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Emissions at different conditions of traffic flow

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Abstract

Although it is widely assumed that congestion causes an increase in exhaust gas emissions, it has always been difficult to quantify this relationship. The project Emissions and Congestion investigated this relationship by simultaneously measuring traffic conditions and emissions. Emission factors were derived for different traffic conditions on motorways, ranging from free flow to heavy congestion.

The results clearly indicate that there are significant differences in emissions and fuel consumption for different types of traffic flow. Heavy traffic dynamics, shortcut traffic, heavy congestion and high speeds lead to significant increases of regulated emissions and fuel consumption of motorway traffic.

Efforts to reduce congestion and traffic dynamics (by traffic management measures) should be concentrated on specific routes or sections with frequent occurrence of heavy congestion and a large share of heavy duty traffic. These are the motorways in the conurbations. Tens of percents of reduction in emissions are possible. The resulting improvements on local air quality can be significant.

Lowering the speed limit to 100 km/h on all sections of Dutch motorways can significantly improve emission levels (most of Dutch motorways have a speed limit of 120 km/h).

1 Why a study of emissions at different conditions?

Last year (2000) the number of Dutch traffic jams increased with another 1000 to the number of 30.000. During peak hours traffic jams are common on major roads, especially in the Dutch conurbation of the Randstad (western part of the

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Netherlands). Several traffic management measures like peaklanes (use of the hard shoulder), controlled access and dynamic route information panels, have been introduced over the last years, to reduce delays. Despite more intensive use of the existing infrastructure, pricing policy and expansion of infrastructure, congestion will be a common phenomenon in the future as well. Before we started the study there were various opinions about the effects of congestion on exhaust gas emissions and fuel consumption of road vehicles. It was unknown what the effects of congestion and traffic management measures could be on total traffic emissions and what the effects could be on the air quality along motorways. In the Netherlands, we have problems with the air quality targets established in the Framework Directive on Ambient Air Quality at different places along the Dutch motorways in the conurbation of the Randstad. The gaps in knowledge about emissions and congestion were the reason for the Dutch Ministry of Transport, Public Works and Water Management and the Ministry of Housing, Spatial Planning and the Environment to commission TNO for a study about the effects of different conditions of traffic flow on exhaust gas emissions and fuel consumption, by measuring emissions related to real world driving in less or more congested situations.

This paper presents the results of the study. The paper is structured as follows: In the next section we focus on the set up of the study (2). In the third section the emission factors and the share of each congestion category in the mileage is shown (3). In the fourth and fifth section we will go into the effects of congestion on the local (4) and the national emissions (5). Furthermore we will explore some policy suggestions (6) and desirable follow-up-research (7). Finally we summarise the main conclusions (8).

2 How did we set up the study?

The study consisted of two main elements:

- Deriving emission factors for different real world traffic conditions on motorways, ranging from free flow to heavy congestion.
- Calculation of the effects of congestion and the effects of traffic management measures for specific road sections in the conurbation of the Randstad and for the entire motorway network of the Netherlands.

2.1 Test phase

In the first stage of the project, two instrumented cars made a test drive on congested motorways in the conurbation of Western Holland, recording speed, time and traffic conditions. At the same time, tail pipe emissions were measured with on board equipment for purpose of determining the possible differences between measuring directly on the road and measuring in a laboratory. In the laboratory the emissions were measured again while projecting the recorded time/speed pattern of the test drives on a chassis dynamometer. In the laboratory measurements were made simultaneously by the lab measurement equipment and

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by the in-car-system, in order to be able to differentiate effects caused by the measurement equipment and those caused by driving on a chassis dynamometer.

In order to find a useful categorisation of congestion types on motorways, the data collected during the test drives were analysed. The final categorisation in 10 congestion types is mainly based on average speed and traffic volumes.

Furthermore the traffic profile of the test drive has been compared to the traffic profile derived from traffic data available from loop detectors in the road surface. Today, many Dutch motorways, especially those in the conurbations have induction loops in the road surface at regular intervals, measuring average speed and traffic volumes every minute (the Monica-system). The profiles of the test drive were compared to the data from the loops and matched quite well. It was therefore decided that the traffic data from loop detectors could be used to represent traffic conditions.

2.2 Determination of emission factors

In the second stage of the project 30 trips were made with an instrumented car (driven by 5 different drivers) in morning and afternoon peak hours, in order to collect statistical relevant speed/time patterns of travelling on Dutch highways. The trips were about 60 km long and all situated in the highly congested conurbation of the Randstad. The trips comprises all types of traffic situations form highly congested up to high speed free flow. After statistical compression of the speed/time patterns into 10 trips (one per congestion type), actual emission factors where established by measuring emissions of 20 different passenger cars driving these trips. The relative emission results per congestion type were combined with a huge amount of emission data available from the Dutch "In Use Compliance programme" resulting in emission factors for the average Dutch car. Using this set up, emission factors for CO_2, NO_x, CO, HC and PM_{10} were determined for each category of motorway traffic (and one for secondary roads). For heavy-duty traffic a different approach was used. A previously determined set of factors was adapted to the traffic categorisation used in this study.

2.3 The calculation of congestion effects

In the third stage of the project, a method was developed to calculate the total emissions on specific *road sections* or routes in the conurbation of Western Holland and on the *entire national motorway network*. Data from the Monica-system and data from a traffic counting monitoring system (Inweva) formed the basis for the calculation of the travelled kilometres by passenger cars and trucks in each congestion category.

The emissions calculated for the actual situation for road sections and for the entire motorway network were compared to the emissions that would occur in other situations: with less or more congestion, with a speed limit of 100 km/h and, if back roads were used, for parts of the trip.

More about the study set up can be found in (Gense [1]).

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3 Congestion categories and emission factors

3.1 Real world driving emission factors

The first two columns of table 1 shows the description of the motorway congestion categorisation as decided on and used in this study. Ranging from heavy traffic congestion to high-speed free flow. Also included is a category for traffic on secondary roads (3). With this factor, the effect of drivers avoiding congested motorways by using back roads could also be taken into account.

Traffic category		CO	HC	NO_x	CO_2	PM_{10}
1 a a	Stop-and-go' traffic, speed below 10 km/h	5.51	0.93	0.63	370	0.06
1 a	Stop-and-go' traffic, speed between 0 en 25 km/h	2.84	0.60	0.50	239	0.05
1 b	Congested traffic, speed between 25 and 40 km/h	1.71	0.43	0.48	178	0.04
1 c	Congested traffic, speed between 40 and 75 km/h	1.15	0.23	0.47	153	0.04
2 a	Speed 75-120 km/h, traffic volume over 1000 vehicles per lane per hour, speed limit = 100 km/h	1.13	0.14	0.49	146	0.03
2 b	Speed 75-120 km/h, traffic volume over 1000 vehicles per lane per hour, speed limit = 120 km/h	1.20	0.14	0.57	157	0.04
2 c	Speed 75-120 km/h, traffic volume below 1000 vehicles per lane per hour, speed limit = 100 km/h	0.90	0.11	0.47	146	0.03
2 d	Speed 75-120 km/h, traffic volume below 1000 vehicles per lane per hour, speed limit	1.17	0.12	0.66	173	0.04
2 e	Speed over 120 km/h, independent of traffic volume	3.42	0.16	0.98	208	0.18
3	Shortcut/back road	2.42	0.19	0.49	177	0.12

Table 1: Emission factors per congestion categorisation for passenger cars

Table 1 shows the emission factors that were found for passenger cars for the different congestion categories. In general driving in the congestion categories 1a and 1 b (= stop and go and speeds < 40 km/h), back road driving (categorie 3) and high-speed-driving (> 100/120) causes significant increases of emissions and fuel consumption. For example driving in category 1a (stop and go traffic, average speed < 25 km/h) gives almost twice the amount of CO_2 compared to the categories 2a/2c (average speed 75-100 km/h). Even driving in congestion with an average speed between 25 and 40 km/h gives an increase of about 20% CO_2.

There are different patterns for the different pollutants. But only NO_x emissions is influenced more by average speed rather than by a combination of

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speed and driving dynamics. Emissions from driving on a back road is rather comparable to motorway congestion (category 1b), except for PM_{10} emissions, which are quite high on backroads.

Table 2 shows the emission factors for trucks that were derived from previous research. Congestion situations and back road driving doubles the NO_x and PM_{10} emissions, whereas CO_2 increases with about one third.

Traffic category		CO	HC	NO_x	CO_2	PM_{10}
1aa	'Stop-and-go' traffic, speed below 10 km/h	4.36	0.93	0.63	370	0.06
1a	'Stop-and-go' traffic, speed between 0 en 25 km/h	4.32	1.50	12.65	824	0.45
1b	Congested traffic, speed between 25 and 40 km/h	4.31	1.50	12.60	814	0.44
1c	Congested traffic, speed between 40 and 75 km/h	4.31	1.50	12.58	809	0.43
2a	Speed 75-120 km/h, traffic volume > 1000 vehicles per lane per/h, speed limit 100 km/h	1.45	0.46	6.53	614	0.22
2b	Speed 75-120 km/h, traffic volume > 1000 vehicles per lane/h, speed limit 120 km/h	1.45	0.46	6.55	617	0.22
2c	Speed 75-120 km/h, traffic volume < 1000 vehicles per lane/h, speed limit 100 km/h	1.26	0.42	6.23	568	0.20
2d	Speed 75-120 km/h, traffic volume <1000 vehicles per lane/h, speed limit	1.27	0.42	6.27	576	0.21
2e	Speed over 120 km/h, independent of traffic volume	1.29	0.42	6.34	589	0.21
3	Shortcut/back road	4.32	1.50	12.61	815	0.44

Table 2: Emission factors per congestion category for trucks and big vans

3.2 Emissions dominated by trucks and old cars

It must be mentioned that trucks and cars without a catalytic converter heavily put their mark on the total emission levels. It is noteworthy that truck emissions are significantly higher per vehicle kilometer than the emissions of passenger cars. Especially the CO_2, NO_x en PM_{10} emissions are dominated by trucks. NO_x emissions per kilometer are 10 to 20 times higher than for the average passenger car, depending on the congestion category.

Another remarkable point is domination of the absolute level of emission factors for passenger cars by cars without a catalytic converter. Even though their contribution to the annual Dutch mileage is only 20% and their contribution to the mileage on the motorways is only about 10%. (The emission factors from each class of technology is weighted using the share in yearly kilometers driven

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on the Dutch motorways.) This is caused by the fact that absolute emissions of these cars are 10 to 30 times higher than those of cars equipped with a 3-way catalyst.

3.3 Share of mileage per congestion category

After establishment of these emissionfactors total emissions were calculated for (I) specific segments of the Dutch motorways in the conurbation of the Randstad and (II) the entire Dutch motorway network. Figure 1 shows the division over congestion categories (1a-c) as found in the different analyses carried out in the study. The first column shows the congestion categories as recorded by the test vehicles, during the 30 trips in the conurbation of the Randstad. For selected *parts* of these routes, data has been collected regarding all traffic on these routes, for the periods when the vehicle was present. These division over the categories is shown in the second column. The third column shows the division when the average day (24 hours) on the entire Dutch motorway network is considered.

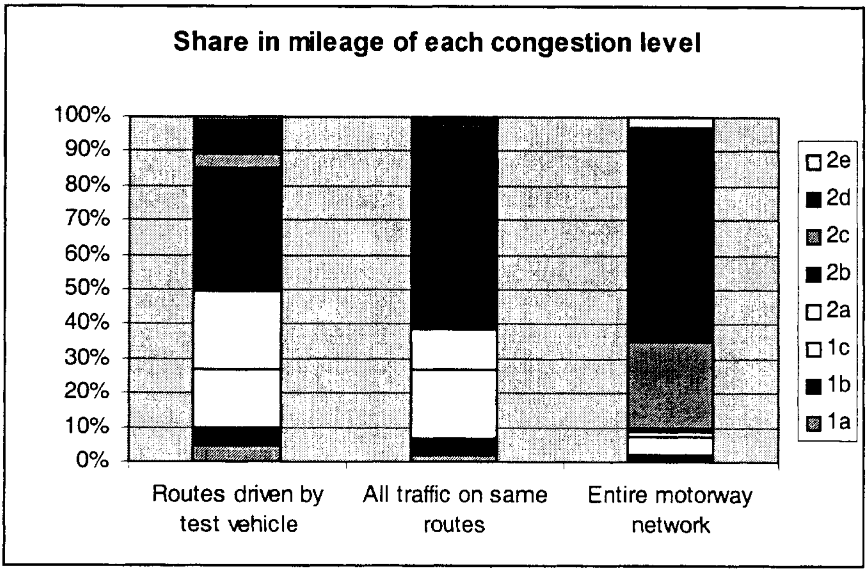

Figure 1: Share in mileage per congestion level

The share of congested traffic in the total mileage in the conurbation of the Randstad during the peakhours is much lager than when the entire motorway network and the entire day is regarded. In contrast to the situation in the Randstad during peakhours, most traffic on the entire motorway network actually drives under good conditions, given the high shares of categories 2c and 2d.

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4 Improvement of ambient air quality

4.1 Effects on section level

From the analyses TNO made by considering sections (of several kilometres long) of the network of the Randstad it can be concluded that solving congestion leads to significant reduction in the local exhaust gas emissions. This holds true especially on specific routes or sections with high amounts of heavy congestion and a high share of heavy duty traffic. Like solving congestion, increasing congestion can effect the ambient air quality as well. In case of an ambient air quality bottleneck along the motorway A13 in Rotterdam it was calculated that a reduction of 20% NO_x and PM_{10} is possible by reducing traffic dynamics and speed limit enforcement. Of course we have to be conscious of the fact that the local traffic is only one of the sources that influences the ambient air quality. In addition we have to keep in mind that congestion isn't a 24 hour a day problem.

Table 3 gives a further impression of the order of emission changes caused by reducing or increasing congestion. It must be mentioned that the calculations do not take into account the effect of changes in congestion on traffic demand. The number of kilometres travelled is kept constant throughout the calculations.

Table 3: Effects of more or less congestion, on selected motorway sections

	CO	*VOC*	*NO_x*	*CO_2*	*PM_{10}*
Less congestion					
Least congested route	-7.9%	-21.3%	-10.3%	-3.4%	-10.8%
Most congested route	-21.3%	-44.1%	-20.3%	-9.6%	-21.1%
All routes	-11.5%	-29.0%	-13.6%	-5.0%	-13.9%
More congestion					
Least congested route	32.1%	67.5%	21.4%	11.6%	22.4%
Most congested route	16.1%	31.2%	10.5%	6.1%	9.6%
All routes	24.9%	53.5%	16.2%	8.7%	14.7%

4.2 Very local effects

The magnitude of the effects calculated depend on whether sections of many kilometres of the network are considered or only a small section. In this study we didn't address the very local effects of congestion. In the second stage of the study it was found that the actual tail pipe emissions of individual passenger cars and trucks increase by at least 50% (up to 800%) during heavy congestion. For local air quality this can have dramatic effects, because if traffic congestion is taking place near a densely populated area, the exposure of people to air polluting substances, will increase dramatically. The fact that in a traffic jam, dispersion of the exhaust gasses is rather poor (there is no aerodynamic

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turbulence behind the cars) increases the ambient concentrations of air pollution even further.

5 The limited effects of solving congestion nation-wide

The calculations of the entire motorway network resulted in much smaller effects. If we could solve all congestion on the Dutch motorways this would lead to limited reduction of emissions (see table 4). For example if we could solve all the traffic jams, without generation of extra mileages, the CO_2 emissions of the motorway network reduces with about 1,5%. This is about 0,22 Mton CO_2. In the Dutch "climate change policy implementation plan" it is presumed that the traffic sector should reduce emissions by about 3 Mton CO_2 equivalent by 2010 compared to 1990. From our study it is clear that lowering the speed by actual speed enforcement for passenger cars to 100 km/h on all sections of the motorway network can improve emission levels much more than solving all the traffic jams. For example, lowering the speed limit to 100 km/h would reduce the CO_2 emissions of the motorway network with about 7%. This is about 1 Mton CO_2 per year at current levels.

Table 4: Effects of less congestion and lowering speed limits nation-wide

	CO	*VOC*	*NO_x*	*CO_2*	*PM_{10}*
Less congestion	-4.1%	-11.3%	-4.1%	-1.5%	-4.3%
Speed limit 100 km/h	-16.6%	-2.0%	-7.1%	-6.7%	-13.4%

6 What to do with the results?

6.1 Traffic management measures

Traffic management measures should aim at keeping motorway velocities as constant as possible, or as it is called "homogenizing traffic". Traffic management measures aiming to reduce traffic dynamics of trucks – for example prohibiting of overtaking for and by trucks, and opening dedicated truck lanes - should have priority, because truck emissions are significantly higher especially in dynamic traffic situations. TNO stated that reduction of traffic dynamics is the most important ingredient for reducing the emissions of heavy duty traffic (Riemersma [2]).

Tests and implementation of traffic management measures that make traffic flows more homogeneous are indicated, since tens of percents of reduction in emissions are possible. Actually a good example is the Dutch pilot on the motorway A1. The objective of this pilot is to homogenize traffic by applying variable speed message signs, route control, providing information and "tit for tat policy" by breaking the speed limits.

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Efforts to reduce traffic dynamics and congestion should be concentrated on road sections with high risks of heavy congestion and a high share of heavy duty traffic in the built-up areas. However, awareness of possible rebound effects is necessary. By reducing congestion it is possible that new traffic is generated. By making use of traffic management it is important to prevent motorway traffic from shifting towards secondary roads, because emissions on the latter are much higher.

6.2 Zoning, pricing, technology and enforcement of speed limits

In specific urban zones where the air quality is really poor, it should be taken into consideration to prohibit or restrict access of heavy duty traffic and old cars without catalytic converter. Apart from restricting access, pricing could support the air quality as well. For instance, by the kilometer-levy formula, by charging for time (higher levy during peak hours), place (higher levy for busy or sensitive environments) and/or the environmental pollution of the vehicle.

Furthermore, in the urban environment several traffic measures that lead to "stop and go" traffic situations, like speed bumps, should be considered from an air quality viewpoint as well. Actually in commission of the Flemish government, TNO looks into the emission effects of speed bumps, roundabouts and phased traffic lights.

In future other possible solutions to reduce traffic dynamics are automatic vehicle guidance or driver assistance systems like intelligent speed adaption.

Another important conclusion of this study is that lowering the speed limit to 100 km/h can improve emission levels, as most of the Dutch motorways have a speed limit of 120 km/h. A discussion about speed limits comes up time and again in the Netherlands. It is still a touchy subject. However efforts to reduce speed by way of enforcement and technical means are clearly indicated. Speeds higher than 120 km/h will have to be avoided wherever and whenever possible. Additionally, in urban areas where the air quality is poor speed limits of 100 km/h should be taken into consideration.

6.3 Using different emission factors

Furthermore it is clear that especially in the urban environment different emission factors have to be used for different congestion categories in order to calculate the ambient air quality along motorways. Until now emission factors only made a distinction between road types not between congestion categories. In congestion situations this probably leads to underestimation of the calculated ambient air quality.

7 Desirable follow-up research

In general we have to be cautious when using emission factors as absolute numbers. There are several influences on the emissions that traditionally are not

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considered. For example from recent studies it is obvious that driving styles, air conditioning and automatic gearboxes clearly have it's effects in fuel consumption and emissions and hence disqualify the European type approval test procedure (Eurotest) for the purpose of determining emission factors (Gense[3]).

For further improvement of emission calculations this study made clear that further attention is needed with regard to the following:

- What are the differences between measuring emissions directly on the road and measuring in a laboratory and how can they be explored. This study is not conclusive in this respect but it is clear that meteorological circumstances, and the possible more nervous throttle use during driving in the laboratory situation, can lead to differences in emissions between directly measuring on the road and measuring in a laboratory.
- Emission factors for trucks for different traffic conditions. Follow-up investigation is recommendable because the investigations of emission factors for different traffic conditions for trucks were less detailed than those for passenger cars. Besides, trucks have a great influence on the total emission levels. In the future this influence will become even more pronounced.
- Increase of knowledge of the composition of motorway traffic. For example there are differences between motorways and secondary roads in the share of number of cars without a catalytic converter. These differences have significant effects on emissions.

8 Conclusions

The study has resulted in a set of emission factors that distinguish between the levels of congestion found in actual traffic on motorways. Significant differences in emissions and fuel consumption were found for different types of traffic. High traffic dynamics, shortcut traffic, heavy congestion and high speeds lead to significant increases of regulated emissions and fuel consumption. Measures to homogenize traffic can play an important role in decreasing driving dynamics and thus lowering emissions and improving ambient air quality. Lowering and enforcing the speed limits on sections of the Dutch motorways can improve total motorway emissions levels significantly.

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