estimates

The emission model VeTESS calculated the emission values based on second-by-second speed measurements. Both the total amount of emissions as well as the emission factors were calculated. Table 3 and Table 4 present respectively the average total emission values and the average emission factors per trip as calculated by the emission model. An unpaired two-sided t test was performed to check the differences between the values of different trip purposes ($p<0.05$). The results in Table 3 show clearly that there is a difference between the total emission values of trips made by men and women. In the first place, the average distance of a trip driven by a man is almost twice as high comparing to the average distance of trips made by woman ($p<0.05$). Mainly due to this, the total fuel consumption and the total amount of emissions per trip are also higher for trips made by men. When taking into account the distance values and calculating the emission factors for every trip, Table 4 shows that the differences between men and women remain significant. The mean emission factors for trips made by women are always higher than the values for trips made by men ($p<0.05$).

Table 3. Distance, total emissions and fuel consumption. Averages per trip and per gender

	Distance (km)	Fuel (l)	CO_2 (g)	CO (g)	NO_x (g)	PM (g)	HC (g)
male	16.34	1.05	2733.99	0.56	12.86	1.36	0.11
female	9.9	0.63	1651.51	0.36	7.65	0.82	0.08
ttest	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Table 4. Emission factors and fuel consumption. Averages per trip and per gender

	Fuel ($l\ 100\ km^{-1}$)	CO_2 ($g\ km^{-1}$)	CO ($g\ km^{-1}$)	NO_x ($g\ km^{-1}$)	HC ($g\ km^{-1}$)	PM ($g\ km^{-1}$)
male	6.77	176.78	0.04	0.89	0.01	0.08
female	7.32	191.18	0.06	1.00	0.01	0.09
ttest	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Driving behaviour

Driving parameters used in this study include average speed (v_{avg}), average positive acceleration (a^+_{avg}), relative positive acceleration (RPA) and percentage of stop time (PST). Table 5 presents the calculated driving parameter values for the trips in this pilot study.

The average driving speed for trips made by men is significantly higher than the average speed for trips made by women ($p<0.05$). Trips with a male driver have an average speed of 40.45 km h^{-1} whilst the trips with female chauffeurs are driven at an average speed of 33.30 km h^{-1}. The parameters concerning the positive acceleration, a^+_{avg} and RPA, and the driving parameter PST are all higher for trips made by women ($p<0.05$).

Table 5. Driving parameters. Averages per trip and per gender

	v_{avg} ($km\ h^{-1}$)	a^+_{avg} ($m\ s^{-2}$)	RPA ($m\ s^{-2}$)	PST (%)
male	40,45	0,56	0,22	20,13
female	33,30	0,64	0,25	26,57
ttest	< 0.05	< 0.05	< 0.05	< 0.05

v_{avg} average driving speed, a^+_{avg} average positive acceleration, *RPA* relative positive acceleration, *PST* percentage of stop time

Discussion

The methodology and results presented in this paper demonstrate that useful information can be obtained by enlarging an AB survey with GPS technology and linking information of the car driver to other parameters like emission estimates and driving parameters. This kind of travel survey does not only provide the necessary information for the calculation of all these parameters, but also offers useful information on the travel behaviour of people. Information is provided on different facets like the reason of the trip, the trip distance and the driving behaviour. Individuals displaying the same travel behaviour can be classified into groups e.g. according to age, income, gender, etc. When aiming policy measures to reduce the traffic air pollution, this kind of information can then be used to work with ‘target groups’ for every action. Since every ‘group’ will respond differently to policy measures these actions can then be tuned to the proper target group. Based on the results of the pilot study one could for example suggest to focus on the target group ‘men’ when considering policy measures like car pooling or the use of public transport since they seem to make only a few trips a day, mainly for work. An analysis of the travel behaviour of women, on the other hand, reveals that women seem to combine several short trips (going to work, shopping, bringing/getting children, etc.), limiting their possibilities to leave the car at home. But since the driving behaviour of women apparently is the main cause of the higher emission estimates per kilometre, this target group would benefit more from other policy measures, like environmentally friendly driving tips.

Still there are some aspects that need to be considered when applying this methodology. Firstly, the travel survey procedure needs to be updated with more recent technology reducing the respondent’s burden and increasing the detail of information. Trip detection needs to be done automatically and the paper work needs to be reduced. Secondly, the emissions should be calculated more realistically. At present, the vehicle emissions are calculated assuming only one vehicle type for all the recorded speed profiles. This assumption needs to be validated since changes in vehicle type have an impact on emission simulations. On the other hand, the use of only one vehicle type offers advantages for the analysis excluding the influence of the vehicle type. Another aspect that needs our attention deals with gear changing behaviour. When calculating the emissions, the default gear changing values were used as provided within the VeTESS model. Since gear shifting behaviour can have a great influence on the emission exhaust, this needs to be taken into consideration. If possible, future research could include an in-vehicle tool recording this information.

The first results from this pilot study demonstrate the application of the developed methodology and indicate the field of application. Real explications and conclusions based on the results will require more data. Future research will therefore also include a large scale survey.

Conclusions

This paper demonstrates the methodology to link information on the driver of a trip to driving parameters and emission estimates. This kind of approach provides useful information when aiming target groups for policy measures. This method includes the completion of an activity-based survey extended with gps-technology and the calculation of parameters like vehicle exhaust emissions and driving parameters. In this pilot study, differences were found between these parameters depending on the gender of the trip driver. Women seem to emit more emissions per kilometer than men, but more data are needed to acquire meaningful results and explanations. Future research will therefore include the application of the developed methodology on a large scale survey.

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