Influence of gear-changing behaviour on fuel use and vehicular exhaust emissions

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Abstract

This study explores the influence of gear-changing behaviour on vehicular exhaust emissions and fuel consumption using real drive cycles as an input. As many as 235 different drive cycles, recorded from people participating in a survey, were imported in an emission simulation tool called Vehicle Transient Emissions Simulation Software (VeTESS). Emissions and fuel consumption were calculated with VeTESS using two different gear change assumptions (normal and aggressive). This paper reports on the differences in vehicle exhaust emissions between trips made with those two different settings.

Introduction

The largest potential to improve fuel use and reduce pollutant emissions in road transport probably lies in enhancing vehicle technology. However, such an approach involves a relatively large implementation time and considerable costs. An effective way to improve fuel economy in the short term is to aim at a change in driver behaviour and promote an environment-friendly driving style.

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Environment-friendly driving includes different behavioural aspects to obtain a more fuel-efficient driving, one of them implying a selective use of gears. By shifting gear early one can avoid high engine speeds and therefore achieve a reduction of emissions and fuel consumption. When applying this kind of soft measures it is therefore important to assess the potential benefits of these actions.

Methodology

This section first describes how data about driving behaviour were collected and then presents how this information can be used to estimate the vehicle exhaust emissions caused by every trip.

Data collection

Data were obtained in a small-scale travel survey, collecting trip information from 32 participating respondents. During a period, varying from two days to 1 week, these respondents were asked to fill in a travel diary and to activate a personal digital assistant (PDA) with built-in Global Positioning System (GPS) receiver when making a trip. The use of this device allows acquiring accurate information about the travel behaviour of the individual respondents. It is able to collect second-by-second trip information (speed, location, etc) for every vehicle trip during the survey period. In total 303 vehicle trips were reported by the respondents of which 235 trips were recorded completely by the GPS receiver. After data processing, 235 speed profiles were developed for the calculation of emission estimates and fuel consumption.

The VeTESS emission model

Within the European Union (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. The final simulation tool, which is called Vehicle Transient Emissions Simulation Software (VeTESS), calculates emissions and fuel consumption made by a single vehicle during a defined “drive-cycle” [1]. The following description of the model can be found more detailed in [2].

In the project DECADE a new method for characterizing engine behaviour was developed, including the description of transient effects. Within the new measuring procedure, the effect on emissions and fuel consumption of sudden torque changes (in a step of about 0.2 s) at constant speed are recorded on an engine test bed. Based on three independent variables from the experimental procedure, namely engine speed, engine torque, and change in torque, four parameters are defined for each pollutant: steady state emission rate, jump fraction, time constant, and transient emissions. The steady state emission rate is the rate at which the pollutant is produced as the engine runs under steady state, i.e., at constant speed and torque. The jump fraction characterizes the fraction by which the emission rate increases or decreases after a change in torque not taking into account the dynamic behaviour. The time constant is a measure for the time required to approach the steady state emission value after a torque change. The transient emission is a discreet amount of additional pollutant generated after the change of torque. The overall emissions of the trip are obtained by adding up the emissions produced under the different load conditions during the drive cycle.

VeTESS calculates the emissions per second for CO_2, CO, NO_x, HC, and particulate matter (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, most vehicle kilometres in Belgium are covered by diesel vehicles, and VeTESS produces the best results for diesel cars, this study was limited to the EURO III diesel car, described in Table 1.

Gear-changing behaviour

VeTESS uses specific gear change rules to determine the gear change points for the vehicle [4]. Three options are available to simulate aggressive, normal, or gentle style driving. A custom option is also available allowing

Table 1. The EURO III diesel car in the VeTESS emissions model [3]

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

the user to alter the values to suit a particular driving style. In this study a comparison was made between the "normal" and the "aggressive" gear-changing behaviour and therefore only those two options will be discussed.

When selecting the "normal" gear-changing assumptions VeTESS will simulate average engine speeds and an average number of gear changes over a given route. "Normal" gear-changing settings will assume a gear shift to a higher gear when the engine speed exceeds 55% of the maximum engine speed. In case of the EURO III diesel car in the model, this maximum engine speed amounts 4800 rpm. The "aggressive" gear-changing assumptions on the other hand will allow higher engine speeds and less engine torque than values used during normal driving. This will result in a larger number of gear changes. When using this "aggressive" setting, gear shifting will occur at 80% of the maximum engine speed.

Analysis

The analysis aimed at answering the following question: What can be the influence of gear-changing behaviour on vehicle exhaust emissions? By using the recorded driving cycles as an input in the emission model VeTESS, emissions and fuel consumption were therefore calculated according to two different gear-changing assumptions. The relative difference of the emission and fuel-use estimates for those two assumptions was discussed.

Results

This section presents the results of the calculations where 235 real driving cycles where converted into emission estimates using the VeTESS emission tool. The results from the emission estimates are presented for the trips made by two different gear-changing assumptions: normal and aggressive.

Tables 2 and 3 present the calculated values for the total emissions and the emission factors, respectively. In Tables 2 and 3 the results indicate that an aggressive gear-changing behaviour will result in higher emissions of CO_2, NO_x, PM, and HC and in an increased fuel consumption. This conclusion accounts for the average total values as well as for the emission factors of those pollutants. The emissions of CO seem to be influenced differently since an aggressive gear shifting apparently implies a decrease of the average CO emissions per trip. A paired two-sided t-test was performed on

Table 2. Average total emissions and fuel consumptions per trip using two different gear-changing assumptions

	Fuel (L)	CO_2 (g)	CO (g)	NO_x (g)	PM (g)	HC (g)
Normal	0.76	1996.98	0.43	9.31	0.09	0.99
Aggressive	0.95	2475.43	0.28	11.91	0.14	1.24
t-test (*p*-value)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Table 3. Average emission factors and fuel consumptions per trip using two different gear-changing assumptions

	Fuel (100 L km^{-1})	CO_2 (g km^{-1})	CO (g km^{-1})	NO_x (g km^{-1})	PM (g km^{-1})	HC (g km^{-1})
Normal	7.15	186.59	0.05	0.97	0.01	0.09
Aggressive	9.19	240.21	0.03	1.1	0.01	0.12
t-test (*p*-value)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

the results to check the differences between the values of different gear-changing settings. The statistical test demonstrated that the differences were all significant ($p < 0.05$).

Tables 4 and 5 present the relative difference of the "aggressive" estimates in comparison with the "normal" estimates to demonstrate the extra emissions one can cause by using an aggressive gear-changing behaviour. In these tables, the results indicate that one will increase the emissions of CO_2 and the average fuel consumption per trip by 30% when applying the aggressive gear-changing settings in the VeTESS model instead of the normal settings. This means that one can save an average of 30% of the fuel consumption per trip by avoiding an aggressive gear change.

The results for the NO_x emissions also indicate an increase of the emissions when the aggressive gear settings were applied. NO_x emissions will increase by 15% when changing gear at higher engine speeds. Concerning the emissions of PM and HC, the results show an average increase of the pollutant emissions of 41% and 38%, respectively. The impact on CO emissions on the other hand shows an average decrease of the emissions by 30%. Apparently the emissions of this pollutant are influenced differently than the pollutant mentioned before.

Table 4. Average total emissions and fuel consumptions using two different gear-changing assumptions. Relative difference of aggressive to normal settings (%)

	Fuel (L)	CO_2 (g)	CO (g)	NO_x (g)	PM (g)	HC (g)
Average %	29.45	29.47	–29.67	15.79	41.59	38.80
SD	8.41	7.88	37.90	17.02	29.44	14.11

Table 5. Average emission factors and fuel consumptions using two different gear-changing assumptions. Relative difference of aggressive to normal settings (%)

	Fuel (100 L km^{-1})	CO_2 (g km^{-1})	CO (g km^{-1})	NO_x (g km^{-1})	PM (g km^{-1})	HC (g km^{-1})
Average %	29.27	29.35	–29.38	15.74	22.84	38.58
SD	7.79	7.86	43.97	17.08	40.54	14.81

Discussion

The emission model VeTESS calculated the emission values based on second-by-second speed measurements of 235 vehicle trips. Both, the total amount of emissions as well as the emission factors were calculated according to two different gear-changing settings. The results indicate that, on average, the use of an aggressive gear-changing behaviour results in an increase of the emissions of CO_2, NO_x, PM, and HC. Fuel consumption will increase by 30% when using an aggressive gear use. The impact on CO emissions appears to be opposite to the other impacts and needs to be studied in future research. Apparently the emission of this pollutant is influenced differently when changing gears at higher engine speeds.

Another aspect that needs to be studied more into detail is the impact on the emissions of PM. The impact of an aggressive gear shifting on the emissions of this pollutant seems to display large variations between the different values. Possibly there is a difference between the different "kinds" of trips, but this assumption needs more research.

Further research should also include other vehicle types to study the impact of gear changing on vehicle exhaust emissions. This study was performed by using the engine details of only one EURO III diesel car, but the same methodology should be applied at other vehicles to gain more insight into the consequences of this kind of measures and obtain some general results. At the moment the VeTESS model is less accurate for gasoline vehicles. This is due to the important role the catalyst plays, an issue which should be investigated in more depth in the future.

Conclusions

This paper demonstrates how a selective use of gears can contribute to a more environment-friendly driving behaviour. By using the driving cycles of real trips as an input in the emission model, VeTESS the benefits of using a more gentle driving behaviour were estimated. When changing gears early, one can reduce fuel consumption by 30% on average and prevent the extra emissions due to running up the engine. Future research will include more vehicle types in the study to generate more results and the differences in impact between the different pollutants will be studied thoroughly.

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