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Influence of traffic conditions on fuel consumption and emissions - Brussels as a case study

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Abstract

In 1996 on-board measurements were performed on six passenger cars. These tests were executed in the centre of Brussels under various traffic conditions. All vehicles were measured for both fuel consumption and CO_2 emissions. Two were also measured for CO, HC and NO_x emissions. The chief emphasis was put on driving in the rush hour and smooth-flowing (on Sundays) traffic. The principal aim was to obtain realistic fuel consumption and exhaust emission values for Brussels. Secondly, to gain an insight into the relationship between consumption and emissions on the one hand and the process of traffic on the other. Furthermore, the measurement results have been used to upgrade an existing microscope traffic model with a fuel consumption module. In the process of designing an intersections and traffic control measures, energy and environmental aspects have to be taken into account if a more sustainable mobility is to be obtained.

1 Introduction

In 1995, VITO carried out an extensive on-the-road measurement campaign into the performance of petrol-driven cars in towns, on rural roads and on motorways. Detailed information on this campaign can be found in the literature, i.e. De Vlieger & Lenaers [1] and De Vlieger [2]. The measurements showed that the fuel consumption, the carbon dioxide (CO_2), the carbon monoxide (CO) and the total amount of hydrocarbons (HC) emissions are highest in urban areas. As a consequence, it was decided to study the urban traffic in more detail.

The process of traffic flow (volume of traffic, phasing of traffic lights, regulation strategies, ...) in urban areas affects fuel consumption and the exhaust emissions from vehicles to a considerable extent. This was studied in a measuring programme at Brussels, which was carried out in 1996 on behalf of the Minister of Energy and Scientific Research of the Brussels Region. The aim of the measuring programme was threefold:

- to obtain real consumption and emission figures for passenger cars in the Brussels Region;
- to gain an insight into the relationship between the consumption and emissions on the one hand and the process of traffic flow on the other;
- to collect data for a simulation tool that would evaluate traffic management concepts with a view to reducing fuel consumption and emission levels of cars.

The following gives a summary of the experimental design and of the most important results.

2 Experimental design

2.1 On-board measurement system

Measurements were taken using VITO's On-the-road Emission and Energy Measurement system (VOEM). The measurement system consists of a sampling system of exhaust gases; the gas analysers; the measurement of the fuel consumption, vehicle speed and lambda value; the power supply; and the data acquisition and automated data processing system. VOEM is based on a brand-new methodology formulated by Lenaers [3,4]. Basically, the emission concentration measurements are combined with the total exhaust gas mass flow which is calculated from the fuel consumption and lambda value determination.

The sampling system dilutes the exhaust gas at a constant rate to prevent condensation of water. Condensation of heavy hydrocarbons is prevented by a high temperature heating system. The monitoring unit consists of gas analysers. CO_2 and CO contents in the exhaust gases are measured by Non-Dispersive InfraRed (NDIR) equipment. The total HC content is analysed by a Flame Ionization Detector (FID), and the nitrogen oxides (NO_x) by a Chemiluminescence Analyser (CLA). A volumetric sensor is used to measure the fuel consumption. The measured volume flow together with the fuel density yields the mass flow. Accurate determination the speed and distance travelled is realized with an optical device. The power supply, from a 12 V battery, is divided into 12 V DC and 220 V AC and is delivered by a DC-AC inverter. The data acquisition processor and data processing system - a laptop PC - handles on-line collection and real-time processing - on the basis of seconds - of the measured data.

Accurate emission values can be determined for CO, HC, NO_x, CO_2 and methane in g/s and g/km. Lenaers [3,5] estimated the accuracies by comparative emission measurements on a chassis dynamometer. Most deviations were found to be below 10 %. The fuel consumption is accurately measured up to 1 %. This on-board measurement system can be fitted into any vehicle. It is suitable for measuring emissions and energy consumption in real traffic situations. VOEM is also used for assessing of the impact of new vehicle technologies, fuels and traffic management systems on the environment and on fuel consumption.

2.2 The urban track

A fixed track, about 7 kilometres in length, was defined in the centre of Brussels. When selecting the track, the traffic flows and the incidence of build-ups along that route were taken into account. It also had to be possible to study the regulation of crossings and the phasing between the different traffic lights. The track consisted mostly of main roads and started near the centre of Brussels. For the purposes of analysis, the track was divided into 45 sections, which were either crossroads or connecting pieces between two successive crossroads.

2.3 Tested vehicles

Six passenger cars were measured, small as well as big cars driving on petrol and diesel. Only one vehicle has been measured for each model. Car details are given in Table 1.

Table 1: The vehicles included in the study.

Model	Fuel	cc-class [l]	Mileage [km]	Catalyst	Measured
VW Golf	diesel	1.9	116,350	no	FC
Ford Mondeo	diesel	1.8	4,544	no	FC
Volvo 850 TDi	diesel	2.5	17,758	oxycat	FC & emissions
Ford Fiesta	petrol	1.3	8,250	TWC	FC & emissions
Toyota Previa	petrol	2.5	22,023	TWC	FC
Renault Laguna	petrol	1.8	7,876	TWC	FC

oxycat = oxidation catalyst; TWC = three-way catalyst; FC = fuel consumption

2.4 Traffic conditions

The urban track was driven during various traffic conditions: morning peak (7.30 - 8.30 AM), evening peak (4.00 - 6.00 PM), normal traffic situation and smooth-flowing traffic situation. The latter was driven on Sundays. Moreover, tests were carried out at a constant speed of 50 km/h as a reference for the ideal situation.

2.5 Measuring

Chief emphasis was put on measuring the real fuel consumption and CO_2 emissions. For two cars, however, the gaseous regulated emissions (CO, HC, and NO_x) were also measured. The six cars were measured in different traffic situations on the urban track, with the emphasis on rush hours and fluent traffic. For each combination of vehicle/traffic condition, 4 to 8 tests were performed. All vehicles were driven by the same motorist, who had a calm to normal driving behaviour. The analysis and evaluation of the results were made in collaboration with TRITEL, a leading consultant in Belgium that has substantial experience in transport telematics and traffic management problems.

3 Results and discussion

3.1 Global urban track

3.1.1 Fuel consumption

Table 2 shows that on Sundays as well as at peak hours, the average speeds are low, namely less than 30 km/h. On the other hand the average consumption on the urban track is very high: during the rush hour more than 10 l per 100 km, even for diesel cars. Compared to the traffic on Sundays, the fuel consumption was 20 to 45 % higher during the rush hour. It should, however, be noted that on Sundays (smooth-flowing traffic), there is still a great potential present for lowering fuel consumption still further (cf. the consumption figures at a constant speed of 50 km/h).

Compared to constant driving at 50 km/h, motoring in the rush hour showed a doubling of the fuel consumption per kilometre driven. In certain cases the consumption was even a factor 2.4 higher.

Table 2: Summary of the average speed and fuel consumption on the urban track and fuel consumption at a constant speed of 50 km/h.

Vehicle	Average speed [km/h]		Average consumption [l/ 100 km]		
	rush hour	on Sundays	rush hour	on Sundays	50 km/h
Diesel:					
VW Golf	14.4	24.6	11.6	9.3	5.2
Ford Mondeo	12.2	25.9	12.2	8.5	5.2
Volvo 850 TDi	13.6	23.3	14.1	10.3	5.8
Petrol:					
Ford Fiesta	13.4	22.6	11.6	9.8	5.9
Toyota Previa	13.6	25.1	21.8	16.6	10.2
Renault Laguna	13.9	24.3	14.2	11.4	7.1

The Volvo 850 TDi and the Toyota Previa indicated a high consumption, because these are heavy cars and the trips were made when the air-conditioning was on (± 15 % more consumption).

3.1.2 CO_2 emissions

During the rush hour, CO_2 emissions were 20 to 45 % higher than in smooth-flowing traffic and had doubled compared to 50 km/h. These conclusions run parallel to those of the fuel consumption; the CO_2 emissions are, after all, closely linked to the consumption and the amount of carbon in the fuel. Figure 1 gives an overview of the CO_2 emissions for all tested vehicles under various traffic conditions.

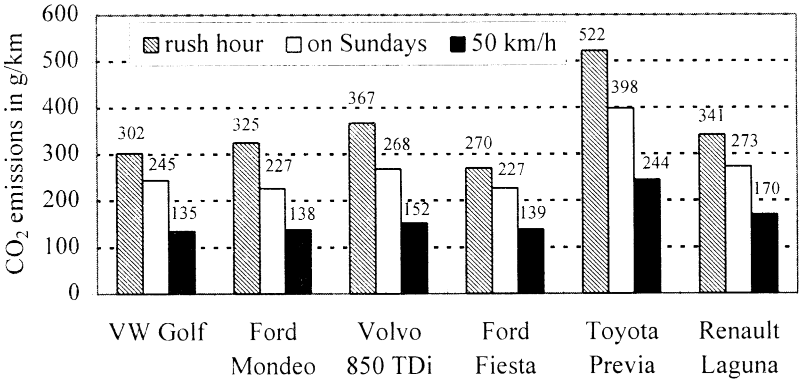

Figure 1: Average measured CO_2 emissions for the urban track under various traffic conditions and at a constant speed of 50 km/h.

3.1.3 Gaseous regulated emissions

For one car on diesel and for one on petrol, the CO, HC and NO_x emissions were also measured. As expected the exhaust emissions were higher during heavy traffic. By way of illustration, Figure 2 shows the average measured emissions for the Volvo 850 TDi on the urban track. The CO and the HC emissions were 80 % higher during the rush hour and the NO_x emission 50 % higher than in smooth-flowing traffic (on Sundays). The emissions in the rush hour were even 10 times higher than when driving at a constant speed of 50 km/h. For the emissions too, one can confirm that smooth-flowing traffic still offers a great potential for further reduction. The pursuit of more equalized traffic flows will be crucial in that respect.

For the Ford Fiesta the average measured emissions during the rush hour were very low, i.e. 0.78 g/km for CO, 0.06 g/km for HC and 0.06 g/km for NO_x.

Even so, this was 69 % and 20 % higher than during smooth-flowing traffic for CO and HC respectively. For NO_x no significant difference has been found. The tested car was fitted out with the latest engine and TWC technology, which enabled it to achieve the new European emission standard 94/12/EC, explainig the low emissions. The new standard came into force from January 1 1997 onwards for all new passenger cars.

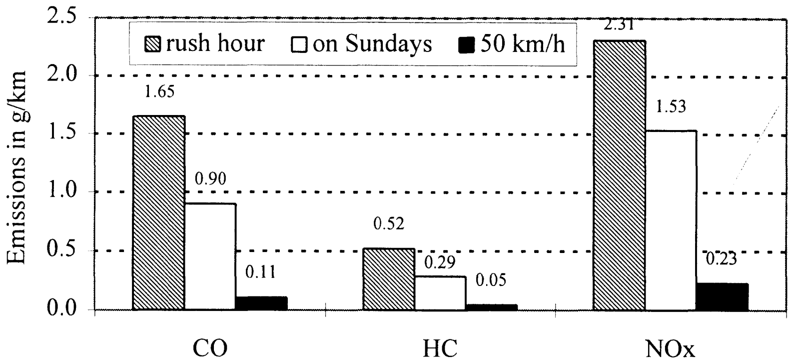

Figure 2: Average measured emissions in g/km for the Volvo 850 TDi on the urban track under various traffic conditions.

3.2 Specific sections of the track

3.2.1 Selection

Besides the global urban track, some specific sections such as two ring road sections, two complex crossings and a crossing with a difficult left turn were analysed. Furthermore, for three cars, measurements were taken along a busy arterial road that crosses the city centre (Belliard street).

3.2.2 Fuel consumption and emissions

Except for one complex crossing, fuel consumption and CO_2 values for the tested vehicles on the selected sections were 42 % higher than those of the global urban track. The emission rates for the Volvo 850 TDi were, on average, about 50 % higher than the levels for the global track. On the Ford Fiesta (petrol+TWC), CO was 40 % higher than for the global track. The increase in HC and NO_x was normally less than 10 %.

3.2.3 Illustration: speed/HC profile

The different sections of the urban track were studied by means of speed/fuel consumption and speed/emission profiles; the measured parameters were plotted against time. Figure 3 shows the speed/HC profile of difficult left turn traffic at an intersection during heavy and smooth-flowing traffic, as experienced in the Volvo 850 TDi. One can clearly see that the fluctuations of speed and emission values were more frequent and more intense during the rush hour. The average speed for this trip segment (shown in Fig. 3) in the rush hour was 7.8 km/h, whereas it was 21.6 km/h during the congestion-free trip. The total HC emission for this trip segment was about 4 times higher during the rush hour compared to smooth-flowing traffic (0.29 g versus 0.07 g). Figure 3 shows that high HC levels occur during acceleration. The HC peaks during the rush hour were often higher than during smooth-flowing traffic. During stops (red light, stop-go traffic) a car is also polluting; for the Volvo 850 TDi this was about 0.001 g HC per second. Qualitatively, these findings also hold for fuel consumption and for the other regulated emissions.

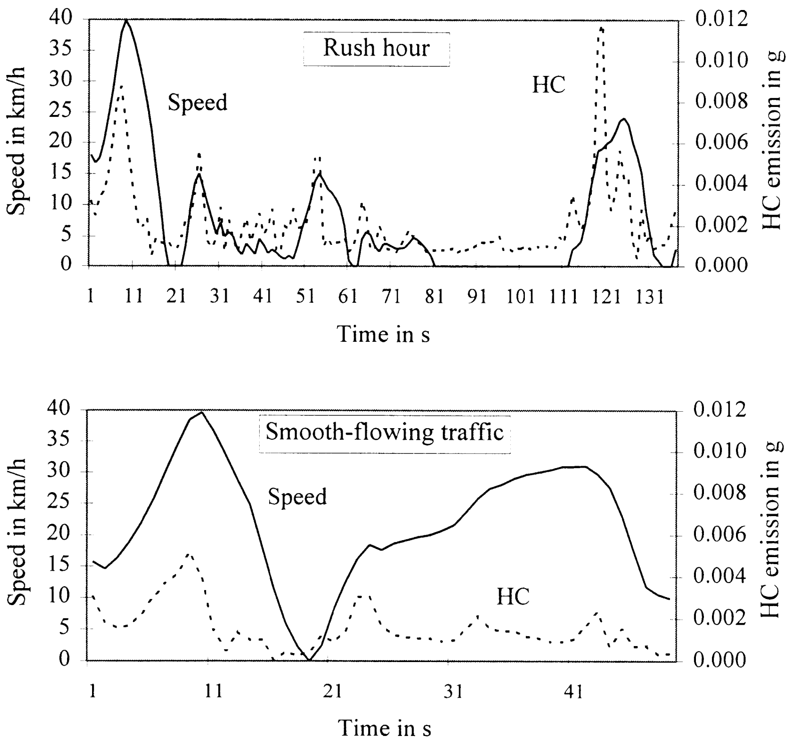

Figure 3: Speed and HC emission plotted against time for difficult left turn traffic during various traffic conditions on the Volvo 850 TDi.

3.3 Relationship with traffic management

When designing traffic and transport plans in urban areas, one especially reckons with the processing capacity of vehicles and with the aesthetic integration into the environment. Within the frame work of the pursuit of a sustainable mobility, we should also include fuel consumption and exhaust emissions as additional parameters when developing traffic and transport plans.

Out of detail analyses (on a time slice basis of 1 s) made on the results from the measurement campaign, threshold levels and remedial measures can be deducted which have a positive effect on the fuel consumption and exhaust emissions. These advantages have been quantified for the fuel use and CO_2 emissions, and partly for the regulated emissions. The remedial measures given below should be implemented with the greatest care, should be feasible in practice and should observe the presupposed priorities (e.g. public transport priority, pedestrian comfort). The implementation should be monitored together with the authorized institutions and with the experts on the subject.

3.3.1 Phased traffic lights

Phased traffic lights, also called green wave, mean that a motorist who keeps to a certain advised speed and who, at a junction, gets a green light, will have a green at the following junctions too provided he keeps to the advised speed. Phased traffic lights result in more equalized traffic flows. In ideal situations they result in a reduction of the fuel consumption and in the CO_2 emission of 50 %.

On the Volvo 850 TDi and the Ford Fiesta, emission reductions of up to 90 % and 60 % respectively could be reached. Under real traffic conditions, results with the Volvo showed reductions of 42 % for CO and HC, and 29 % for NO_x. For the Ford Fiesta a reduction of 28 % for CO and HC should be achievable. For NO_x, no significant gain was found.

3.3.2 Turning left without conflicts

Turning left without conflicts means that crossings with traffic lights are given an additional signal for vehicles which have to turn left, namely a "green arrow". In fact this amounts to an additional phase for those that have to turn left at the crossing, as they do not follow the traffic that drives straight on or that turns right. In this way the vehicles that want to turn left, pass through in a block once the green arrow comes on. At an open crossing vehicles have to wait their turn, with many stops and goes. Turning without conflicts results in reductions of up to 30 % in fuel consumption and CO_2. To facilitate the integration of left-turners without conflicts at crossings, there has to be a separate lane available for those turning left. Furthermore, turning left without conflicts can only be introduced if there is sufficient capacity at the crossing. If the introduction of turning to the left without conflicts results in increased

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congestion, there will be no net gain in fuel consumption and emissions, perhaps even an increase.

3.3.3 Regulation of congestion
The aim of measures to ease congestion is to avoid the pattern of stop-go driving. This can be achieved by giving green light priority at the crossing provided there is sufficient capacity to do so at the following crossings. This can lead to a fuel saving of up to 20 %.

3.3.4 Short-long cycle of traffic lights
The cycle of a traffic light is the time to run through the full sequence of red, green and orange in the main direction as well as in the side direction. The results of the analysis of the short-long cycle at a traffic light were rather surprising. The long and short cycles resulted in comparable fuel consumption and CO_2 emissions. So long as there is not a capacity problem (congestion) elsewhere, a short cycle is recommended because the crossing time for the pedestrian is shorter and the priority for the public transport does not suffer.

3.4 Implementation of the measuring results in a simulation model

On the basis of the results of the measurement campaign, the fuel consumption and the exhaust emissions have been determined as a function of the instantaneous speed and acceleration. As far as fuel consumption is concerned, the analyses resulted in functions which give a better approach to congested urban traffic than classic functions. The latter functions are only dependent on the average speed and only valid for average speeds higher than 10 km/h, see McInnes [6].

The last-mentioned functions derived from the above measurements have been used to upgrade the microscope traffic simulation model “VISSIM” with a fuel consumption module. This module uses one second values for fuel consumption which correspond to one second values of speed and acceleration. Besides the traffic flows at a crossing, the simulation model also indicates the fuel consumption of all cars that are negotiating the crossing at a given moment. For more details about VISSIM and the module for fuel consumption, the reader is referred to Tegenbos [7]. Future interesting work may lie in the integration of an emission module.

4 Conclusion

The measurements in Brussels have shown that the fuel consumption in urban traffic is very high. In the rush hour the fuel consumption of passenger cars went above 10 1 /100 km, even for diesel cars. Although consumption was 20 to 45 % higher in the rush hour than in smooth-flowing traffic, even in the last traffic situation, there is still a huge potential present for further reductions. The same conclusions can be made for the CO_2 emissions. Compared to fluent traffic, CO and HC emissions were up to 80 % higher in the rush hour and for NO_x 50 %.

In order to further minimise the fuel consumption and the CO_2, CO, HC, NO_x emissions and to arrive at a more sustainable mobility, one should, besides the improvements in vehicle technology, reorientate traffic management to highlight other considerations, such as fuel consumption and environmental aspects. Worthwhile measures for lowering consumption and emission are: phased traffic lights, turning left without conflicts and congestion regulation. In ideal circumstances this can result in a halving of the fuel consumption and the CO_2 emissions. For CO, HC and NO_x a reduction of even 90 % could be reached. Passing judgement on these measures is much more complex in the case of heavy congestion. Moreover, one should pay sufficient attention to the practical implementation of these measures. Rather surprising, were the comparable fuel consumption values for long and short cycles of traffic lights. If there are no capacity problems, the short cycle is recommended. For the latter the crossing time for pedestrians is after all shorter and the priority for public transport does not suffer.

Measures which may reduce consumption and emissions on the urban track should therefore be sought by exploring avenues as follows: congestion regulation at busy junctions (e.g. the inner ring road) or setting up “green wave” along major exit routes from the capital. At junctions where volume of left-turners is considerable and turning left without conflicts in a separate lane would be ideal, remodelling will depend on whether there is sufficient capacity at the junction.

Even so, we should not forget that prevention is better than cure and that measures to restrict car mobility in urban area will bring about even more effects on condition that they are flanked by a better expansion of public transport.

5 Acknowledgements

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