



## PM, NO<sub>x</sub> and CO<sub>2</sub> emission reductions from speed management policies in Europe

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### ABSTRACT

Speed reduction measures rank among the most common schemes to improve traffic safety. Recently many urban streets or entire districts were converted into 30 kph zones and in many European countries the maximum permissible speed of trucks on motorways is under discussion. However, besides contributing to traffic safety, reducing the maximum speed is also seen as beneficial to the environment due to the associated reduced fuel consumption and lower emissions. These claims however are often unsubstantiated.

To gain greater insight into the impact of speed management policies on emissions, this paper examines the impact on different traffic types (urban versus highway traffic) with different modelling approaches (microscopic versus macroscopic). Emissions were calculated for specific types of vehicles with the microscopic VeTESS-tool using real-world driving cycles and compared with the results obtained using generalized Copert-like macroscopic methodologies. We analyzed the relative change in pollutants emitted before and after the implementation of a speed reduction measure for passenger cars on local roads (50–30 kph) and trucks on motorways (90–80 kph). Results indicate that emissions of most classic pollutants for the research undertaken do not rise or fall dramatically. For the passenger cars both methods indicate only minor changes to the emissions of NO<sub>x</sub> and CO<sub>2</sub>. For PM, the macroscopic approach predicts a moderate increase in emissions whereas microscopic results indicate a significant decrease. The effects of specific speed reduction schemes on PM emissions from trucks are ambiguous but lower maximum speed for trucks consistently result in lower emissions of CO<sub>2</sub> and lower fuel consumption. These results illustrate the scientific uncertainties that policy makers face when considering the implementation of speed management policies.

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### 1. Introduction

Road transport provides economic and social benefits for the entire society. Unfortunately, traffic also causes a number of unwanted effects like congestion, traffic accidents and traffic related air pollution. To counter these negative impacts, local policy makers in Europe have introduced, amongst other measures, permanent or temporary speed restrictions aimed at improving traffic flows, traffic safety or both.

The conversion of entire districts, streets or street sections into 30 kph zones is usually done near schools or in residential areas where the previous speed limit was 50 kph. These measures, mainly aimed at increasing traffic safety and promoting cycling or walking, are usually seen or even promoted by local authorities as being also beneficial to the environment because of reduced

emissions and lower exposure of inhabitants or other road users (Jouard, 1987; Anderson et al., 1997; Int Panis et al., 2010). The claims for these environmental benefits stem from the belief that speed reduction measures in urban areas have similar benefits as those on motorways (Keller et al., 2008; Keuken et al., 2010). However, in contrast to this popular belief, wide spread emission estimation methods using quadratic functions, such as the European Copert/MEET approach (Ntziachristos, 2009) predict that emissions may even rise dramatically and for this reason urban speed reduction policies are sometimes vigorously opposed. Copert (Computer Program to calculate emissions from road traffic) is based on average speed emission factors to estimate emissions on a macroscopic level (e.g. the national level; see examples in Beckx et al., 2009). Unfortunately, the speeds typical for urban traffic (especially 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 this macroscopic approach. Therefore, more sophisticated methods are needed to estimate the impact of the

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introduction of low speed zones on vehicle exhaust emissions in urban areas. Using microscopic models permits for the accounting of lower average speeds which may also be associated with less variability resulting in environmental benefits (Int Panis et al., 2006; Beusen et al., 2009).

Similarly, the reduction of the maximum speed of trucks is under discussion in several European countries. Reducing the speed limit for trucks from 90 to 80 kph is seen as beneficial for traffic safety and for the environment (Dijkema et al., 2008). However, this implementation often results in criticism from (economic) stakeholders and policy makers in relation to time and economic losses, in addition to casting doubts over the assumed environmental and safety benefits. Unfortunately, scientific analysis is often unavailable or ignored in the political discussions on this theme.

In this paper, we shed some light on the environmental impacts of speed management policies by presenting the results from two different approaches: a sophisticated vehicle based microscopic emission modelling approach based on detailed second-by-second driving cycles (using the VeTESS model) and the traditional macroscopic approach based on average speeds (using a Copert-type model). The impact of speed measures on vehicle emissions is evaluated with both modelling approaches in two different settings (urban versus highway). Both types of models have some drawbacks but by combining results of two complementary models we can gain a better and more robust understanding of the potential impact of different speed management policies on exhaust emissions.

## 2. Methodology

In this section, we describe the modelling approaches and driving cycles that were used to examine the impact of speed reduction measures on vehicle emissions.

### 2.1. Description of the modelling approaches

For the microscopic emission modelling we used the VeTESS model (Vehicle Transient Emissions Simulation Software) that was developed within the European project 'Decade' (Pelkmans et al., 2004). It simulates fuel consumption and emissions during transient vehicle operation. VeTESS is specifically designed to calculate dynamic emissions, and thereby aiming at higher accuracy than traditional emission simulation models using steady state engine maps (Ajtay and Weilenmann, 2004). We briefly describe the approach used to obtain the dynamic microscopic emission model but refer to Pelkmans et al. (2004) for a full description.

The VeTESS simulation procedure assumes that a vehicle engine moves through a series of "quasi-steady-state" conditions, described by a combination of engine speed and torque, whereby the engine power and speed are calculated based on the second-by-second duty cycle of a vehicle. The emissions and fuel consumption associated with each of these combinations is then derived from the so-called emissions maps. 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. Considering modern engines and their emission control equipment, dynamic, or transient, effects must be definitely taken into account when assessing the emissions. Variations of engine load and engine speed require a high level of flexibility in regard to the control of the fuelling system. In the particular case of spark ignition engines with three-way catalysts, transient operation complicates the formation of a stoichiometric air–fuel mixture

which negatively affects the performance of the catalyst. Other controls like exhaust gas recirculation valves (a technique that reduces NO<sub>x</sub> emissions by recirculating a portion of the exhaust gas back into the engine) or turbochargers (a compressor driven by exhaust gases that compresses ambient air resulting in a greater amount of air entering the cylinder) and their transient behaviour can also have an important impact on emissions. The steady state engine maps in VeTESS are therefore supplemented by a parameter measuring dynamic engine performance. The parameter chosen is torque change, which is linked to a specific change in throttle position. These torque changes can occur immediately, while a speed change is merely the consequence of a torque change. Starting from a steady state condition at a certain speed and torque, the torque is suddenly changed (in a step of about 0.2 s) to a different torque at the same constant speed. The emissions and fuel consumption related to this step change are recorded as an integrated value over 15 s to compensate for the delay and response time in the emission measurements (exhaust pipe, transport of the sample gas to the analyzers and analyzer response). All measurements included in VeTESS were performed under hot conditions with a minimum mileage of 5000 km to avoid running in effects of engines and catalysts. Cold start effects are not accounted for in VeTESS.

VeTESS simulations for fuel consumption and CO<sub>2</sub> emissions have a high accuracy (generally within 5%) for the three control vehicle technologies when the gear shifting strategy is properly matched. The introduction of transient corrections increases the calculated fuel consumption by around 6% for the diesel vehicles, compared to 10% for the gasoline vehicle. The simulation of NO<sub>x</sub> and PM emissions from diesel technologies generally has an accuracy of 10–20%. The introduction of transient corrections increases the calculated PM emissions for the diesel vehicles by around 15%. Transient corrections only have a minor impact on the calculated NO<sub>x</sub> emissions for the diesel vehicles, but are more important for CO and HC emissions.

The VeTESS model has recently been used to study the effects of different policies on transport emissions (e.g. Pelkmans et al., 2005; Beevers and Carslaw, 2005; Beckx et al., 2010). A good review of microscopic emission models and a full discussion of the advantages and drawbacks of dynamic versus static modelling can be found in Ajtay and Weilenmann (2004). Work similar to the VeTESS modelling used in this paper has been carried out on vehicle specific second-by-second emissions (e.g. Chen and Yu, 2007; Silva et al., 2006).

For the macroscopic approach, the Copert/MEET methodology was adopted. This approach, mainly used to make national emission inventories (see e.g. Kelly et al., 2009), is based on average speeds and corresponding average speed emission factors to calculate vehicle emissions for groups of vehicles and for larger study areas. Because this approach is well known and easier to understand compared to the microscopic emission modelling, we will not discuss this method in detail. Copert uses functions that predominantly have a quadratic form, emission estimates therefore tend to be much higher at very low and very high speeds. We refer to Ntziachristos (2009) for a good description of the emission factors and applied modelling parameters. The model was recently updated to include all new results of the ARTEMIS and PARTICULATES projects.

### 2.2. Description of the driving cycles

#### 2.2.1. Urban driving cycles for passenger cars and light duty vehicle

Urban driving cycles were recorded during on-the-road emission measurements in the town of Mol (Belgium, 32474 inhabitants) and the city of Barcelona (Spain, 4.2 million

inhabitants). Both locations represent quite different traffic situations, resulting in different driving patterns. On the other hand, both locations represent 'urban traffic conditions' so urban policy measures (such as a conversion of 50 kph zones into 30 kph zones) might apply to both places. Examining the impact of policy measures in different settings will offer better insight into the range of possible outcomes.

Speed (kph) and position (lat–lon coordinates) were recorded with a frequency of 1 Hz using a GPS receiver and an optical speedometer. Three different vehicles were considered: VW Polo passenger car (Euro 4, petrol), Skoda Octavia passenger car (Euro 3, diesel) and a Citroen Jumper light duty vehicle (LDV, Euro 3, diesel). These vehicles are representative for an important fraction of car sales in Europe. The same engines can be found in other European cars such as the Skoda Fabia, Seat Ibiza (petrol), VW Golf, Audi A3 and Seat Toledo (diesel). 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 six recorded urban driving cycles we derived a modified version in which the maximum speed was cut at 30 kph without changing either acceleration or deceleration (similar to the procedure followed in the European Prosper project, Int Panis et al., 2006). The effect of these modifications on the average speed, however, is limited. The time driven at the new top speed was extended accordingly to preserve the original cycle distance. A summary of statistics describing the original cycles and the modified ones is given in Table 1. It is clear from the average speeds and the number of stops that these cycles represent urban trips in heavy traffic.

### 2.2.2. Motorway driving cycles for trucks

A compilation of speed profiles was registered for trucks driving on Belgian motorways during off-peak non-congested traffic. The normal speed limit for trucks is 90 kph and the average real speed of approximately 86 kph is representative for many European motorways. The small speed variations that occur between 85 and 90 kph can be attributed to the presence of other vehicles on the motorway. To simulate the introduction of a policy reducing the speed limit from 90 to 80 kph, the measured speed profiles were linearly converted to lower speeds. The speed variation was left unchanged whereas the average speed decreased to 77 kph.

## 3. Results

### 3.1. Modelling results for light vehicles in urban driving

The emissions for each of the three light vehicles (two passenger cars, one LDV) were first simulated with VeTESS using the six original urban driving cycles and the six corresponding modified versions (Table 1). This resulted in 18 relative change estimates per pollutant for reducing the top speed from 50 to

30 kph. Overall results of this analysis are summarized in Fig. 1. Positive values indicate that emissions go up when the new speed limit is implemented; negative values indicate that emissions decrease. Results for CO and HC differ widely between vehicles and cycles. Vehicles available in VeTESS were equipped with oxidation catalysts, resulting in extremely low CO and HC emissions ( $< 0.05 \text{ g km}^{-1}$ ). To our opinion they are not modelled with sufficient accuracy to warrant further interpretation of 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  $\text{CO}_2$  and hence fuel consumption it was found that reducing the top speed only had a limited impact. For the emissions of  $\text{NO}_x$  the speed reduction measure tends to slightly reduce emissions in most cases. Relative changes vary between  $-25\%$  and  $+5\%$ . PM emissions cannot be modelled with VeTESS for petrol fuelled vehicles (i.e. the VW Polo). Both diesel vehicles (Octavia and Jumper) showed a moderate to large decrease in the modelled emissions of PM in each of the cycles.

In addition to the VeTESS model, the average speeds of the original and modified urban driving cycles were also used as input for the macroscopic Copert/MEET approach, using the characteristics of the same three vehicles. The comparison of the VeTESS results with the Copert/MEET values is presented in Figs. 2–4. Fig. 2 presents detailed results for the Skoda Octavia for one representative cycle in each city. Results for most of other vehicle/cycle combinations yield similar results. Not surprisingly, due to its quadratic functions, the macroscopic methodology results in slightly higher emission estimates when the top speed is reduced. The small difference can be attributed to the fact that the resulting change in average speed is quite limited although the derived driving cycle may seem very different. The results from the VeTESS model runs are less straightforward to interpret due to the large number of factors contributing and interacting. This is the combined result of lower top speeds, longer driving periods at

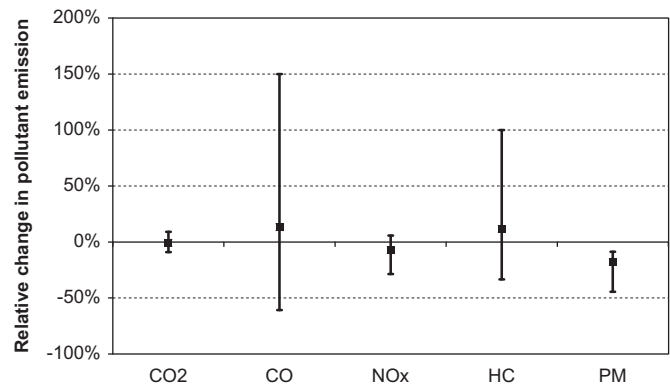
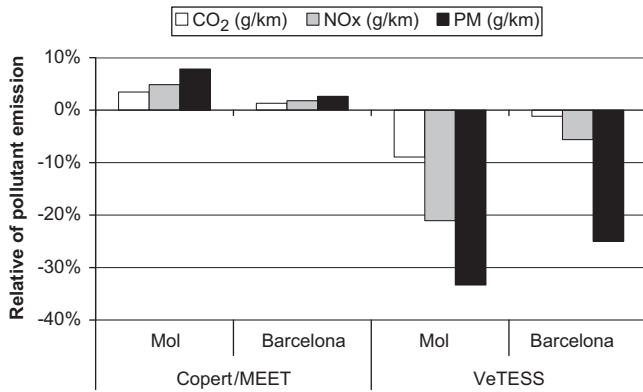


Fig. 1. Estimated relative change in emissions for 5 pollutants for a reduction of the speed limit from 50 to 30 kph in urban traffic. Results from the VeTESS model. Average and range for 18 estimates.

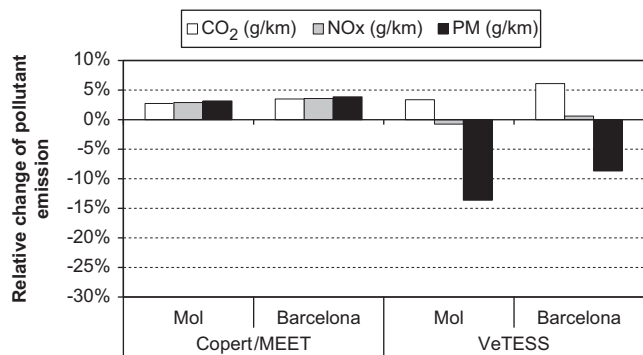
Table 1

Summary of descriptive statistics for the urban driving cycles (Cycles 1–3: Barcelona, Cycles 4–6: Mol). Data for the modified cycles (speed limit 30 kph) are given in the last two columns.  $a$ =acceleration;  $-a$ =deceleration;  $v$ =speed.

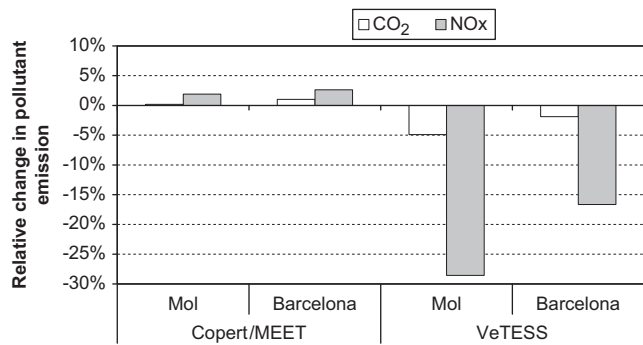
Cycle no.	Duration (s)	Length (km)	Stops	Max $a$ ( $\text{m/s}^2$ )	Max $-a$ ( $-\text{m/s}^2$ )	Avg speed $v$ (kph)	Modified cycle Additional time span (s)	Modified cycle Avg speed $v$ (kph)
1	1615	6.6	22	7.8	10.2	14.8	107	13.9
2	1765	7.1	27	7.8	10.5	14.5	72	13.9
3	1475	7.3	22	9.4	15.4	17.8	173	15.9
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



**Fig. 2.** Relative change between the emissions of two urban driving cycles (30 kph limit relative to 50 kph limit), driven with a Skoda Octavia passenger car (Mol, Cycle 4: 25.2- > 22.7 kph; Barcelona, Cycle 1: 14.8- > 13.9 kph; see Table 1 for details).



**Fig. 3.** Relative change between the emissions of two urban driving cycles (30 kph limit relative to 50 kph limit), driven with a Citroen Jumper diesel LDV (Mol, Cycle 5: 18.9- > 18.3 kph; Barcelona, Cycle 2: 14.5- > 13.9 kph; see Table 1 for details).



**Fig. 4.** Relative change between the emissions of two urban driving cycles (30 kph limit relative to 50 kph limit), driven with a VW Polo petrol passenger car (Mol, Cycle 6: 21.8- > 20.3 kph; Barcelona, Cycle 3: 17.8- > 15.9 kph; see Table 1 for details).

30 kph and extended driving to reach the end of the cycle. Nevertheless it is clear that emissions of CO<sub>2</sub>, NO<sub>x</sub> and PM decrease in each situation for this specific vehicle. Emissions of CO<sub>2</sub> decrease with small percentages (1–9% on average) and NO<sub>x</sub> emissions are reduced by 5–21%. The largest reduction however is found for emissions of PM which decrease by approximately one third in most cases.

The results of detailed microscopic emission modelling for the Citroen Jumper correspond with the simpler Copert/MEET calculation for CO<sub>2</sub> emissions (Fig. 3). Fuel consumption and CO<sub>2</sub> emissions are predicted to increase slightly (~3–5%). Results for NO<sub>x</sub> emissions are mixed due to the small increase predicted by

the macroscopic functions that is not reproduced by VeTESS, indicating that the change is insignificant. For the PM emissions, VeTESS predicts an important decrease (although smaller than for the passenger car) under the speed-limited driving cycle in contrast with the small increase predicted by Copert.

Results for the petrol car include only CO<sub>2</sub> and NO<sub>x</sub> emissions (PM is not modelled by VeTESS for petrol fuelled cars) (Fig. 4). The relative changes in CO<sub>2</sub> emissions for the VW Polo are comparable to the results presented in Figs. 2 and 3. For NO<sub>x</sub>, VeTESS results indicate that emissions may significantly decrease in the 30 kph limited driving cycles compared with the original 50 kph driving cycles. However, this result should be treated with caution due to limited VeTESS model accuracy in estimating NO<sub>x</sub> emissions of 3-way catalyst petrol cars (Pelkmans et al., 2004). Copert/MEET results on the other hand predict slightly increased NO<sub>x</sub> emissions.

### 3.2. Modelling results for trucks in motorway driving

For four types of Euro 2 trucks we estimated the impact of imposing new speed limits (i.e. a reduction of the maximum speed from 90 to 80 kph) on exhaust emissions. As in the previous section we calculated the impact with two different modelling approaches to test whether similar results can be obtained. Summarizing the VeTESS results for a number of individual trucks in Table 2, we find that total CO<sub>2</sub> emissions (and hence fuel consumption) would decrease by approximately 10% for a reduction of the maximum speed from 90 to 80 kph. This trend

**Table 2**  
Relative emission changes for different trucks for a speed limit reduction from 90 to 80 kph (VeTESS results).

Types of trucks	CO <sub>2</sub> (%)	NO <sub>x</sub> (%)	PM (%)
IVECO Eurocargo 7500 kg	-16	-29	-16
IVECO Eurocargo 12,000 kg	-14	-28	-0
MAN 30,000 kg	-9	-11	+3
Scania 30,000 kg	-10	-15	n.a.

**Table 3**  
Relative difference in emissions for the 3.5–40 tonnes trucks, 90 kph compared to 80 kph (maximum speed) and 86 to 77 kph (realistic speed) (macroscopic model results for average fleet composition in 2010 and 2020 respectively).

Policy	90 kph → 80kph		86 kph → 77 kph	
	2010 (%)	2020 (%)	2010 (%)	2020 (%)
<b>CO<sub>2</sub> (tonnes)</b>				
3.5–7.5	-14	-14	-14	-14
7.5–16	-14	-14	-11	-11
16–32	-8	-8	-5	-5
32–40	-9	-9	-6	-6
<b>Fleet average</b>	<b>-9</b>	<b>-9</b>	<b>-6</b>	<b>-6</b>
<b>NO<sub>x</sub> (tonnes)</b>				
3.5–7.5	-16	-16	-16	-16
7.5–16	-11	-11	-7	-7
16–32	-6	-6	-3	-3
32–40	+5	+5	+5	+5
<b>Fleet average</b>	<b>+2</b>	<b>+3</b>	<b>+3</b>	<b>+3</b>
<b>PM (tonnes)</b>				
3.5–7.5	-3	-3	-2	-3
7.5–16	+2	+2	+3	+2
16–32	-3	-2	-2	-2
32–40	+6	+6	+5	+6
<b>Fleet average</b>	<b>+4</b>	<b>+4</b>	<b>+4</b>	<b>+4</b>



is consistent for all trucks for which detailed engine data is available in the VeTESS model.

Results from the macroscopic approach describe the emissions of specific weight classes of trucks (not of individual vehicles) (Table 3). These results confirm the VeTESS results for CO<sub>2</sub>. In absolute numbers the CO<sub>2</sub> emission factors would on average drop by approximately 100 g km<sup>-1</sup> if the policy actually resulted in a decrease from 90 to 80 kph. Using more realistic estimates of the impact of the policy on real traffic speeds (i.e. a decrease from 86 to 77 kph) yields a reduction of only 50–70 g km<sup>-1</sup>. Emission factors of NO<sub>x</sub> show a decrease for all types of trucks available in VeTESS (Table 2). In sharp contrast the macroscopic model simulates increased emissions for the heaviest trucks (32–40 tonnes, +0.2 to +0.5 g km<sup>-1</sup>). The results for PM are inconsistent. According to the VeTESS model PM emissions either increase or decrease depending on the type of truck. The macroscopic results on the other hand show that PM emission factors decrease for the 3.5–7.5 and 16–32 tonnes weight classes and increase for the 7.5–16 and 32–40 tonnes weight classes.

#### 4. Discussion

The evaluation of speed reduction policies on vehicle emissions not only depends on the traffic situation (urban versus highway), but also on the methodological approach that is applied to simulate the impact of the traffic measure.

To assess the impact of a speed management policy in urban areas in this study, six widely different speed profiles were recorded in the town of Mol and the city of Barcelona. In the case of an extreme decrease in neither the urban speed limit, neither the naïve assumption that emissions will decrease nor the straightforward (but methodologically unjustified) application of the macroscopic Copert/MEET methodology seem to be correct. The variation in driving cycles (both town and city) makes the modelling exercise relevant for a wider range of towns/cities and will make the conclusions more robust.

Considering motorway speed reductions for trucks, we find that CO<sub>2</sub> emissions decrease but emissions of NO<sub>x</sub> and PM may increase, which is consistent with the results from other studies. Using other models and different fleets, similar results were obtained by HBEFA (2004) and IEA (2005). The COST 346 (2005) working group decided that policies implying a further speed reduction (below 80 kph) would not affect fuel consumption but would increase emissions of NO<sub>x</sub> and PM. We examined that further speed reductions below 80 kph indeed resulted in much higher emissions for some (but not all) trucks although the fuel consumption remained fairly stable. The large uncertainties in emissions estimated in these studies are due to uncertainty in relation to fleet composition and in difficulties deriving typical driving patterns (HBEFA, 2004; COST 346, 2005). The results from this study were presented to and discussed with stakeholders, several individual manufacturers and the ACEA expert group. From these discussions it is clear that they design and build long distance haulage trucks to minimize fuel consumption at the most prevailing speed limit in Europe (80 kph on motorways). The optimum design speed for heavy trucks is between 80 and 85 kph which confirms our findings. At higher speeds there is a trade-off between fuel consumption and travel time which are two conflicting economical considerations in the road haulage sector. Manufacturers confirm that fuel consumption is not perceived as an issue for lighter trucks where manoeuvrability and other qualities prevail but declined to comment on our estimates for the other emissions. However, discussing the economic aspects is beyond the scope of this study. The importance of traffic dynamics on the emission reduction on motorways was recently

emphasized in Keuken et al. (2010). They conclude that, the larger the ratio of traffic congestion prior and after implementation of speed management, the larger the obtained emission reduction.

Concerning the methodological approach that was applied to assess the impact of speed management policies, two different methods were examined, each approach with its own drawbacks.

For the macroscopic approach the well-known Copert/MEET methodology was applied in this study. Copert is based on average speed emission factors to estimate emissions on a macroscopic level. Copert uses functions that predominantly have a quadratic form, as a result of which emission estimates tend to be much higher at very low and very high speeds. However, as already mentioned, the speeds typical for urban 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 with this model.

The use of the detailed microscopic emission model VeTESS has the obvious disadvantage that the necessary engine and vehicle data is only available for a limited number of vehicles. For instance no data for vehicles with particle filters are available within the model. Nevertheless the detailed analysis of the behaviour of these specific vehicles' emissions is relevant for multiple reasons. First, the available data used for this study are from quite popular vehicles that represent analogous models from other brands in addition to vehicles with similar engines. Secondly, the engines and after treatment technology of these modern cars is a fair proxy to what may become the average fleet in the near future in many European countries as well as in the US and Japan. Thirdly, transient effects are taken into account. This being said, there are some important aspects which we have not taken into account. Firstly, a weakness in the microscopic VeTESS model is the failure to consider cold starts that will typically be important in urban traffic. It is not clear how the consideration of cold starts will influence the impact of speed limit reduction on emissions. Further, we have not made any changes to the acceleration and deceleration behaviour in the selected driving cycles. This is an implicit assumption that needs to be validated. Theoretically, this problem can be circumvented by using microscopic traffic simulation models generating instantaneous speed estimates (and hence also acceleration) for individual vehicles. Unfortunately, detailed as the traffic models may seem at first glance, the acceleration estimates are largely based on very rough estimates that have never been validated (Journard, pers. comm., 2005; Int Panis et al., 2006). Finally, the choice of gears is one of the characteristics of a driving pattern that is likely to be influenced by changes to the speed limit. Driving behaviour (other than the choice of speed) also has an effect on PM emissions (De Vlieger et al., 2000). Although this may be more important in urban locations than on motorways, the VeTESS model was used to study the effect of different gear shifting strategies in connection with different speed limits. Our conclusions were confirmed for any gear shifting strategy and for any speed reduction down to 80 kph.

Regarding the application of the presented results to other, non-European, regions such as Japan and the US, the following remarks can be made. Both VeTESS and Copert are models that were built on emission measurements for European cars and equipped with engines that comply with European emission standards. These standards have, however, been adopted by other countries and regions outside Europe (e.g. the Indian Bharat standards). From our results we cannot be sure that results for e.g. US built cars would be exactly the same. However, engine technologies (diesel and petrol with advanced after treatment) are sufficiently similar in Europe and other regions to assume that similar speed management policies in Japan or the US would have similar effects on emissions. The main conclusion "that evaluations of speed management policies should not rely on a macroscopic approach only" is therefore robust and valid beyond Europe.

## 5. Conclusions

The results of this paper demonstrate that it is unlikely that strict speed limits in urban environments will have a significant influence on the emissions of NO<sub>x</sub> or CO<sub>2</sub>. Regarding the impact on emissions of PM the microscopic results indicate that the exhaust from the diesel vehicles may show a significant decrease, whereas the macroscopic approach assumes a moderate increase. Considering these results, policy makers should cautiously interpret emission modelling results that estimate the impact of speed reduction policies on emissions in urban areas. Changing speed limits in urban environments should mainly be considered from a safety perspective. The impact on the environment should not be the deciding factor to tip the balance between implementing and not implementing lower speed limits.

Further, lower interurban speed limits are often portrayed as being good for the environment but bad for the economy. Our analysis of changing speed limits for trucks from 90 to 80 kph generally confirmed the environmental benefit. All results for trucks consistently indicate that lower maximum speeds for trucks on motorways result in lower emissions of CO<sub>2</sub>. Results for NO<sub>x</sub> and PM are not consistent. The impact on the economy and traffic safety was not discussed.

The results presented in this paper demonstrate that estimating the impact of speed limit reductions on emissions from vehicles is a complex endeavour. Estimating the impact of policies on emissions and air quality is even more difficult (Int Panis et al., 2006; Beckx et al., 2009), an inconvenience that is often overlooked but crucial in deciding on environmental transport policies. More and more environmental policy makers nowadays rely on computer models to test traffic policies. The results in this paper illustrate the scientific uncertainties that policy makers face when considering the implementation of speed management policies and demonstrate that evaluations of speed management policies should not exclusively rely on a macroscopic assessment.

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## References

- Ajtay, D., Weilenmann, M., 2004. Static and dynamic instantaneous emission modelling. *International Journal of Environment and Pollution* 22 (3), 226–239.

- Anderson, R., McLean, A., Farmer, M., Lee, B., Brooks, C., 1997. Vehicle travel speeds and the incidence of fatal pedestrian crashes. *Accident Analysis & Prevention* 29 (5), 667–674.
- Beevers, S.D., Carslaw, D.C., 2005. The impact of congestion charging on vehicle speed and its implications for assessing vehicle emissions. *Atmospheric Environment* 39, 6875–6884.
- Beckx, C., Arentze, T., Int Panis, L., Janssens, D., Vankerom, J., Wets, G., 2009. An integrated activity-based modelling framework to assess vehicle emissions: approach and application. *Environment and Planning B: Planning and Design* 36 (6), 1086–1102.
- Beckx, C., Int Panis, L., Janssens, D., Wets, G., 2010. Applying activity-travel data for the assessment of vehicle exhaust emissions: application of a GPS-enhanced data collection tool. *Transportation Research Part D* 15, 117–122.
- Beusen, B., Broekx, S., Denys, T., Beckx, C., Degraeuwe, B., Torfs, R., Int Panis, L., 2009. Using on-board logging devices to study the longer-term impact of an eco-driving course. *Transportation Research Part D* 14, 514–520.
- Chen, K., Yu, L., 2007. Microscopic traffic-emission simulation and case study for evaluation of traffic control strategies. *Journal of Transportation Systems Engineering and Information Technology* 7 (1), 93–99.
- COST 346, 2005. Emission and fuel consumption from heavy duty vehicles. Final Report, 2005. Available from: <[http://www.transport-research.info/Upload/Documents/200906/20090619\\_171904\\_26922\\_II\\_COST346\\_WGA\\_FinalReport.pdf](http://www.transport-research.info/Upload/Documents/200906/20090619_171904_26922_II_COST346_WGA_FinalReport.pdf)>.
- De Vlieger, I., De Keukeleere, D., Kretzschmar, J., 2000. Environmental effects of driving behaviour and congestion related to passenger cars. *Atmospheric Environment* 34 (27), 4649–4655.
- Dijkema, M., van der Zee, S., Brunekreef, B., van Strien, R., 2008. Air quality effects of an urban highway speed limit reduction. *Atmospheric Environment* 42 (40), 9098–9105.
- HBEFA, 2004. Infrast handbook emission factors for road transport. Version 2.1, Vienna 2004.
- IEA, 2005. Saving oil in a hurry. OECD/IEA, ISBN 92-64-109414.
- Int Panis, L., Broekx, S., Liu, R., 2006. Modelling instantaneous traffic emission and the influence of traffic speed limits. *Science of the Total Environment* 371 (1–3), 270–285.
- Int Panis, L., de Geus, B., Vandenbulcke, G., Willems, H., Degraeuwe, B., Bleux, N., Mishra, V., Thomas, I., Meeusen, R., 2010. Exposure to particulate matter in traffic: a comparison of cyclists and car passengers. *Atmospheric Environment*, doi:10.1016/j.atmosenv.2010.04.028 available on-line.
- Joumard, R., 1987. Influence of speed limits on road and motorway on pollutant emissions. *Science of the Total Environment* 59 (1987), 87–96.
- Keller, J., Andreani-Aksoyoglu, S., Tinguely, M., Flemming, J., Heldstab, J., Keller, M., Zbinden, R., Prevot, A.S.H., 2008. The impact of reducing the maximum speed limit on motorways in Switzerland to 80 km h<sup>-1</sup> on emissions and peak ozone. *Environmental Modelling and Software* 23 (3), 322–332.
- Kelly, J.A., Ryan, L., Casey, E., O'Riordan, N., 2009. Profiling road transport activity: Emissions from 2000 to 2005 in Ireland using national car test data. *Transport Policy* 16, 183–196.
- Keuken, M.P., Jonkers, S., Wilmink, I.R., Wesseling, J., 2010. Reduced NO<sub>x</sub> and PM<sub>10</sub> emissions on urban motorways in The Netherlands by 80 km/h speed management. *Science of the Total Environment* 408, 2517–2526.
- Ntziachristos, Z., 2009. Copert – general information website. Available from: <<http://lat.eng.auth.gr/copert/>>.
- Pelkmans, L., Debal, P., Hood, T., Hauser, G., Delgado, M.R., 2004. Development of a simulation tool to calculate fuel consumption and emissions of vehicles operating in dynamic conditions. SAE 2004 Spring Fuels and Lubricants, SAE Int., Warrendale, PA, USA, 2004-01(1873).
- Pelkmans, L., Verhaeven, E., Spleesters, G., Kumra, S., Schaerf, A., 2005. Simulations of fuel consumption and emissions in typical traffic circumstances, SAE 2005. Brazil Fuels and Lubricants Meeting and Exhibition, 2005-01-2159.
- Silva, C.M., Farias, T.L., Frey, H.C., Roupail, N.M., 2006. Evaluation of numerical models for simulation of real-world hot-stabilized fuel consumption and emissions of gasoline light-duty vehicles. *Transportation Research Part D: Transport and Environment* 11 (5), 377–385.