Estimating PM-emission reductions from speed management policies

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Abstract

Speed reduction measures have become an increasingly popular way to increase traffic safety especially in urban areas. Recently many cities have converted entire districts into 30 km/h zones. In many European countries the maximum speed of haulage trucks is under discussion or review sometimes in combination with a ban on overtaking. Reducing the maximum speed is perceived and promoted by policy makers as beneficial to the environment because of reduced fuel consumption and lower emissions.

These claims however have not been scientifically validated. They stem from the popular believe that the widely used Copert-approach, which is scientifically valid for average trip speeds, can be used to assess the environmental impact of speed management policies at a local scale. It is obvious that speed reductions in urban areas or on highways may have very different effects on PM emissions. On the other hand the simplistic idea that speed reductions increase urban emissions and decrease emissions on highways is probably wrong. Although few experts would make this assumption explicitly, it is very frequently made implicitly by the way that traffic and emission models are integrated. Integrating macroscopic traffic models with emission functions based on average speed only is clearly unsatisfactory. In addition, the lack of such functions for the PM emissions of petrol fuelled cars is an important problem even with advanced models such as VeTESS.

In this paper we study the problem of accurately estimating the effects of speed managements policies on exhaust emissions of PM. Emissions for specific types of vehicles were calculated with the microscopic VeTESS-tool using real-life driving cycles and compared with results obtained using Copert-like methodologies.

Our results indicate that emissions of most pollutants should not be expected to rise or fall dramatically. Nevertheless the conclusion for emissions of PM could be different. The effects of specific speed reduction schemes on PM emissions from trucks are ambiguous, but VeTESS results indicate that the PM exhaust from diesel passenger cars shows a significant decrease in urban areas converted to 30 km/h zones. Exposure of residents to one of the most toxic components of the urban air pollution mixture may therefore also decrease.

Unfortunately linking microscopic emission and traffic models raises other concerns such as a lack of validation of the most prominent parameters: acceleration and gear change behaviour.

Keywords
Speed management policy, PM-emissions, Traffic, Modelling

Introduction
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 is 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, 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. 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., 2006). 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.

In June 2005 the Flemish transport Minister proposed to lower the maximum speed for trucks on highways from 90 to 80 km/h. This resulted in an enormous wave of critique from various stakeholders. Reference was made to time losses, economic losses and serious doubts were cast over the assumed environmental and safety benefits. Unfortunately most of the discussion was on the basis of ideology and prejudice. Scientific analysis was either ignored or was unavailable for use in the discussion at that time (De Vlieger et. al, 2005).

We suggest that more sophisticated methods are needed to estimate the impact of speed management policies on the emissions of PM.

Methods
Description of the VeTESS model
VeTESS (Vehicle Transient Emissions Simulation Software) was developed within the European project Decade as a vehicle level tool for the simulation of fuel consumption and emissions for real traffic transient vehicle operation (Pelkmans et al, 2004). It is specifically designed to calculate dynamic emissions, and thereby reaching higher accuracy than traditional emission simulation models including those using steady state engine maps. We used this model to calculate emissions and fuel consumption on a second-by-second basis for specific vehicles on a given speed profile. The calculations in this vehicle simulation tool are based on a detailed calculation of the engine power required

to drive a given vehicle over any particular route. This includes the rapidly changing (transient) demands placed on the engine.

Description of the driving cycles

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 where appropriate to preserve the original cycle distance. Figure 1 shows an example comparison between one of the original driving cycles and the derived cycle.

Table 1 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 1 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.

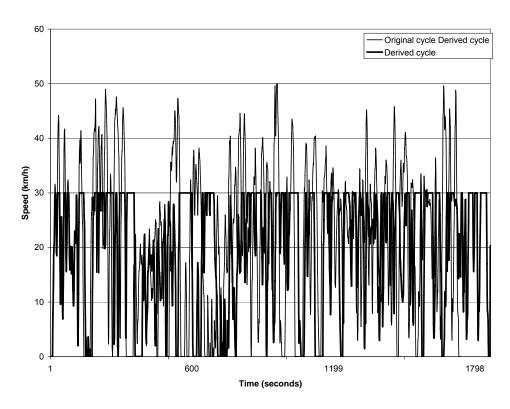| Cycle N°	Length		Stops	Max a	Max -a	Avg v	Additional length	New avg v
	(s)	(km)		m/s.s	-m/s.s	km/h	(s)	km/h
1	1615	6.6	22	7.8	10.2	14.8	107	13.9
2	1765	7.1	27	7.8	10.5	14.5	72	13.9
3	1475	7.3	22	9.4	15.4	17.8	173	15.9
4	1497	10.5	16	8.3	11.3	25.2	163	22.7
5	2003	10.5	22	6.7	8.8	18.9	68	18.3
6	1735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

Figure 1: Example showing the conversion of cycle 6 to a cycle with limited top speed

Results
Zone 30 km/h introduction in urban areas
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 2. 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; Pelkmans, pers. comm., 2005.) 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. Emissions decreased for both cars, but increased for the LGV. For the emissions of NO_x the LGV mostly showed a small increase whereas the results for the cars indicate moderate to important decreases of the emission. Both diesel vehicles (Octavia and Jumper) showed a moderate or large decrease in the modeled emissions of PM in each of the cycles. No PM emissions can be modeled with VeTESS for petrol fueled vehicles (i.e the VW Polo).
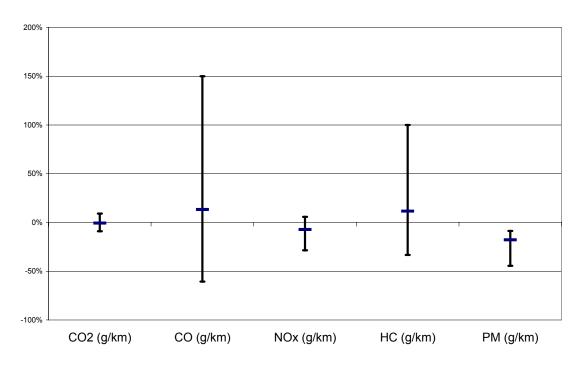
Figure 2 Estimated relative change in emission for 5 pollutants. Average and range for 18 estimates.

In Figure 3 we present the detailed results for the Skoda Octavia for one representative cycle in each city. The emissions estimates were made with the relevant MEET functions based on average trip speed and with VeTESS on the full speed profile respectively. Results for most other vehicle/cycle combinations yield similar results. Not surprisingly, the MEET methodology results in a slightly higher estimate for the emissions. The small difference can be attributed to the fact that although the derived driving cycle may seem quite extreme (e.g. Figure 1) the resulting change in average speed is quite limited (Table 1). The results from the VeTESS model runs are less straightforward to interpret or explain because a large number of factors contribute and interact. Nevertheless 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 1). 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.

In Figure 4 we present some detailed results for the light delivery van. In this case the result of detailed emission modeling agrees well with the simpler MEET calculation for CO_2 emissions. Both fuel consumption and CO_2 emissions are projected to increase slightly (~3-5%). Results for NO_x emissions are mixed because the small increase evident from the MEET functions is not reproduced by VeTESS which indicates insignificant changes. For the PM emissions, this vehicle would show an important decrease (although smaller than for the passenger cars) under the speed-limited driving cycle.
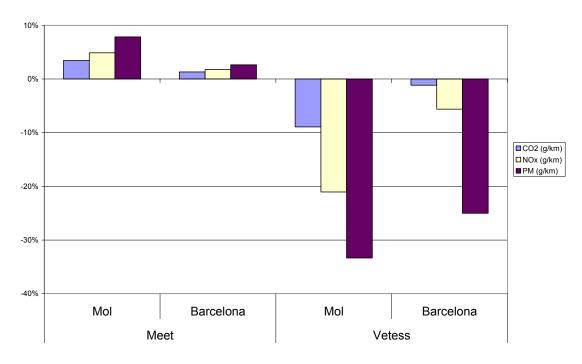
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Figure 3 Relative change between two normal urban drive cycles (up to 50km/h) and drive cycles limited at 30 km/h (Skoda Octavia; Cycle 4: 25.2->22.7 km/h in Mol, Cycle 1: 14.8->13.9 km/h in Barcelona
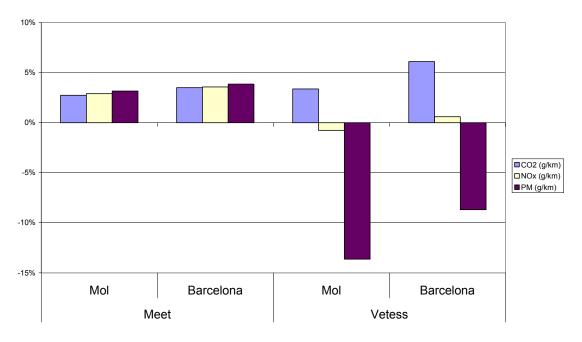

Figure 4 Relative change in emissions between two urban driving cycles and a derived cycle limited at 30 km/h (Citroen Jumper Van; Cycle 5: 18.9 -> 18.3 km/h in Mol, Cycle 2: 14.5 ->13.9 km/h in Barcelona)

80 km/h speed limit for haulage trucks on highways

In this section we discuss the relative emissions when speed limits for lorries are decreased from 90 to 80 km/h. The total CO_2 emission is projected to decrease by 5 to 10 % and this trend is consistent for all trucks studied (Table 2).

We compare these results with the estimates from TEMAT (the Belgian standard, Copert-based emission model). TEMAT confirms the results of the detailed vehicle based modelling (VeTESS) which makes the results more credible.

In absolute numbers the CO_2 emission factors would on average drop by approximately 100 g/km if the policy resulted in a decrease from 90 to 80 km/h. Using more realistic estimates of the impact of the policy on real traffic speeds yields a reduction of only 50 to 70 grams/km.

For exhaust emissions of PM, TEMAT predicts an increase in the fleet average emissions with 3-4%. The detailed results for PM are however very confusing (Figure 5). 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. All changes (increases and decreases) become smaller in the future. Because of the dominance of the largest trucks the fleet average emission factor also increases**.**

Table 2. Relative emissions for different speed reductions (VeTESS results)

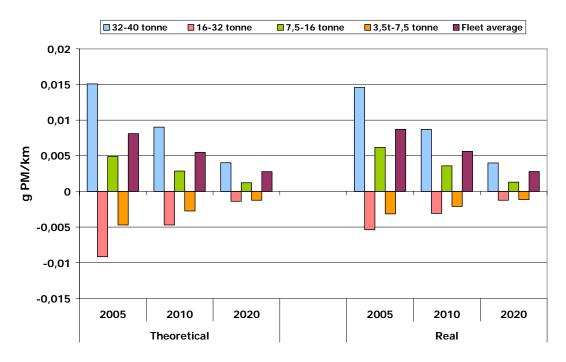|	CO_2	NO_X	PM
Scenario: 90 km/h to 80 km/h			
IVECO Eurocargo 7500 kg	84%	71%	84%
IVECO Eurocargo 12,000 kg	86%	72%	100%
MAN 30,000 kg	91%	89%	103%
Scania 30,000 kg	90%	85%	n.a.
Scenario 2: 100 km h^{-1}→ 90 km h^{-1}			
IVECO Eurocargo 7500 kg	73%	85%	71%
IVECO Eurocargo 12,000 kg	80%	88%	67%

Figure 5 Absolute difference in the PM fleet emission factors for the 3.5-32 tonne trucks, 90 km h^{-1} compared to 80 km h^{-1} (TEMAT)

A high R^2 was reported in MEET for this emission function, indicating it was based on a small sample. The lack of consistency between the effects for the different classes indicates a large amount of uncertainty.

Detailed modelling of the engine and vehicle characteristics with VeTESS provides us with an additional set of results. Emissions of NO_x are expected to decrease for the selected vehicles while only one vehicle showed a very small increase in PM emissions.

Trucks below 12 tonnes are currently the only class that can drive faster than 90 km/h. Policy options for these vehicles include the installation of mandatory speed limiters like those used on all heavier trucks at this moment or reducing their speed even further to 80 km/h similar to the proposed policy for heavier trucks. In the results presented in Table 3 we see that there is a difference between both weight classes. The PM emissions for the smallest category (3.5 - 7.5 tonnes) would decrease by 3 to 9 % but trucks in the 7.5-16 tonnes class could see their PM emissions increase by up to 5%.

Table 3 Relative PM-emissions for lighter truck categories (TEMAT results)

	Maximum speeds			Real speeds		
Scenario 100 to 80 km/h	2005	2010	2020	2005	2010	2020
3.5-7.5 tonnes	91%	91%	91%	92%	93%	93%
7.5-16 tonnes	103%	103%	102%	104%	104%	105%

Discussion

The emission modeling and results presented in this paper demonstrate that estimating emissions, even of classical pollutants, from vehicles is a complex endeavor. Estimating the impact of policies on emissions proves to be even more difficult (e.g. Cornelis et al, 2005, Int Panis et al, 2005). In the case of a severe decrease of the urban speed limit, neither the naïve assumption that emissions will decrease nor the straightforward (but methodologically unjustified) application of the MEET methodology seem to be correct. We have tried to shed some light on this problem by applying a very detailed model that can take changes in the speed pattern into account because it models the entire drive train including transient effects in the engine. The obvious disadvantage is that the necessary engine and vehicle data for the model is only available for a limited number of vehicles and it is not feasible to apply this model to look for changes in emissions at the macroscopic emission inventory level. Nevertheless the detailed analysis of the behaviour of these vehicles emissions' is relevant for two reasons. First the available data used for this study are from quite popular vehicles that represent analogues models from other brands as well as other cars 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. This is clearly more relevant to the study of policies than the ability to accurately model older model years.

This being said, there are some important aspects which we have not taken into account and that could potentially invalidate our results and conclusions. Firstly we have not made any changes to the acceleration and deceleration of the driving cycles. This is an implicit assumption that needs to be validated because changes in driving style (e.g. between individual drivers) have a major impact on emissions (De Vlieger et al, 2000). It is generally assumed that reducing the speed limit will also lead to a less dynamic driving style and a more fluent traffic flow. On the other hand it is not unlikely that very low speed limits such as those discussed here irritate people who then try to make up for the time lost by accelerating faster (although they may also simply not obey the speed limit). In cases where the speed limit is imposed by a device in the cars (e.g. ISA) is was shown that some drivers accelerated faster up to the speed limit (Vlassenroot et al., 2006). Unfortunately we cannot take this into account in this study because detailed (i.e. measured) data are currently lacking. A large scale monitoring programme will start later in 2006 (Broekx, pers. comm., 2006). Theoretically this problem can be circumvented by using microscopic traffic simulation models that generate instantaneous speed estimates (and hence also acceleration) for individual vehicles. Unfortunately detailed as the models may seem at first glance the acceleration estimates are largely based on very rough estimates of vehicle performance and driver behaviour. More importantly, the results of such model studies are, if conducted properly, validated against counted vehicle flows and measured speeds. The results for acceleration however are never validated. It would therefore be questionable to use them as a basis for any emission estimates (Joumard, pers. comm., 2005). In addition several authors have found

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it very difficult or impossible to include acceleration (as the most straightforward variable that describes dynamics) as an input variable for Copert-like emission functions. For example the results of multiple non-linear regression techniques (e.g. Int Panis et al., 2006) are rather disappointing. From this point of view the methods used in this study are certainly justified.

Other types of models may be used to study some other consequences of the zone 30 introduction such as the avoidance of the area by transit traffic or the shift to slow modes by local residents (e.g. the class of "Activity-Based" models; e.g. Beckx et al, 2005, 2006a). But these considerations are far beyond the scope of the study presented in this paper.

One of the most conspicuous differences in driving behaviour, because it is not a continuous variable, is gear shifting behaviour. The decision to shift up or down depends on a combination of technical factors specific to the vehicle (gear ratio, torque, …) and personal preferences. In this study we have used the default values for each car provided within the VeTESS-tool. It is however possible that imposing a speed limit influences the gear shifting behaviour. Unfortunately, again no data are available to account for this. In a follow-up study different gear shifting strategies (e.g. gentle, aggressive,…) will be used in a sensitivity analysis. In cases where the speed limit is very close to the point where most people shift e.g. between second and third gear, this may have a significant effect on the emissions (Beckx et al, 2006b).

The finding that PM emissions of trucks could increase following speed reductions on motorways is consistent with the results from other studies (HBEFA 2004, IEA 2005). The COST 346 working group decided that a further speed reduction (below 80km/h) would not improve fuel consumption but would increase PM emissions. The large uncertainties are blamed on the fleet composition and on difficulties to derive a typical driving pattern. The choice of gear features among the most prominent changes to the driving pattern and is likely to be influenced by changes to the speed limit. Although this may be more important in urban locations than on highways. The VeTESS model was therefore 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 for any speed reduction down to 80 km/h although there seems to be some variation in the magnitude of the effect. Further speed reductions below 80 km/h resulted in much higher emissions for some (but not all) trucks although the fuel consumption remained fairly stable.

Although the measures discussed are deemed important to reduce accidents, it is unlikely that they will have a significant effect on emissions at a regional or national level. The number of vehicle kilometers affected is likely to be very small. In addition the sign of the changes for most pollutants is not clear from our modeling. Nevertheless it cannot be ruled out that the effect on exposure to PM is important. Our (very limited) set of estimates point to a consistent decrease in PM emissions. Increased concentrations of PM and especially those emitted by

road transport have often been blamed to be the cause of adverse health effects. Some epidemiological studies have found significant relationships between health effects and peoples proximity to important sources of traffic related air pollution. There is a growing consensus that the link between health effects and PM concentrations may be causal. Any decrease of PM emissions, concentrated in urban areas with poor mixing (e.g. street canyons) and high densities of people should therefore be considered an important benefit.

Finally we would like to draw the readers attention to the fact that this paper only refers to exhaust emissions of PM. PM emissions from the wearing of tyres, brakes and road surfaces or the re-suspension of road dust were not considered. It is likely that speed is a factor that influences these emissions, but today no functions exist that are accurate enough to complement the exhaust modeling discussed in this paper.

Conclusions

It is unlikely that imposing strict speed limits in urban areas has a significant influence on emissions of NO_x or CO_2. Concerning the impact on emissions of PM VeTESS results indicate that the exhaust from the diesel vehicles may show a significant decrease, whereas MEET functions assume a moderate increase. The effect on emissions of PM should be confirmed by further research, also focusing on the impact of acceleration or gear shifting behaviour.

All results for trucks consistently indicate that a lower maximum speed on motorways result in lower emissions of CO_2. Results PM are not consistent and uncertain but probably too small to offset the clear benefits of the CO2 reduction.

Acknowledgement

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