THE APPLICATION OF THE SIMULATION SOFTWARE VETESS TO EVALUATE THE ENVIRONMENTAL IMPACT OF TRAFFIC MEASURES

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Abstract: This paper demonstrates how the environmental consequences of traffic measures can be evaluated using the simulation software VeTESS. VeTESS (VEhicle Transient Emissions Simulation Software) was developed within the EU 5th framework project DECADE (2001-2003) as a vehicle level simulation tool for the simulation of fuel consumption and emissions. It is specifically designed to calculate dynamic emissions, reaching higher accuracy than traditional emission simulation models. Two different traffic measures were evaluated using the simulation software VeTESS. First the impact of a speed limiting measure, the conversion of 50 km/h zones into 30 km/h zones, on vehicle emissions was examined. The second application of VeTESS concerns the evaluation of a different gear changing behavior on vehicle exhausts.

Keywords: VeTESS, vehicle emissions, traffic measures, gear change, driving behavior

1. 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. Furthermore, these measures are often regulated at a high policy level, limiting the contribution of the local authorities to this regard. On the other hand, policy measures to improve fuel economy can also be taken at a lower policy level, like actions focusing on a change in driving behaviour (De Vlieger et al, 2000).

Speed limiting measures for example, mainly aimed at increasing traffic safety, are usually seen or even promoted by local authorities as beneficial to the environment because of reduced fuel consumption and emissions. However, the claims for these environmental benefits need to be examined thoroughly before drawing any conclusions. Next to speed limiting measures, actions to stimulate a more fuel-efficient driving style are also put forward to contribute to a reduction in environmental pollution. An environmentally friendly driving style includes different behavioral aspects to obtain a more fuel-efficient driving, one of them being a selective use of gears (Beckx et al, 2006). Unfortunately, a quantification of the potential reduction one can achieve with a different gear changing behavior is very difficult to make.

Before implementing this kind of traffic measures, it is important to assess the potential benefits of these actions. When public money is spent on schemes designed to reduce air pollution, policy makers like to know in advance that the objectives (complying with air quality standards) will be met. Therefore simulation models are necessary to assess the impact of certain measures.

This paper presents how the simulation model VeTESS was used to assess the impact of two different traffic measures on vehicle exhaust emissions. It will present the results of calculations that were made with real driving cycles as with theoretical driving cycles. Finally, the paper concludes and defines some interesting topics for further research.

2. THE VETESS EMISSION MODEL

This section provides a brief description of the VeTESS model and the approach that was used to develop this model. More detailed information can be found in Pelkmans (2004) or in the VeTESS user manual (VeTESS V1.18B).

2.1 Description of the model

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 and transient operation conditions. 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’. The drive cycle is a representation of the route to be driven by the vehicle. It contains details of the speed of the vehicle and the road gradient over a complete route. The drive-cycle could be from a recorded journey, calculated from traffic flow models or produced from knowledge of typical journeys.

Starting with a given driving cycle, VeTESS uses simple mathematical calculations involving gear ratios and their efficiencies to determine the engine's operating conditions from the force on the vehicle. The total force on the vehicle is calculated through the equation of motion, namely: total force = acceleration resistance + climbing resistance + rolling resistance + aerodynamic resistance. The engine provides the force required to overcome the resistances to motion. This force is produced by the engine as a torque. This torque is converted from rotational to linear motion by the driven wheels.

2.2 DECADE approach for measuring dynamic emissions

Microscopic emission simulation generally starts from a map-based approach. Based on the second-by-second duty cycle of a vehicle, the engine power and speed is calculated. The simulation procedure assumes that the engine moves through a series of "quasi steady-state" conditions, described by a combination of engine speed and torque. The emissions and fuel consumption associated to each one of these quasi steady-state conditions can be looked up on so-called emissions maps. These maps are generated by operating the engine in a series of steady-state conditions. In reality, the production of pollutants depends to a large extent on the rate of change of load. Some of the emissions are generated by the change itself, rather than as a function of a series of steady states. These dynamic, or "transient" effects must be taken into account when doing the simulation. Therefore, the aim of the DECADE project was to convert the quasi steady-state method into one that takes into account the dynamic behavior of the engine system. The key implication of this is that a new method of characterizing engine behavior had to be developed that includes 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 seconds) 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. The emissions considered are CO_2, CO, HC, NO_x and PM.

A lot of effort is put in the user-friendliness of VeTESS. The following

Figure 1 shows a typical user interface of VeTESS.

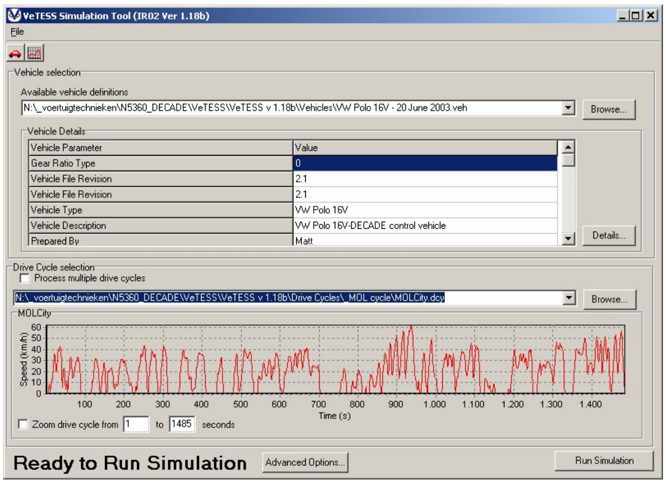

Figure 1: Example of the VeTESS user interface

2.3 Vehicle types

VeTESS calculates the emissions per second for CO_2, CO, NO_x, HC and PM based on second-by-second speed profiles. The speed profiles can either be made theoretically or recorded from real vehicle trips. For the moment, concerning passenger cars, detailed engine maps are only available for three types of cars: a Euro II LGV, a Euro III diesel car and a Euro IV petrol car (Table 1).

Table 1. The vehicle types considered in the VeTESS emissions model (Beevers and Carslaw, 2005)

	Skoda Octavia 1.9 Tdi	Citroen Jumper 2.5D	VW Polo 1.4 16V
Engine size	1896 cm3 diesel engine	2446 cm3 diesel	1390 cm3 petrol
Fuel system	Direct injection	Indirect injection	Multipoint fuel
Euro class	EURO III certified	EURO II certified	EURO IV certified
Max. power	66 kW at 4000 rpm	63 kW at 4350 rpm	74 kW at 6000 rpm
Max. torque	210 Nm at 1900 rpm	153 Nm at 2250 rpm	126 Nm at 4400
Engine aspiration	Turbo + intercooler		
Exhaust gas	Yes	Yes	Yes
Emissions control	Oxidation catalyst	Oxidation catalyst	Lambda control

3. EVALUATION OF TRAFFIC MEASURES

In this section we demonstrate how the VeTESS emission model was used to assess the environmental impact of two different traffic measures. First the impact of a speed limiting measure was evaluated and next we examined the effect of a different gear changing behavior on emissions.

3.1 Introduction of 30 km/h zones in urban areas

3.1.1 Description of the traffic measure

Since September 1st 2005 zone 30 stretches are mandatory near all Belgian schools with some exceptions made for schools on the busiest regional roads. The conversion of entire districts, streets or street sections into 30 km/h zones was usually done in residential areas where the previous speed limit was 50 km/h (e.g. city of Ghent; Int Panis et al, 2005).

These measures are usually seen as beneficial to the environment because of reduced fuel consumption and emissions. The claims for these environmental benefits stem from the believe that speed reduction measures in urban areas have similar benefits as those on highways (Int Panis et al., 2006a). However, in contrast to this popular believe, wide spread emission estimation methods using quadratic functions such as the Copert/MEET approach would lead us to believe that emissions may even rise dramatically. Unfortunately the speeds typical for urban traffic (esp. congested traffic) are very close to or lower than what is usually considered to be the minimum average trip speed for which relevant estimates can still be made using the Copert/MEET approach (Int Panis et al., 2006b). Apparently more sophisticated methods are needed to estimate the impact of this measure. Therefore the VeTESS-tool was used to calculate the environmental effects of the introduction of zone 30 stretches on vehicle exhaust emissions in urban areas. VeTESS modeled the emissions for real-life urban driving cycles and for artificially modified driving cycles limiting the top speed to 30 km/h. A comparison could then be made between the emission results for both situations.

3.1.2 Description of the driving cycles

Modeled driving cycles were recorded during on-the-road emission measurements in the cities of Mol (32 474 inhabitants, Belgium) and Barcelona (4.2 million inhabitants, Spain), using three different vehicles: VW Polo (Euro 4, petrol), Skoda Octavia (Euro 3, diesel) and a Citroen Jumper (Euro 3, diesel) light commercial vehicle. We believe these vehicles are representative for an important fraction of current car sales in Belgium. We refer to Pelkmans et al. (2004) for a detailed technical description of the vehicles and set-up of the test cycles.

From each of the 6 different driving cycles we derived a modified version in which the top speed was limited to 30 km/h without changing the acceleration or deceleration. The length of time driven at the new top speed was elongated to preserve the original cycle distance. Figure 2 shows an example comparison between one of the original driving cycles and the derived cycle.

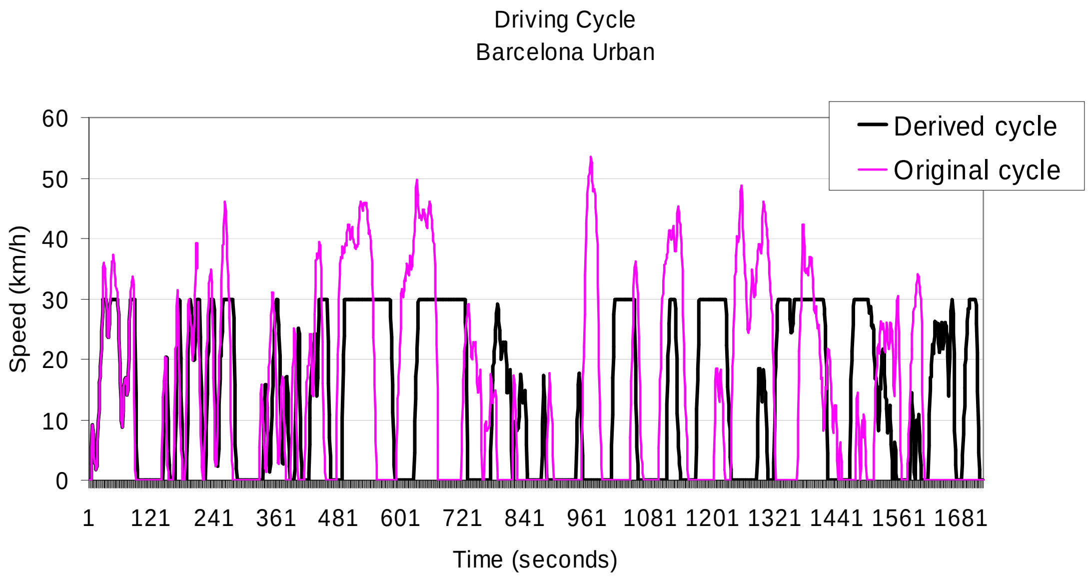

Figure 2. Example showing the conversion of cycle 6 to a cycle with limited top speed

Table 2 shows a summary of statistics describing the cycles and the modifications that were made. It is clear from the average speeds and the number of stops that these cycles represent urban trips in heavy traffic.

Table 2. Summarized descriptive statistics for the urban driving cycles used in this study (Cycles 1-3: Barcelona, Cycles 4-6: Mol). Data for modified cycles in last two columns.

Cycle	Length		Stops	Max a	Max -a	Avg v	Additional	New
	(s)	(km)		m/s.s	-m/s.s	km/h	(s)	km/h
1	1615	6.6	22	7.8	10.2	14.8	107	13.9
2	1765	7.1	27	7.8	10.5	14.5	72	13.9
3	1475	7.3	22	9.4	15.4	17.8	173	15.9
4	1497	10.5	16	8.3	11.3	25.2	163	22.7
5	2003	10.5	22	6.7	8.8	18.9	68	18.3
6	1735	10.5	22	9	11.3	21.8	125	20.3

3.1.3 Results

The emissions of each of the three vehicles were modeled with each of the 6 available urban driving cycles, resulting in 18 emission estimates for a reduction of the top speed from 50 km/h to 30 km/h. Overall results are summarized in Figure 3. Positive values indicate that emissions go up when the new speed limit is implemented. Negative values indicate that pollutant emissions decrease.

Results for CO and HC differ widely between vehicles and cycles. Because emissions of these pollutants are very low in modern cars, we believe that they are not modeled with sufficient accuracy to lend credibility to the relative changes shown in the graph (even a 100% increase represents only a tiny amount of pollutants emitted, close to the smallest amount that can be measured). For the emissions of CO_2 and hence fuel consumption it was found that the change to the driving cycle only had a limited impact, either positive or negative, on the emission. Concerning the emissions of NO_x the model results differ between cycles and vehicle types. Both diesel vehicles (Octavia and Jumper) showed a moderate to large decrease in the modeled emissions of PM in each of the cycles (no PM emissions could be modeled with VeTESS for petrol fueled vehicles).

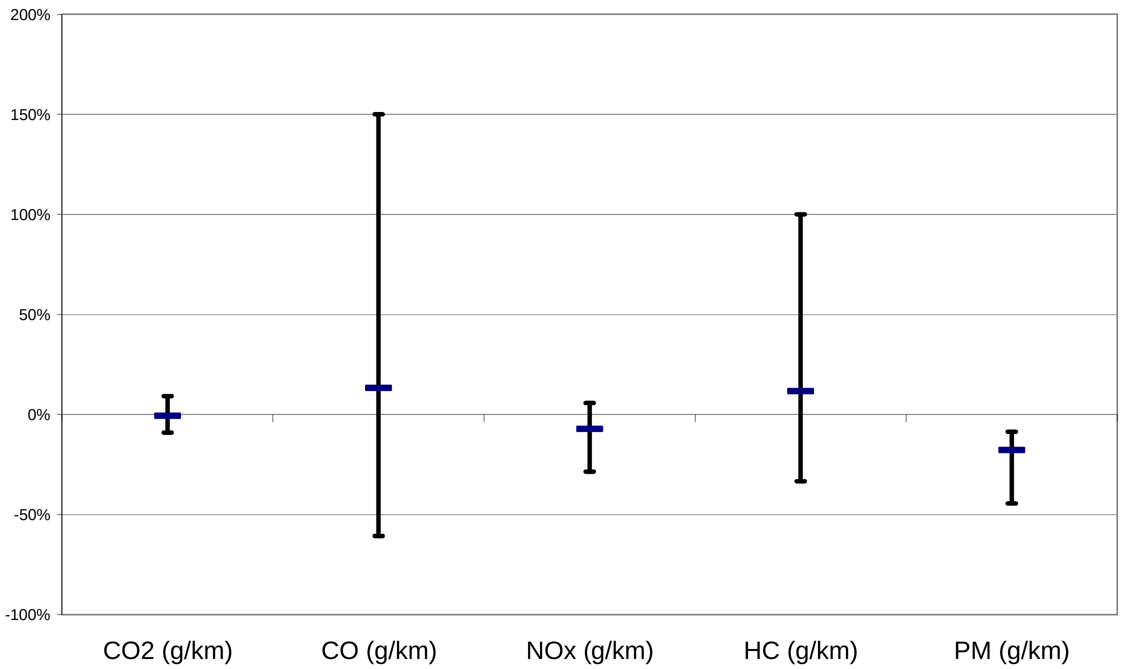

Figure 3: Estimated relative change in emission for 5 pollutants. Average and range for 18 estimates.

In Figure 4 we present the detailed VeTESS results for the Skoda Octavia for one representative cycle in each city. Results for most other vehicle/cycle combinations yield similar results. It is clear that emissions of CO_2, NO_x and PM decrease in each situation for this specific vehicle. This is the combined result of lower top speeds, longer driving periods at 30 km/h and extended driving to reach the end of the cycle (i.e additional length in Table 2). Emissions of CO_2 are marginally smaller and NO_x emission factors are also lower. The largest reduction however is found for emissions of PM which decrease in most cases by approximately one third.

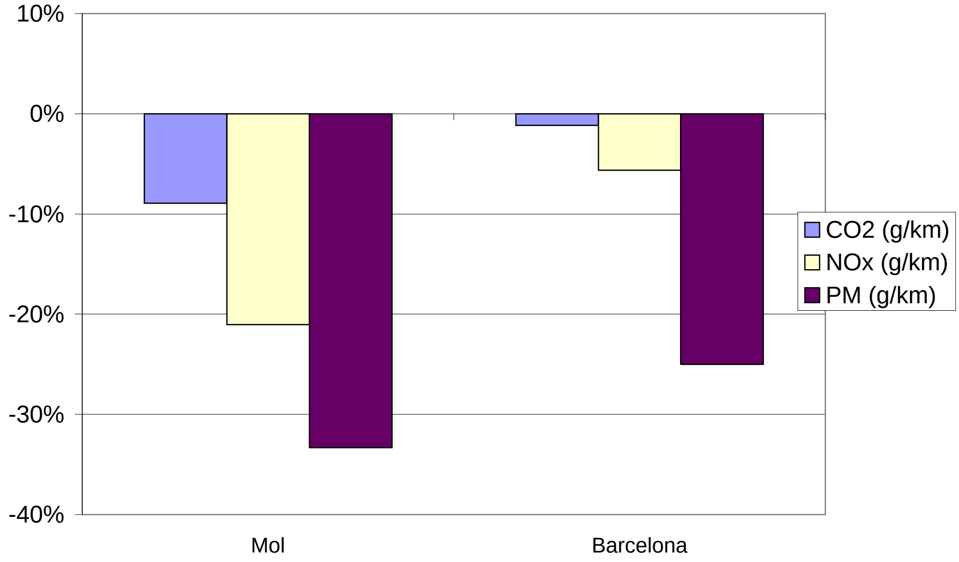

Figure 4. Relative change between two normal urban drive cycles (up to 50km/h) and drive cycles limited at 30 km/h (Skoda Octavia; Cycle 4: 25.2->22.7 km/h in Mol, Cycle 1: 14.8->13.9 km/h in Barcelona

In Figure 5 we present some detailed results for the light delivery van. In this case the result of detailed emission modeling predicts a slight increase for both fuel consumption and CO_2 emissions. Results for NO_x emissions are mixed, but for the PM emissions, this vehicle would show an important decrease (although smaller than for the passenger cars) under the speed-limited driving cycle.

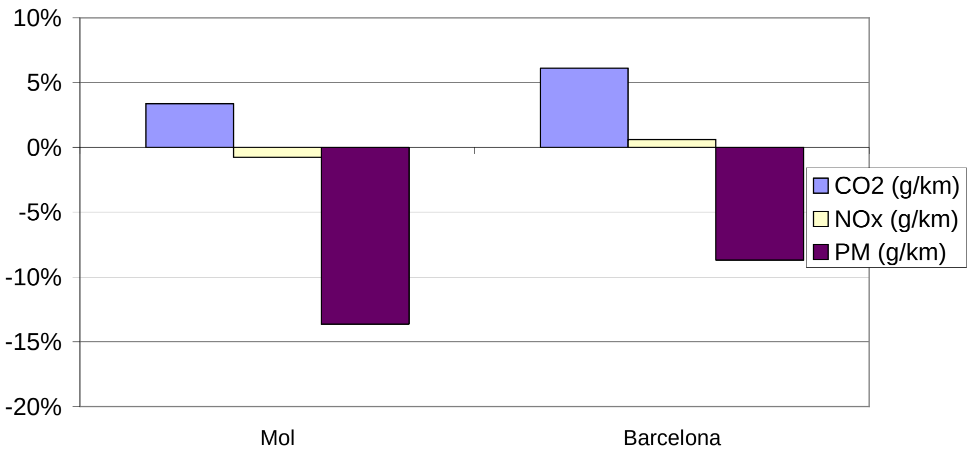

Figure 5: Relative change in emissions between two urban driving cycles and a derived cycle limited at 30 km/h (Citroen Jumper Van; Cycle 5: 18.9 -> 18.3 km/h in Mol, Cycle 2: 14.5 ->13.9 km/h in Barcelona)

3.2 Introduction of an environmentally friendly gear changing behavior

3.2.1 Description of the traffic measure

Environmentally friendly driving includes different behavioral aspects to obtain a more fuel-efficient driving, one of them implying a selective use of gears. By shifting up gear early one can avoid high engine speeds and therefore should achieve a reduction of emissions and fuel consumption (Beckx et al, 2006). Campaigns and education should be organized to inform people, especially drivers with an aggressive driving style, about this potential fuel-saving technique.

Before investing in campaigns that stimulate people to display an environmentally friendly driving behavior authorities are interested in knowing the potential impact of this kind of measure. What will it yield to avoid people from driving aggressively? Since the VeTESS model is able to simulate different kinds of gear changing behavior, this simulation tool is suited for this kind of impact assessment.

3.1.2 Description of the driving cycles

Real-life driving cycles were obtained in a small scale travel survey collecting trip information from 32 respondents driving a diesel car for a period varying from two days to one week. The use of a GPS receiver allowed to acquire accurate second-by-second trip information (speed, location,…) for every vehicle trip during the survey. In total 235 vehicle trips were recorded by the GPS receiver and these were used for the calculation of emission estimates and fuel consumption with the VeTESS emission model.

When calculating the emissions for certain driving cycles with VeTESS one can indicate which gear changing behavior, gentle, normal or aggressive, is most appropriate for each driving cycle. VeTESS uses specific gear change rules to determine the gear change points for the vehicle for each of these driving styles. A custom option is also available allowing the user to alter the values to suit a particular driving style.

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. For this case study, only the passenger diesel car was used for modeling in VeTESS (see Table 1). The maximum engine speed for this EURO III diesel car in the model 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.

3.1.3 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.

Table 3 and Table 4 present the calculated values for respectively the total emissions and the emission factors. These results indicate that an aggressive gear changing behaviour will result in significantly 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 the results to check the differences between the values of different gear changing settings. The statistical test demonstrated that the differences were all significant ($p<0.05$).

Table 3. Average total emissions and fuel consumptions per trip using 2 different gear changing assumptions.

	Fuel	CO_2	CO	NO_x	PM	HC
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
Ttest	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Table 4. Average emissions factors and fuel consumptions per trip using 2 different gear changing assumptions.

	Fuel	CO_2	CO	NO_x	PM	HC
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
Ttest	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Table 5 and Table 6 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 (or the reductions of emissions one can achieve by avoiding an aggressive driving style). 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 in stead 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 respectively 41 and 38 %. 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 pollutants mentioned before.

Table 5. Average total emissions and fuel consumptions using 2 different gear changing assumptions. Relative difference of aggressive to normal settings (%).

	Fuel	CO_2	CO	NO_x	PM	HC
Average %	29.45	29.47	-29.67	15.79	41.59	38.80
Stdev	8.41	7.88	37.90	17.02	29.44	14.11

Table 6. Average emission factors and fuel consumptions using 2 different gear changing assumptions. Relative difference of aggressive to normal settings (%).

	Fuel	CO_2	CO	NO_x	PM	HC
Average %	29.27	29.35	-29.38	15.74	22.84	38.58
Stdev	7.79	7.86	43.97	17.08	40.54	14.81

4. CONCLUSION

This paper demonstrates how the simulation software VeTESS can contribute to the assessment of the environmental impact of traffic measures. Two case studies were examined in this paper. First of all the VeTESS model was used to evaluate the impact of lowering a speed limit from 50 km/h to 30 km/h. Next, the simulation tool was applied to assess the impact of an environmentally friendly driving behavior. Future research should further explore the use of this model for other purposes and should examine the possibility of using more vehicle types in the model.

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