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Evaluation of the Landscape around Roads

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Abstract

The inclusion of care for the environment in transport policies should be based on the results obtained after scientifically evaluating different environmental variables.

As road use increases, the importance of the relationship between landscape and highways must increase: this relationship contributes to the public's attitude towards Nature and their sensitisation towards the environment.

This paper proposes a method for studying the landscape value of roads. This requires taking into account two major features - the road as a landscape element, and the road as a tool bringing viewers closer to the landscape. The analysis is approached from the standpoint that roads are an inherent component of the landscape and evaluates how well they integrate into the environment.

The proposed method provides a way of selecting scenic routes for roads and of evaluating how the landscape will be appraised from them.

***Keywords**: landscape, roads, scenic routes*

Introduction

Taking landscape as a cultural heritage and resource belonging to mankind is acquiring increasing consideration in the set of environmental values demanded by the general public. Owing to this new dimension of landscape as a resource, there is a tendency to objectify it, giving it aesthetic and environmental appraisal, and this implies conserving it adequately in some places and reproducing it in others to set up contacts and relationships with individuals.

Furthermore, engineering works, particularly roads as one of the main points for observing the countryside, have given rise to a different way of perceiving the environment, (Escribano et al, 1987). In this respect, roads are not only

transport routes but also constitute a means through which individuals come into contact with the landscape. Roads can therefore imply a negative impact of anthropication and another positive one of communication with the landscape.

When a road crosses an attractive landscape, a large part of our visual perception activity is directed towards the surrounding scenery. The visual character of a road depends on a great many factors, some of which are irreversible, such as the physiography, and others are subject to change, such as land use. This implies that the character of a road can be controlled or managed to a certain extent (Kent, 1993).

Objectives

This paper aims to facilitate a tool enabling roads to be integrated into the landscape in such a way that they are not perceived solely as an element altering the natural values of a territory, but that they also serve to bring people closer to the environment, letting us appraise its values through the landscape.

It will therefore contribute a methodology for developing routes through areas of the greatest scenic value.

Methodology

1. Defining Regional Landscapes

First of all the major regional units of a landscape need to be defined. To this end, the basis used in this study was the "Atlas de los Paisajes de España" (Atlas of Spanish Landscapes) drawn up by the Universidad Autónoma de Madrid headed by Mata & Sanz (2003), configured as a general 1:4,000,000-scale map of the landscapes of Spain and setting up 24 major landscape groups or associations for the Iberian Peninsular. This map in turn is divided into different landscape subgroups located within the associations and drawn on a 1:200,000 scale.

Having set up the major landscape groups or associations, the second step consisted of evaluating them as a function of the characteristics of the main features making up each landscape (relief, altitude, position/influence, morphological features, land uses and population centres).

2. Evaluating Landscape Types

Taking these features as basis, the evaluation was tackled in two stages:

- Stage 1: rating the 24 major landscape types or associations on a score of 1 to 10
- Stage 2: rating the different subgroups within each association on a score of 0 to 3.

The end score for each landscape type is given by the following expression:

$$VF = VA \pm \left[\frac{(VA \cdot VS)}{30} \right]$$

where:

VF = final landscape value

VA = association value

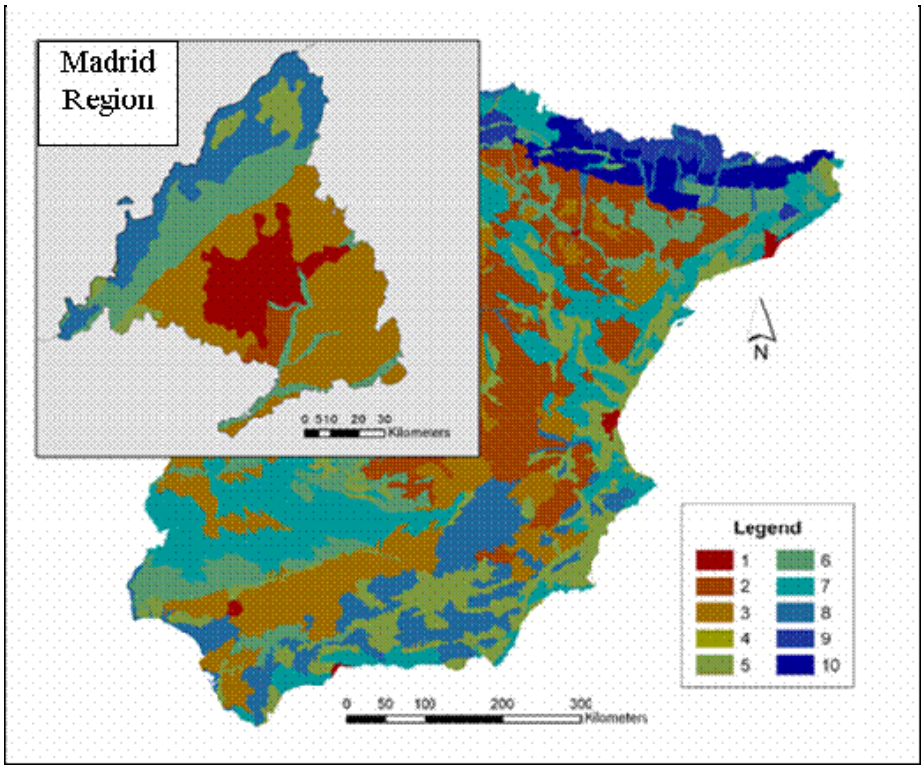
VS = subgroup value within the association.

Taking into account the final sum qualifies the evaluation of the different associations, deemed necessary in view of their amplitude and spatial variability.

Based on this evaluation, a map of Spain was drawn up (Fig. 1) reflecting the landscape value assigned the different landscape associations and subgroups involved, on a 1 to 10 scale.

Figure 1: Landscape evaluation of Spain and the Madrid Region

Figure 1: Evaluation du paysage de l'Spagne et de la région de Madrid



3. Local Landscape

The case study was located in the Madrid Region, which is why the general methodology was applied to the Madrid Region and is described below.

In order to locate the routes from which the landscape would be evaluated, the first to be selected were areas of acknowledged high landscape values and the following stages were taken.

- The above-cited "Atlas de los paisajes de España" uses a rising scale for landscape quality with scores from I to 10. Within the Madrid Region only areas with a rating of 7 were selected (top value for this Region).

  The units presenting the highest score are the Massifs and High Ranges of the Central Mountain System (with a rating of 7.46) and the Central System Ranges (7.15).
- From the "Mapa de paisaje valorado para el uso recreativo en la Comunidad de Madrid" [Madrid Region Map of Landscapes Rated for Recreational Use] included in the thesis: "El Uso Público Recreativo: modelo de planificación mediante la utilización de un Sistema de Información Geográfica" [Public Recreational Use: GIS-based Planning Model] (García, 2004), the areas taken into account had a rating of 1, "very high landscape quality but with high fragility" and of 5, "high or medium-high landscape quality".
- The areas selected were superimposed onto both maps. The result obtained by intersection gave the top landscape quality areas in the Madrid Region.

4. Landscape Evaluation

Having located the areas that in theory had the highest landscape quality, the next step was to evaluate the landscape from the roads crossing them.

Landscape should be scored from the different visuals existing from the road. Depending on the longitudinal direction of the road, in the direction of travel and in the inverse, as also on both sides, to left and right, as the view of the landscape is not the same for the different occupants in a vehicle (Fig 2).

An attribute-based method is proposed as a basic method for evaluating a landscape seen from a road, designed from the works by Cañas (1995).

The following physical attributes are taken into account:

- water (including four variables: type, banks, movement and quantity)
- ground shape (one variable: type)
- vegetation (four variables: cover, diversity, quality and type)
- snow (one variable: coverage)
- fauna (three variables: presence, interest and ease of spotting)
- land use (two variables: type and intensity)
- views (two variables: type and intensity)
- sounds (two variables: presence and type)
- smells (two variables: presence and type)

- cultural resources (four variables: presence, type, ease of seeing and interest)
- elements altering the character (four variables: intrusion, landscape fragmentation, horizon obliteration and view obliteration).

The following aesthetic descriptors are studied:

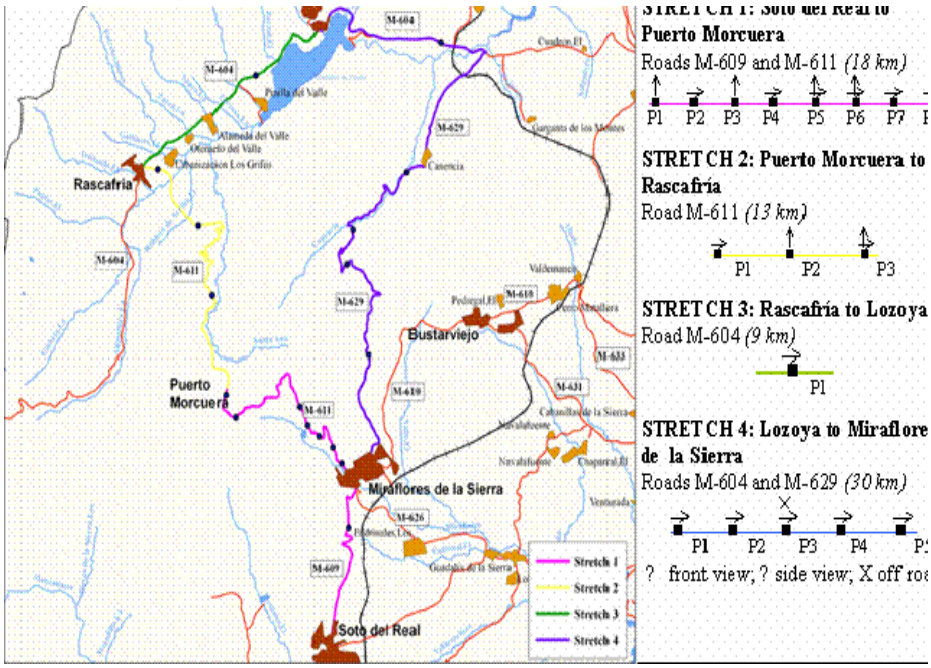
- shape (three variables: diversity, contrast and compatibility)
- colour (three variables: diversity, contrast and compatibility)
- texture (three variables: diversity, contrast and compatibility)

The following psychological descriptors are taken into account:

- unity (two variables: structural lines and proportion)
- expression (five variables: structural lines, proportion, affectivity, stimulation and symbolism).

Figure 2: Route between Soto del Real and Miraflores de la Sierra

Figure 2: Route entre Soto del Real et Miraflores de la Sierra



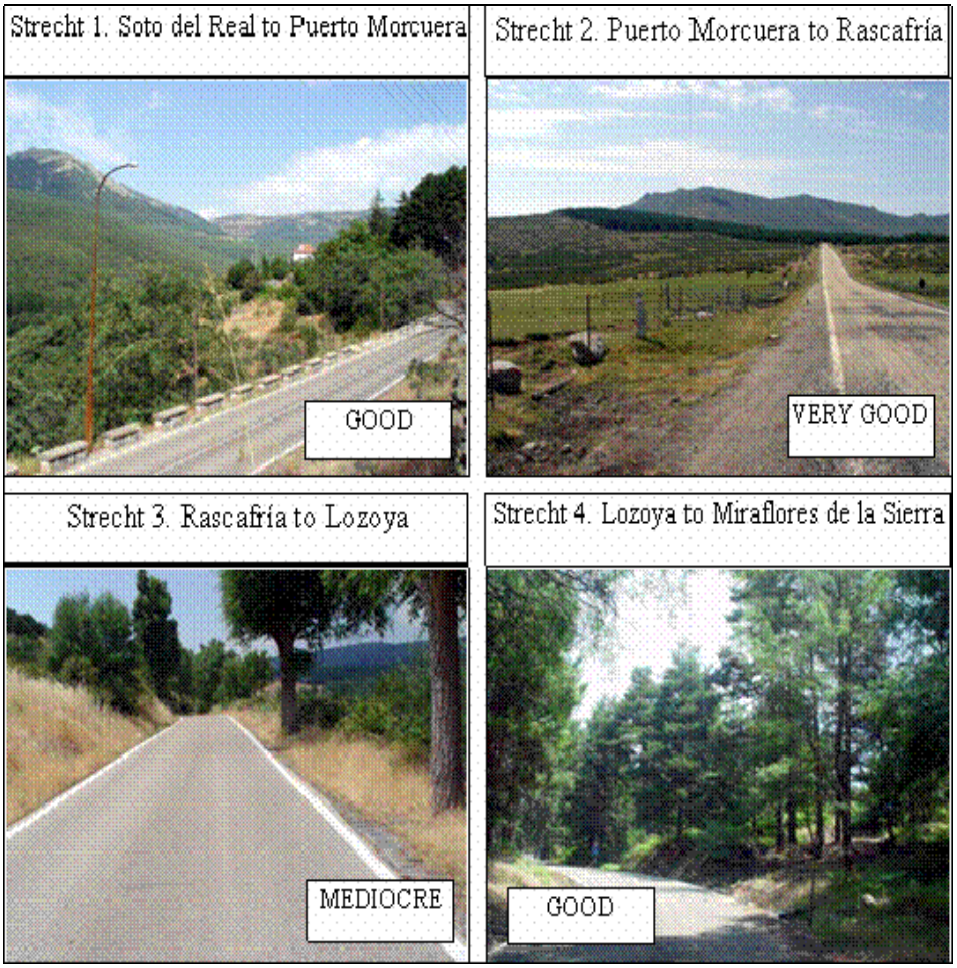
Scoring runs from 0 to 100. This makes the method highly sensitive, even to small changes occurring in the landscape as they are reflected in the evaluation or in the notes. The files containing the evaluations summing up all these parameters are structured in such a way that they are easy to fill in. Scoring can be done on the spot or through photographs (except for the odd attribute).

To prevent the evaluation being tainted by distorting elements, landscape rating does not include the sky nor any close-up items (0-50 m). However, view rating does take elements at a distance of 300 m onwards into account.

Having determined the attributes present in the landscape, the next step is to rate the different parameters using a predefined set of scores (Cañas, 1995) in order to obtain the final evaluation for a landscape as the sum of the scores assigned to each attribute (Fig. 3).

Figure 3: Scenery on stretches of the route

Figure 3: Le décor aux environs des segments de la route



Results

Applying this method means that roads can be classified as a function of the scenery they cross and allows scenic routes with a high landscape value to be determined, comprised of the roads with the highest score.

The process for selecting scenic routes uses a joint study of both the scenery appraised and the roads that would be involved in the routes, endeavouring to take advantage of the roads with least impact on the landscape crossing the areas of greatest scenic value. Major regional landscape and road-related units are thus defined (Figs. 1 and 2).

A number of conditioning factors are taken into account to make an adequate selection of the routes:

- an overall length of around 150 km is fixed for all the routes as a set;
- the routes should include both roads linking important population centres, considering travellers probably have to pass through them, and those providing access to more remote areas of interest (townships, campsites, tourist spots, etc.);
- routes do not necessarily have to be continuous but may contain branches off from the main stretch;
- bearing traffic regulations in mind, special attention is paid to minor roads as they offer travellers the possibility of driving slowly or even of stopping without danger at the roadside, in a lay-by or lane diversion.

Conclusion

By way of conclusion to the work presented, it is the effectiveness of the methodology that should be stressed, designed as a simple way first to select scenic roads and then to evaluate the landscape to be seen from them.

The evaluation method allows the features of the overall landscape in the area to be rated, eliminating the influence of areas very close to the road that can modify the general nature of the landscape.

In addition, the evaluation method allows for variations, making it possible to vary the angle of appraisal of the landscape features for instance as they vary with the speed of travel.

The effectiveness of the method is based on the following points:

- it takes the information available in digital format and easily GIS-integrated as starting data, meaning that scenic roads can be clearly and simply selected;
- the landscape evaluation method entails a particularisation of a well-checked methodology backing up its efficiency with deliberately coherent and easily understood factors being selected for landscape appraisal;
- the evaluation, both direct in situ and through photographs, is an affordable process.

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The composition and relationships between trace element levels in Pm_{10} released from vehicles and in leaves of *Saraca indica* and *Lantana camara*

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Abstract

Composition and levels of inhalable trace elements (Ba, Cu, Fe, Mn, Pb, Ti and V) in PM_{10} of atmospheric particles and leaves of two plants species viz. Saraca indica and Lantana camara was studied to show the relationship between them. Leaves were collected from two sites of Varanasi, one remote control site (village) having negligible traffic density and other in the heart of city having high traffic density. At control site content of Cu and Fe in PM_{10} was significantly lower ($p < 0.05$) than at the other site. A positive and significant correlation ($p < 0.05$) was found between leaf content of S. indica and PM_{10} content for Cu and Fe. This suggests that S. indica is better than L. camara as an ecological indicator for biomonitoring trace elements pollution of air caused by vehicular traffic.

Keywords: *$PM_{10;}$ ecological indicator; biomonitoring; trace metals;*

Résumé

La composition et les niveaux de traces des éléments inhalables (Ba, Cu, Fe, Mn, Pb, Ti et V) dans les PM10 de particules atmosphériques et de feuilles de deux espèces de plantes, à savoir Saraca indica et Lantana camara, ont été étudiées pour montrer la relation entre eux. Les feuilles ont été recueillies sur deux sites de Varanasi, un site de contrôle (le village) ayant une densité de circulation faible et l'autre dans le coeur d'une ville ayant une forte densité de circulation. Sur le site de contrôle, le contenu de Cu et à Fe dans les PM10 était significativement plus bas ($p <0,05$) que pour l'autre site. Une corrélation positive et significative ($p <0,05$) a été trouvée entre le contenu de feuille de S. indica et le contenu de PM10 pour Cu et Fe. Ceci montre que S. indica est un meilleur indicateur écologique que L. camara pour le biomonitoring des traces des éléments de pollution d'air causé par la circulation.

Mots-clefs : *PM10 ; indicateur écologique ; biomonitoring ; traces des métaux ;*

Introduction

Particulate matter (PM_{10}) has been widely studied in recent years due to its potential health impact and need for its control. Links between asthma attacks and coughs with particulates have also been reported (Freer-Smith et al., 1997). Studies indicate that finer PM has the strongest health effects (Schwartz et al., 1996; Borja- Aburto et al., 1998). Vehicular traffic, industrial processes and fossil fuel stations are primary source of airborne particulate matter (Beckett et al., 1998) which is responsible for contamination of urban areas (Janssen et al., 1997; Monaci et al., 2000; Fernandez et al., 2001). In aerosols, magnetite is associated to other heavy metals like zinc, cadmium and chrome (Georgeaud et al., 1997).There are references that plants capture trace elements and can be used in biomonitors (Rossini Oliva and Valdes, 2003; Barghigiani et al., 1991; Sawidis et al., 1995; Aksoy and Ozturk, 1997; Bargagli et al., 2003; Rossini Oliva and Valdes, 2003, 2004; Rossini Oliva and Rautio, 2004). Keane et al. (2001) compared the metal content (Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in dandelion leaves with the PM10 levels. Higher plants function as biomonitors of aerial metal contamination due to their accumulation properties. Nerium oleander and Lantana camara are known to assimilate metals (La Malfa et al., 1996; Rossini Oliva and Valdes, 2003; Rossini Oliva and Mingorance, 2004).

The aim of this work was to study the composition and relationships between trace element levels in PM10 released from vehicles and in leaves of *Saraca indica* and *Lantana camara* and to evaluate if there exists any correlation between the metal content in the air and on plants leaves.

Materials and methods

1. Sampling

The city of Varanasi (82° 15'E to 83° 30'E and 24° 35'N to 25° 30'N, India), and its surrounding area, is characterized by little industry but, due to more than a million inhabitants, a substantial volume of traffic exists. So, traffic represents the most important pollution.

Samples of particles smaller than 10 µm (PM10) and adult leaves of *Saraca indica* and *Lantana camara* were collected simultaneously in two sampling sites during June 2004. The dust holding capacity is influenced by weather conditions, pollutant properties, plant surface characteristics, plant and leaf morphology and, particle size (Alfani et al., 2000, Freer-Smith et al., 1997, Harrison and Chirgawi, 1989).The leaves of *Saraca indica* are Leaves are narrowly lanceolate 15.25 cms long cork like at the base and with a short petiole. It occurs widely in urban and rural areas and it is used in motorway, grows in nutrient poor soils and in drought conditions. The leaves of *Lantana*

camara are 2-5 in (5-12.7 cm) long by 1-2 in (2.5-5 cm) wide with rounded tooth edges and a textured surface. Both these species were selected because they occur widely in both urban and rural areas and having a wide geographical range and ecological distribution throughout the country and both are easy to identify and samples.

A total of 12 samples of PM_{10} were collected simultaneously samples of both species of plants. One of the sampling sites represents the area of Varanasi most affected by the highest vehicular emissions (Nadeshar, NS) and the others being less contaminated, having negligible traffic density (Sarnath, SN). Several branches from three healthy-looking plants were cut off from sides of the canopy at 2.5 m for *Saraca indica* and at 0.5 m for *Lantana camara*. About 300 g of fresh mature leaves (including the petioles) were mixed to provide a unique sample. Samples were dried overnight at 70 °C and ground to a fine powder. Atmospheric particulate matter was collected with a standard high volume sampler (HVS) with respirable unit (Envirotech APM 410 Model). PM10 inlet was used to collect all particles of less than 10 µm. The sampling system was set at a flow rate of 1.1 m^3/minute. Fibreglass filters were used as collection media (Whatman GF/A, 20.3 x 24.5 cm). Before analysis of airborne samples, filters used for particle collection were dried, before and after weighing, in a high-volume desiccator under 3% RH for a 48 h period.

2. Analytical determination

Plants and filter paper were placed in closed teflon vessels for digestion with 15 ml of a mixture of concentrated acids HNO_3– $HClO_4$ v/v (3:1). Sample solutions were transferred into sterile tubes after digestion and cooling. Since individual blanks were not available for each filter used for sampling, a set of unexposed filters for each type of filter was analyzed as blanks. The mean unexposed filter values were determined and subtracted from each sample to obtain the best estimate of each element in the particulate material.

The concentrations of Ba, Cu, Fe, Pb, Mn, Ti and V metals were determined by atomic absorption spectrophotometer (Model- 2380).

Results and discussion

The various elements found in PM_{10} and in plants in different sites are reported in Table 1. The values of PM_{10} metal concentrations for all sampling sites cannot be considered dangerous for human health, because these values are in lower concentrations than those indicated by the Unit Risk (UR) values on cancer of the WHO (World Health Organization).

The multiple means comparison test showed that the air pollutant concentrations were not significantly different ($p < 0.05$) between both the sampling sites, except for Mn, Cu and Fe. The Mn concentration was significantly low at the control site with respect to Nadeshar. This was also the case for Cu and Fe when compared to Nadeshar. The Nadeshar site has a higher amount of vehicular traffic, suggesting that atmospheric pollution by both

elements is higher due to traffic. In the case of *Saraca indica*, the results of Scheffle test showed that differences of Pb, and V concentrations between the sampling sites were not found, while lower Cu and Fe concentrations were found in the control site. In case of *Lantana camara*, multiple means comparison test showed that element concentrations were significantly different between the sampling sites. In addition, like in *Saraca indica*, the Ti concentration in the control site was significantly higher than that of the other site. Even when *Lantana camara* retained elements the concentration gradient between the sampling sites was not detectable. A relationship between the elements concentration in PM_{10} and plants was found for *Saraca indica* (only for Cu and Fe) and not for *Lantana camara*, indicating that *Saraca indica* can be a more useful biomonitors of PM_{10} than lantana.

Even though *Lantana camara* has a rougher leaf surface than *Saraca indica*, a characteristic feature that usually helps in trapping of particulates, present study showed this character as not affecting the capacity to retain pollutants. The ANOVA results showed that significant differences ($p < 0.05$) between the two species only existed for the Cu and Fe contents.

Table 1: Mean concentration of pollutant elements (±SD) in airborne particles (PM_{10}, ng/m^{-3}) and plants (mg kg^{-1})

Tableau 1: La concentration moyenne d'éléments de polluants (±SD) dans les particules aéroportées (PM10, ng/m-3) et les plantes (en kg de mg-1)

Sampling sites and sample type	Pb	Mn	Cu	Fe	V	Ti	Ba
P, NS (n=6)	3.85 ± 1.04	5.70 ± 1.92	23.52 ± 5.60*	208 ± 53.25*	2.89 ± 1.56	10.52 ± 4.20	-
P, SN (n=6)	1.04 ± 0.62	2.35 ± 0.95*	10.56 ± 4.02	63.50	1.76 ± 1.22	8.14	-
S, NS(n=6)	0.84 ± 0.36	16.32 ± 2.54*	7.58 ± 1.26*	98.56 ± 14.58*	0.8 ± 0.12	7.54 ± 1.86*	23.08 ± 3.52*
S, SN(n=6)	0.22 ± 0.18	22.25 ± 6.54	2.56 ± 1.23	58.65 ± 12.98	0.48 ± 0.10	13.25 ± 2.24	18.24 ± 4.58
L, NS(n=6)	0.46 ± 0.35*	22.58 ± 5.87*	4.45 ± 0.55*	74.24 ± 10.87*	0.40 ± 0.22	4.85 ± 1.25*	5.42 ± 1.23*
L, SN (n=6)	0.68 ± 0.12	32.06 ± 3.58	6.92 ± 0.54	124.64 ± 22.08	0.82 ± 0.05*	23.01 ± 4.20	2.56 ± 1.28
Particle limit values[a]	500	150			1000		

P- PM_{10}; S- Saraca indica; L- Lantana camara; NS- Nadeshar; SN- Sarnath

* Difference between the means from control site and other site are statistically significant (Scheffle' test, $p< 0.05$)

P- PM_{10}; S- Saraca indica; L- Lantana camara; NS- Nadeshar; SN- Sarnath

** La différence entre les moyens du site de contrôle et de l'autre site est statistiquement significative (Scheffle' test, $p< 0.05$)*

[a] Unit Risk (ng m^{-3}) values based on cancer of the WHO (World health Organization)

[a] *Le Risque d'unité (ng m^{-3}) les valeurs basées sur le cancer de l'OMS (l'Organisation Mondiale de la Santé)*

Conclusions

Urban air pollution by metals of Varanasi can be considered low and not dangerous for human health. Fe and Cu were specially differentiated between the control site (SN) and the urban sites (NS). Only these two metals showed correlation between particles and *Saraca indica* leaf concentrations, indicating that this species is a more useful biomonitor of atmospheric Cu and Fe than *Lantana camara*. *Lantana camara* accumulated high amount of air pollutants through its leaves, but this is unable in reflecting quantitative differences of atmospheric quality. The content of PM_{10} at the road sites containing concentrations of Cu and Fe in higher amounts than the values at the control site suggests that the source comes from traffic emissions.

Acknowledgements

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Driver exposure to air pollution inside a car – effects of ventilation method

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Abstract

The main objectives of the study presented here were to assess the effects of the ventilation method on air pollution inside the car, and to derive recommendations aimed at reduction of driver and passengers exposure to air pollution.

Experiments were carried at various traffic conditions, during all working days of the week, 7 AM - 7 PM. Concentrations of CO, NO, NO_2, PM10, PM2.5 and PM1 were measured, over total travelled distance of more than 4,000 km.

Analysis of the collected experimental results allowed comparison of internal air pollution for various ventilation methods, assessment of continuous driver exposure to high levels of air pollution for these ventilation methods, evaluation of vehicle age influence on air pollution inside a car, etc. Effects of smoking on air pollution levels were also studied.

***Keywords**: driver exposure, air pollution inside a car, ventilation mode.*

Introduction

It is quite well established now that road users, such as cyclists and especially drivers and passengers, are exposed to higher levels of air pollution than background or curbside data might suggest, Chan et al (1991), Colwill and Hickman (1980), Kingham et al (1998), Rudolf (1994),Van Wijnen et al (1995), Taylor and Fergusson (1998). According to the latter source, road users in the centre of the roadway are likely to be travelling through a tunnel of the most polluted air and this is the principal reason for their raised relative exposure to pollutants.

Despite the fact that ventilation of a vehicle was noted as possibly affecting the level of internal air pollution, Taylor and Fergusson (1998), according to authors' knowledge, there is still lack of detailed studies dealing with the effects of the ventilation mode on air pollution levels inside a car. Chan et al (1991) have performed very limited number of VOC and CO measurements at few ventilation modes. The mode with air conditioning (AC) switched on and introduction of outdoor air into the car was not studied.

In countries with hot climate conditions, the majority of the vehicle fleet is equipped with AC systems, and the driver usually makes a decision about the desired method of car ventilation: without air conditioning and opened window, with AC and internal recirculation of air, or with AC and introduction of outdoor air into the car. Car ventilation by introduction of outdoor air with the AC switched-off and windows closed is also used sometimes.

Objectives

The main objectives of the study presented here are to assess the effects of the ventilation method on air pollution inside the car, and to derive recommendations aimed at reduction of driver and passengers exposure to air pollution.

Methodological approach

The research methodology included a survey, aimed at collection of data on vehicle ventilation "behaviour" of drivers and experimental measurements of air pollution inside cars.

1. Target pollutants

Concentrations of CO, NO, NO_2, PM10, PM2.5 and PM1 were measured in this study. Interscan gas analyzers of models 4140, 4540 and 4150 with electrochemical cells served for measurements of CO, NO and NO_2 concentrations, respectively. Particulates concentrations were measured by the GRIMM 1.107 PM meter that allowed simultaneous measurement in the PM10, PM2.5 and PM1 size ranges.

2. Vehicles tested

Seven cars of different ages participated in the tests. They were divided into two groups: so called "new" vehicles with mileage accumulated not exceeding 25,000 km and so called "old" vehicles with mileage of 150,000 km or more. The cars are listed in Table 1.

Table 1: Vehicles tested in the study.All the vehicles that participated in experiments are typical of the Israeli fleet. They were checked and found to meet the requirements of Directive 2003/27/EC for in-service emission testing.

Car model	Production year	Mileage, km	Doors No.	Saloon type	Tests group
Toyota-Yaris	2005	6,000	5	Hatchback	New
Peugeot-206	2002	23,000	5	Hatchback	New
Peugeot-307	2002	25,000	5	Hatchback	New
Suzuki-Baleno	1998	150,000	4	Sedan	Old
Renault-Express	1994	190,000	3	Minivan	Old
Renault-Clio	1994	260,000	5	Hatchback	Old
Subaru EA71	1993	338,000	5	Station wagon	Old

3. Testing routes

All tests were carried out in the Haifa region on two pre-selected routes representing different traffic conditions. The first route, 3.6 km length, representing downtown urban driving conditions, is characterized by relatively high traffic volumes, low average speed (measured to be about 22 km/h) and flat topography. The second route is an 11.6 km length segment of a main road on the northern entrance to Haifa, characterized by very high traffic volumes (two times more than in the downtown), moderate average speed (measured to be about 41 km/h) and zero road gradients.

4. Data collection and analysis

All readings of the gas analyzers and PM meter, as well as stop events, were logged at 0.33 Hz frequency by a Squirrel 1023 data logger and subsequently analyzed after downloading to a computer. Sampling collection was performed in the driver's breathing zone. Experiments were carried out on both testing routes during all working days of the week, 7 AM - 7 PM. Total travelled distance of more than 4,000 km was accumulated during the measurements, in order to ensure collection of sufficient experimental data. Experiments have been performed during summer – autumn period in Israel with ambient temperatures in the range 20-30 ^{o}C.

5. Testing program

The following car ventilation modes have been tested in the study:

- AC switched on and introduction of outdoor air into the car (vent on), windows closed – "AC out";
- AC switched on, internal air recirculation, windows closed – "AC rec";
- AC switched off, vent on, windows closed;
- AC switched off, vent off, window of the driver fully open – "Window open".

About 170 – 185 trips have been done with each ventilation mode. It is noted that no significant differences were found between results measured at modes (1) and (3). Therefore, only limited number of tests has been performed in mode 3, and these modes are not separated in the discussion hereafter.

Results and discussion

Fig.1 presents results of comparison between average air pollution levels inside a car for different ventilation modes. The data appearing in the figure relate to the “old” cars group and were calculated as weighted average values for both tested routes together. Table 2 contains data with maximal observed values of pollutants concentrations for “new” and “old” car groups.

Figure 1: Ventilation mode effects on air pollution inside a car – "old" cars group.

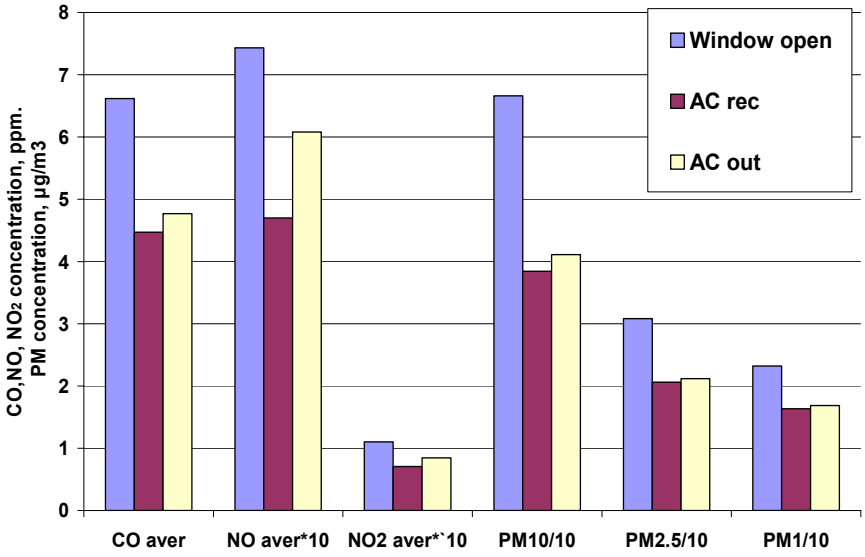


Table 2: Maximal measured values of internal air pollution.

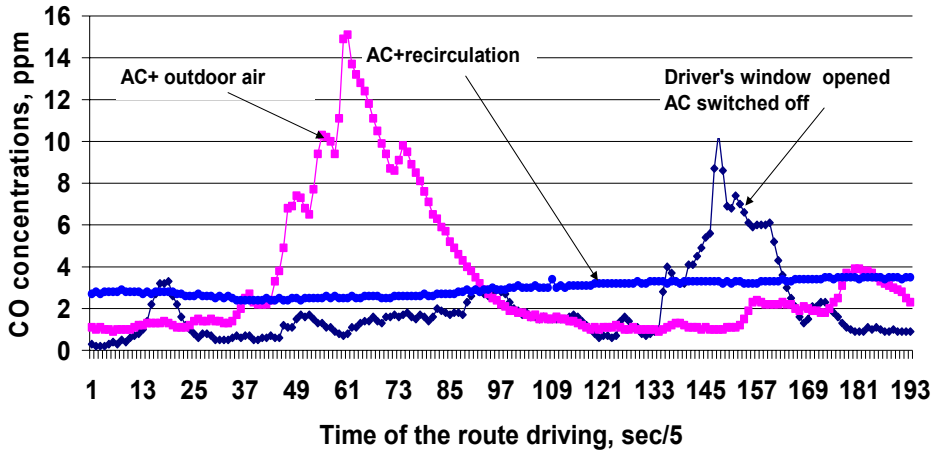
Ventilation mode	Maximal measured values of air pollution inside a car											
	CO, ppm		NO, ppm		NO_2, ppm		PM_{10}, µg/m3		$PM_{2.5}$, µg/m^3		PM1, µg/m^3	
	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old
AC on, recirculation, windows closed (AC rec)	16.6	20.1	1.3	1.45	0.15	0.23	65	122	30	43	26	37
AC on/off, vent on windows closed (AC out)	39	38	1.02	2.24	0.21	0.25	104	200	30.4	109	26	102
AC off, vent off, driver window open (Window open)	18.2	20	1.48	0.85	0.36	0.38	110	197	59	100	55	87

As can be clearly seen from Fig.1, the highest values of air pollution for all measured pollutants were found for the “Window open” ventilation mode with AC switched off, vent off and fully opened driver window. The lowest internal air pollution levels were observed using the “AC rec” ventilation mode with air conditioning switched on, internal air recirculation and windows closed. A

similar trend was found also for the “new” cars group. The differences measured between “AC rec” and “Window open” modes are statistically significant (p-values are less than 0.01 for all pollutants at 95%confidence level) and lie between 42 – 73% (“old” cars) and 22- 97% (“new” cars), dependent on pollutant type – see Table 3.

It is important to note that using “AC rec” ventilation mode results in some kind of “freezing” of air pollution levels inside a car: changes of pollutants concentrations become very slow – see Fig. 2. Therefore, it would be reasonable to use this mode only in clean environments: for example, highly ventilated road with low traffic volume, in order to prevent “freezing” of high air pollution levels inside a car for long exposure times.

Figure 2: Example of internal CO concentrations for different ventilation modes – "new" car.



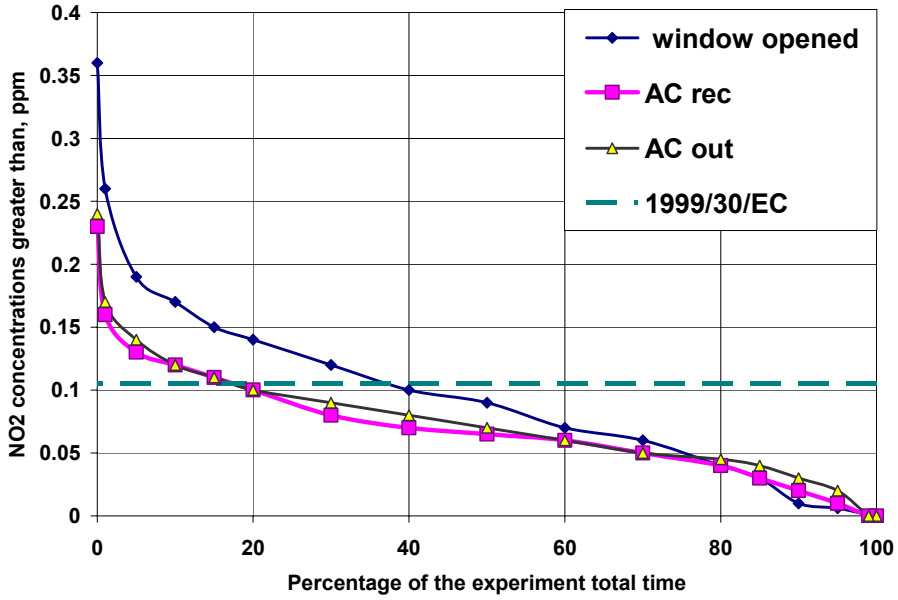
Distribution analysis of the measured air pollution levels inside a car shows (Fig. 3) that regarding NO_2 pollution, if the “Window open” ventilation mode is used, the driver and passengers are exposed to pollution levels higher than 1h limits of the Directive 1999/30/EC (0.2 mg/m3) during about 40 and 60% of the total driving time, for the "old" and “new” cars group, respectively. Driving in the “AC rec” or even “AC out” ventilation modes reduces by more than two times the duration of exposure to pollution levels higher than 1h limits of the Directive 1999/30/EC.

Table 3: Internal air pollution depending on ventilation mode.

Ventilation mode	Air pollution inside a car, %											
	CO		NO		NO_2		PM10		PM2.5		PM1	
	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old
AC on, recirculation, windows closed (AC rec), reference case	100	100	100	100	100	100	100	100	100	100	100	100
AC on/off, vent on windows closed (AC out)	115	107	125	129	144	120	128	107	135	103	143	103
AC off, vent off, driver window open (Window open)	122	148	166	158	172	156	197	173	182	149	188	142

Comparison of internal air pollution levels between “new” and “old” car groups is quite a challenging task, taking into account the large number of factors affecting ambient roadway concentrations of pollutants and the fact that no simultaneous measurements were performed with “new” and “old” cars. Available data do not show statistically significant changes in ventilation mode influence on gaseous pollutants concentrations between groups of different age – see Fig. 4 with an example of NO concentrations. The picture is somewhat different for PM concentrations – see Fig.5. As can be seen from this figure, the average measured PM10 levels in the “Window open” ventilation mode were higher by 17% for the “new” cars group, which most probably followed from higher ambient roadway PM10 concentrations. Despite this fact, in the “AC rec” mode for the “new” cars group, lower average PM10 levels by approximately 25% were measured. A possible reason for this could be the better sealing of new cars and, probably, higher efficiency of new air filtration systems. A similar trend was observed also for PM2.5 and PM1 concentrations. The changes observed are statistically significant – p-values are less than 0.01 at 95%confidence level.

Figure 3: Distribution of internal measured NO_2 concentrations – "old" cars group.



Special series of experiments were carried out on a separate route without traffic (inside the university campus), in order to assess effects of smoking inside a car on driver exposure to air pollution. All these experiments were carried out only in "Window open" ventilation mode with two types of smoking: smoking out of the opened window (so called "passengers friendly smoking") and smoking inside the vehicle. The results are shown in Fig. 6. As can be seen, smoking inside the car leads to a dramatic increase in air pollution levels, especially, but not only, PM concentrations. In case of smoking "outside of the vehicle" (Fig. 6a), measured PM10 concentrations increased by 5 times and PM2.5 – by 8 times. It is noted that for this smoking pattern, ultra-fine particles PM2.5 reach above 90% of the total PM10. In case of smoking inside the car (Fig.6b), the observed PM levels were extremely high and approached 2400 µg/m3 (PM10) – almost 50 times more than the ambient 24h limit of the Directive1993/30/EC. Measured PM2.5 concentrations increased, as a result of smoking inside the car, by approximately 90 times and reach about 98% of the total PM10.

Figure 4: Comparison of average internal NO concentrations for "new" and "old" cars.

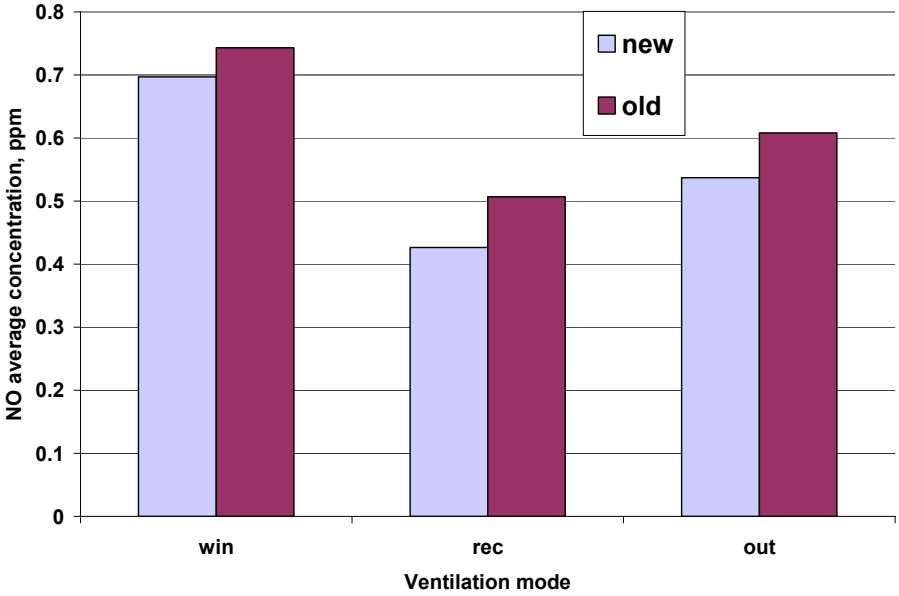


Figure 5: Comparison of average internal PM10 concentrations for "new" and "old" cars.

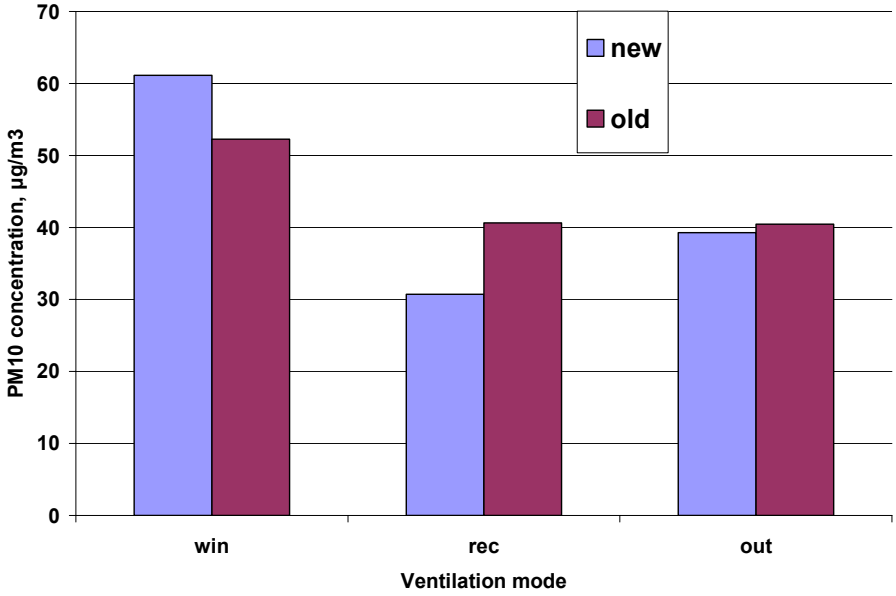
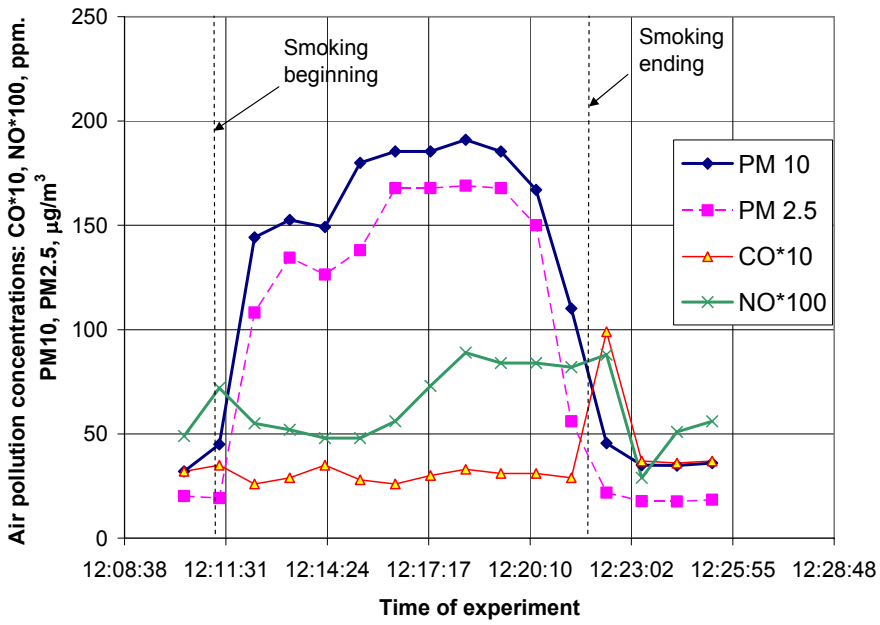
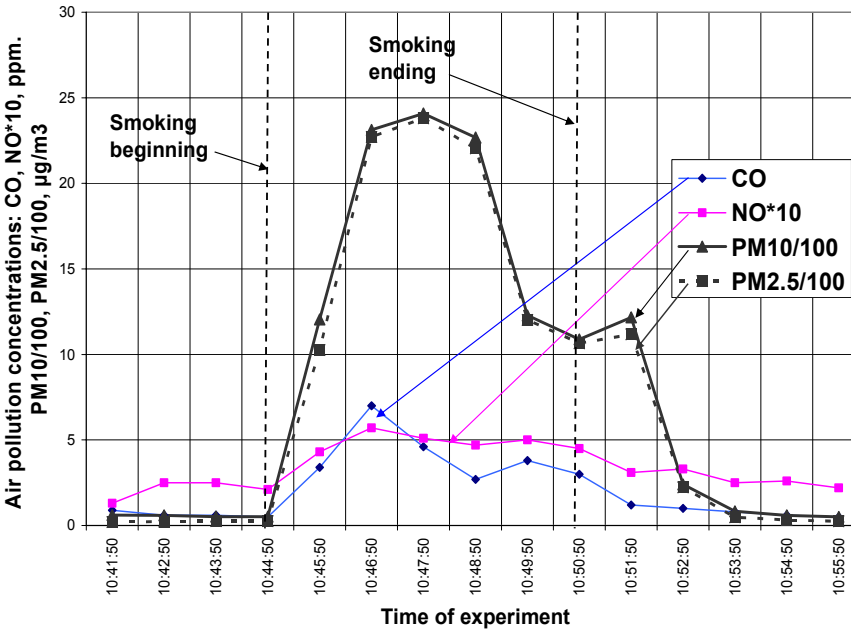


Figure 6: Effects of smoking inside the car on air pollution levels.



a) Smoking "outside" the vehicle



b) Smoking inside the vehicle

Conclusions

The highest values of air pollution for all measured pollutants were found for the ventilation mode with AC switched off, vent off and fully opened driver's window. The lowest internal air pollution levels were found at the ventilation mode with air conditioning switched on, internal air recirculation and windows closed. The differences between these modes were statistically significant (p-values are less than 0.01 for all pollutants at 95% confidence level) and lied in the range 42 – 73% (“old” cars) and 22 – 97% (“new” cars), dependent on pollutant type. The smallest changes (22 – 48%) were observed for CO concentrations.

It is recommended to switch on the "AC rec" ventilation mode only in clean environments: for example, highly ventilated road with low traffic volume, in order to prevent “freezing” high air pollution levels inside a car for long exposure times.

Measured data do not show statistically significant changes in ventilation mode influence on gaseous pollutants concentrations between groups of different age. Regarding PM pollution, better sealing of new cars and, probably, higher efficiency of new air filtration systems allow lower PM concentrations inside a car of lower age, if the “AC rec” ventilation mode is used.

Smoking inside a car leads to dramatic increase in air pollution levels, especially, but not only, PM concentrations. In the case of smoking "outside" the vehicle, measured PM10 concentrations increased by 5 times and PM2.5 – by 8 times. In the case of smoking inside the car, the observed PM10 levels were extremely high and approached 2400 µg/m3 – almost 50 times more than the ambient 24h limit of the Directive1993/30/EC. Measured PM2.5 concentrations increased, as a result of smoking inside the car, by approximately 90 times and reach about 98% of the total PM10.

It is noted that completion of the study by additional measurements of volatile organic compounds concentrations would definitely enrich the gained knowledge and would provide more information about the effects of different ventilation modes on driver and passengers exposure.

Acknowledgments

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Laser Ablation-ICP-MS as a tool to identify autocatalyst particles in urban road dust

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Abstract

The Laser Ablation Inductively Coupled Plasma Mass Spectrometry technique (LA–ICP–MS) has been applied for tracking the occurrence of autocatalyst particles, emitted with car exhaust fumes in the order of few ng/km, in urban dusts and soils. The high intensity signals of Ce and PGEs, joint to the time simultaneity of these peaks, reveals the presence of wash-coat fragments in the samples, since the signals of these analytes are extremely lower and not time linked in particles not related to catalytic converters.

The even up to now limited enrichment of catalyst particles in dust and urban soil is a consequence of air pollution and particle deposition. These particles, after their dispersion in the atmospheric particulate, are deposited along roadside areas.

Our analytical result confirm that LA–ICP–MS can successfully track and identify catalyst particles in road dust although they are present in the order of some tens of ng/g, and the characteristic association of Ce and PGEs peaks is a valid approach for distinguish the source of the PGEs enrichment.

Keywords*: Laser Ablation; ICP-MS; Autocatalyst; Exhaust fumes; Urban environment; Platinum Group Elements.*

Introduction

Road traffic is the main and abundantly widespread contamination source of urban areas, because cars represent a mobile source of pollution that can involve different sites in a little time, producing harmful gas and particles. The fuel combustions mainly release NO_x, CO and hydrocarbons (HC). The PGEs based autocatalysts promote the conversion of these pollutants in CO_2, N_2 and H_2O. Autocatalysts are made of a honeycomb structure in ceramic or metallic material, which is crossed by the exhaust fumes, coated by an alumina layer (wash-coat) on which the PGEs are deposed. However, the thermal and mechanical degradation of catalysts lead to the release of wash-coat particles, in the order of few ng/Km, distributed in a wide range of sizes: the most

abundant fraction have a diameter >10µm (~66%), while the portion in the range of 3.1-10µm and the one <3.1µm are respectively 21% and 13% (Artelt et ali, 1999). These particles are primarily dispersed in air and then mainly deposited in the road-side environment (road dust and soil) in few hours, because the major fraction is fairly heavy and can't be reside in air for long time. On the other hand, the fraction <10µm can reside in air even for days or weeks, and, due to the small dimension, can reach the tracheobronchial region and the lungs (Artelt et ali, 1999). Besides, the catalyst particles accumulated in soils may alter, in time and in its upper layer, the geochemical background of PGEs, because platinum, palladium and rhodium are generally presents in soil at ng/g levels (Angelone et ali, 2006a; Cinti et ali, 2002). Moreover, a fraction of PGEs emitted by catalyst, even though it's a small fraction, may be transformed into bioavailable species (Alt et ali, 1997; Zereini et ali, 1997; Lustig et ali, 1998) as a result of the interaction with the environment (depending of soil pH, sulphur concentrations in soil, water pH and water chlorides content). For these reasons, the traffic and autocatalyst related pollution represents a hazard for the air quality, the environment and for the human health.

Usually, the studies on environmental samples for the autocatalyst pollution are based on acid dissolution (performed on dust, soil, particulate-filters, etc.) followed by ICP-MS. This is the analytical technique that offer the best performances, in term of limit of detection and limit of quantitation, for PGEs (Angelone et ali 2006b). This is an efficient approach for total quantitative purposes, but in this way it's impossible to track the contribution directly derived by autocatalyst. In fact, at the end of an acid dissolution we have a solution that represent the total amount of the analytes in the sample, but, at this point, it's not more possible to distinguish the PGEs contribution derived from autocatalyst and the PGEs contribution derived from other source (e.g. parent-material contribution in soil samples).

Laser-Ablation-ICP-MS is an analytical technique commonly used for mineralogy or material-science purposes, but, as demonstrated in previous works (Motelica-Heino et ali, 2001; Rauch et ali, 2002), it can be successfully adapted for recognize catalyst particles. A Laser-Ablation system can work directly on solid materials without any pretreatment (Thomas, 2003), and so it's possible to identify any variation in the sample composition linked to its dishomogeneity. In fact, apart from the specific model of autocatalyst, the honeycomb structure has always a high concentration of Ce in association to concentrations of PGEs significantly higher than the background ones. Such composition is not common in the environment and represents a characteristic fingerprint for the autocatalyst particles. For this reason, the association of high concentrations of Ce and PGEs is the best evidence for identify and track catalyst particles in urban samples.

Experimental

1. Sampling and preparation

For this study three environmental matrices exposed to traffic pollution, collected in urban areas of Latium (Central Italy), were analyzed: road dust, urban soil and tunnel dust. In addition were analyzed also used autocatalysts, with the aim to have a characterization of the pollution source.

Road dust samples were collected directly on roadway, using a brush and a shovel, in 9 sites in the urban area of Viterbo. Each sample of road dust was dried and then sieved for the fraction <63µm (this fraction was used for both quantitative analysis with ICP-MS and qualitative analysis with LA-ICP-MS).

Urban top soil samples were collected in 31 sites in the Viterbo area digging in the first 5 cm from the surface and considering also the distance from the road. Each soil sample was dried and two sub-samples was sieved at 2 mm (for the quantitative analysis with ICP-MS) and at 63µm (for qualitative analysis at LA-ICP-MS).

Tunnel dust samples were collected, instead, in 4 sites in Rome, applying the same procedure adopted for road dust. These samples were dried and sieved for the fractions <20µm and 20-63µm. Considering that tunnels are circumscribed sites, and characterized by a limited air circulation, their dusts are consequently much enriched in catalyst fragments and are appropriate to study the distribution of catalyst particles in the different sample's fractions.

We have selected, in particular, the fraction below 63µm because, as can be found in literature, this is the sample's fraction with the highest environmental relevance (Gómez et ali, 2001). This is, consequently, the fraction generally used for studying the autocatalyst pollution. Besides, since the exhaust fumes release prevalently particles >10µm, it's assumed that the urban samples are enriched specially in particles between 10-63µm. This assumption was confirmed by a study on airborne particulate matter (Gómez et ali, 2001), in samples collected in the same site, using WRAC collectors (for the fraction 10-65.3µm) and PM-10 collectors (<10µm), where the results showed a lower Pt content in PM-10 samples. Therefore, considering that road dust and soil are sensibly richer in particles >10µm respect the airborne particulate matter, since the particles larger than 10µm can remain suspended in air for a short time, it's reasonable to identify in the 10-63µm range the fraction most abundant in catalyst particles.

Aged autocatalyst were taken from two cars: one of them was based on a ceramic honeycomb, while the other one on a metallic honeycomb. Each catalyst sample was ground and retained for analysis.

Before to perform LA-ICP-MS analysis, all samples were analyzed for the total quantification of the elements related to traffic pollution (especially Pt). These analysis were performed with ICP-MS (Perkin Elmer-ELAN-6100), after an acid dissolution based on an acid mixture of $4HNO_3+1H_2O_2+2HF+1HClO_4$. Spectral interferences were corrected using the following formula: $S_{A,c} = S_{A,m} –$

($S_{I,m}$ X R) where $S_{A,c}$ is the corrected analyte intensity, $S_{A,m}$ and $S_{I,m}$ are the analyte intensity and the interfering element intensity measured in the sample solution, and R is a correction coefficient obtained from standard solutions with appropriate concentration of the interfering element. The analytical procedure was validated with the use of four certified reference materials (Table 1).Compared to conventional ICP-MS, LA-ICP-MS is less subjected to spectral interferences since, not using dissolution or dilution, are sensibly reduced the formation of polyatomic species (Thomas, 2003). The results of ICP-MS quantitative analysis (Table 2) were then used to select some samples of dust and soil on which perform the LA-ICP-MS. In fact, the road dust sample, the tunnel dust sample and the soil sample with the highest Pt concentrations were selected for LA-ICP-MS study (Table 3). The single catalyst particles, however, are up to now extremely rare in urban samples, and it's very difficult to find them in a solid and heterogeneous sample such as soil or dust, therefore, with the selection of the most enriched samples, we tried to gain the maximum probability to find them within the minimum time.

Table 1: Pt means concentration in certified reference materials (CRM) used to validate the analytical procedure

CRM	Pt (certified values)	Pt (this study)
WGB-1	6,1±1,6 (ng/g)	6,89±0,72 (ng/g)
BCR-723	81,3±3,3 (ng/g)	81,74±5,31 (ng/g)
NIST-2556	697,4±2,3 (mg/Kg)	673,18±16,42 (mg/Kg)
NIST-2557	1131±11 (mg/Kg)	1044±78,47 (mg/Kg)

Table 2: Pt means concentration in the different environmental matrices of Latium and in used autocatalysts

SAMPLES	Pt
Urban soil (mean concentration of 31 samples)	10.27±3.57 (ng/g)
Road dust (mean concentration of 9 samples)	110.19±26.47 (ng/g)
Tunnel dust (mean concentration of 4 samples)	344.40±249.78 (ng/g)
Ceramic aged autocatalyst (mean concentration of 6 replicates)	990±21.02 (mg/Kg)
Metallic aged autocatalyst (mean concentration of 6 replicates)	2424±89.10 (mg/Kg)

Table 3: Pt concentration in the urban samples selected for LA-ICP-MS analysis

Urban matrices	Pt
Urban soil	19.99 (ng/g)
Road dust	146.78 (ng/g)
Tunnel dust	702.04 (ng/g)

Samples used for LA-ICP-MS analysis were fixed on adhesive tape (Scotch 3M, two sided transparent, 12mm x 6.3mm) and then placed in the ablation cell.

The use of sticky strips is preferred for the LA-ICP-MS analysis of urban matrices, because, in this way, the sample's particles are more dispersed and it's more probable for the laser beam to hit a single particle or small groups of particles.

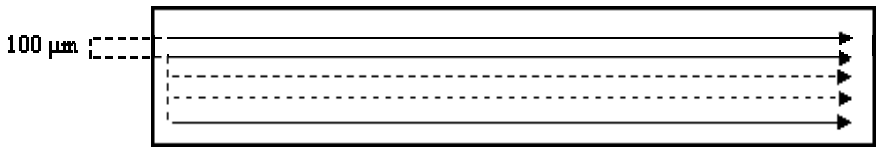
2. Laser-Ablation parameters

The elemental association in solid samples was investigated with a Cetac-LSX-200 laser ablation system, joined to a Perkin-Elmer-ELAN-6000 ICP-MS. Each sample, putted on its sticky strip, was placed in the laser sampling chamber of the LSX-200, then focused respect the laser pointer and, at last, ablated toward a line by the laser beam. The laser ablation system requires numerous settings, but one of the most important, in this case, is the spot-size of the laser beam. Previous studies (Rauch et ali, 2000) shown that element's associations in particles could be obtained when the laser is adjusted with a small spot size (10µm), that grant a better resolution, together with a low energy, that allow ablating only the particles surface. In our study, that is a preliminary approach to the use of laser-ablation, we have differently settled the instrument. Since the catalyst particles have hugely greater concentrations in Ce and PGEs (and a different elemental association) respect the other particles in the samples, also a bigger spot size (lower resolution) permit to discern them. In addition, since the samples ablated were sieved for the fraction <63µm, and because the majority of the catalyst particles has a dimension >10µm, a spot-size of 50µm was preferred. This spot dimension, besides, ensure that the time required for each scanning session is not excessively long. The scanning time is a very important aspect in a study like this one. In fact, considering that the catalyst particles are present in limited number in urban samples, several ablation lines are necessary before to find one of them. Consequently, the smaller the spot-size is, the longer will be the time of analysis. For these reasons, a spot-size of 50µm represents a good balance between a laser beam compatible with the particle size and a scanning time not too long. It is evident that a sample sieved at 63µm will contain also particles lower than 50µm. However, since the sample was dispersed on a sticky strip, the particles are not too compacted; in other word they are sufficiently separated, and therefore the laser beam can generally successfully ablate single particles. A summary of LA-ICP-MS parameters adopted is reported in table 4.

Table 4: LA-ICP-MS parameters

LASER ABLATION		ICP-MS	
Spot size	50 µm	Analytes	^{103}Rh, ^{140}Ce, ^{195}Pt
Scan rate	50 µm/s	Dwell time	30 ms
Energy	~3.2 mJ	Sweeps per reading	10
Repetition rate	20 Hz	Data acquisition	Peak hoping

Fig. 1: Scheme of ablation lines (the bold rectangle symbolize the sticky strip).



3. Scanning Laser-Ablation execution

The graphs concerning road dusts and urban soil (Fig. 2-8) were obtained from several single ablation lines. Each line has crossed the sample for all its length (that is the length of the sticky strip) and, at the end of each line, the laser was stopped and its pointer was moved down of 100µm for ablate a new line in another zone of the sample (Fig. 1.). The LSX-200 system can perform also a continuous ablation trough a path of connected multiple lines; our ICP-MS software, however, didn't allow to perform more than 1000 replicates, therefore, considering that each urban sample was scanned in total at least for one hour, was impossible to ablate a unique and continuous segmented line, and for this reason we have chosen to execute more single lines. Each graph about dust or soil, consequently, has been obtained by joining in a single diagram the results of a sequence of several single ablation lines (16 lines for dust analysis and 40 lines for soil analysis).

Results

1. Scanning laser-ablation on road dust

The diagram obtained for a sample of road-dust (Fig. 2) show clear peaks of Ce and PGEs (so much elevated to shift the magnitude of the Y axis to such a level that the baseline signals are quite invisible). This is a first clue that will allow us to recognize the catalyst particles; in fact, this suggests that there are, in the sample, particles with very high concentrations of Ce and PGEs (signal intensity is proportionally to analyte concentration).

Moreover, the peaks appear exactly at the same time, and this means that those high concentrations have been found in the same part of the sample. This is our second evidence, because the simultaneous presence of Ce and PGE in the same particles is not common (unless the particles derive from a catalyst).

The definitive proof was obtained from a laser-ablation analysis made on a catalyst sample (Fig. 3): the signal intensities of Ce and PGEs, in fact, have the same order of magnitude of those found in urban samples. This validate that the peaks found in road dust can undoubtedly be associated to a catalyst particle.

Fig. 2: Scanning laser-ablation on road-dust.

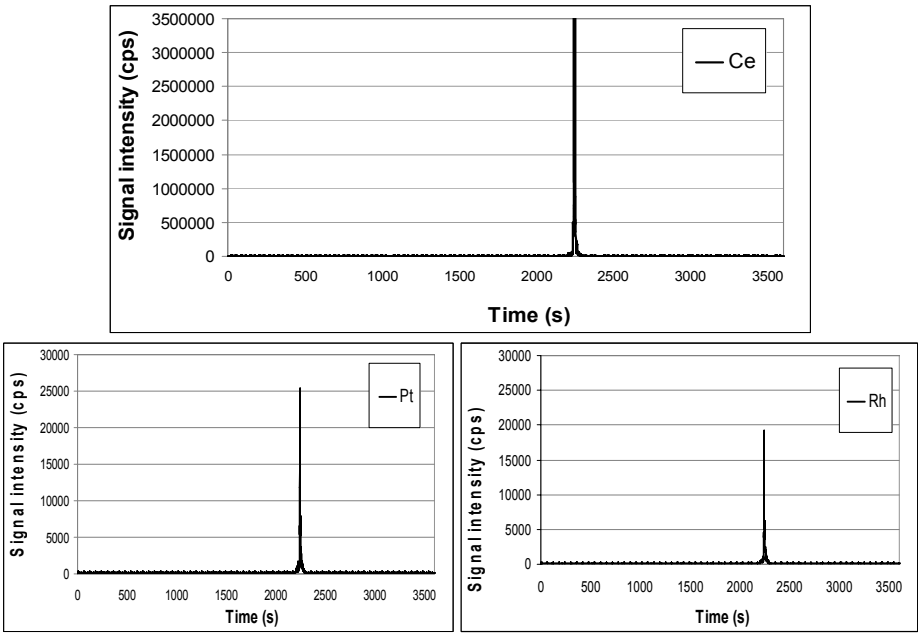
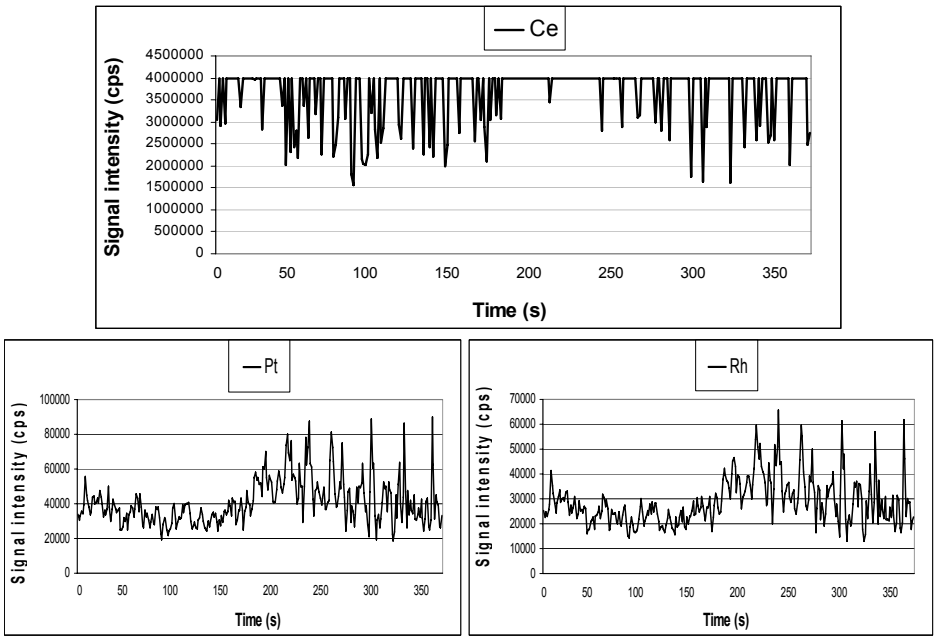


Fig. 3: Scanning laser-ablation on autocatalyst.



2. Scanning laser-ablation on urban soil

The analysis across urban soil (Fig. 4) required more time, in order to find out peaks that were similar to those found in road dust, because the catalyst particles are less abundant in such samples. Once more, the peaks of Ce and

PGE are clearly distinct from the baseline signal and have the same magnitude of the ones found in catalyst samples.

Fig. 4: Scanning laser-ablation on urban soil.

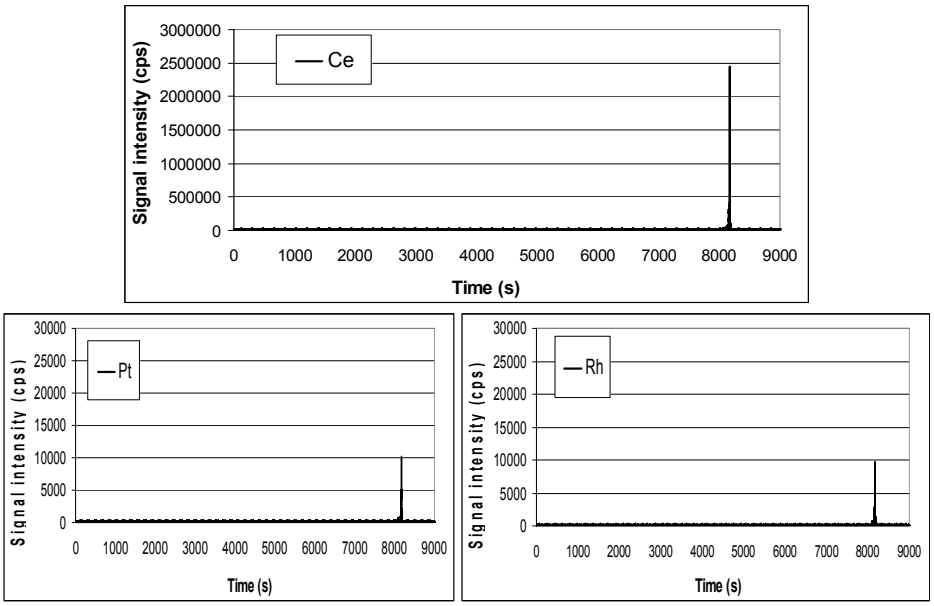
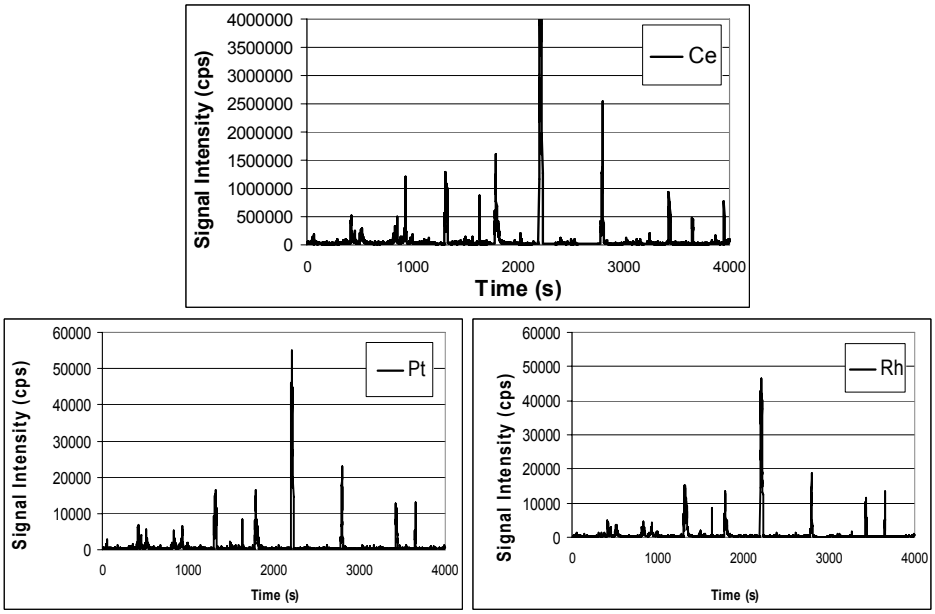


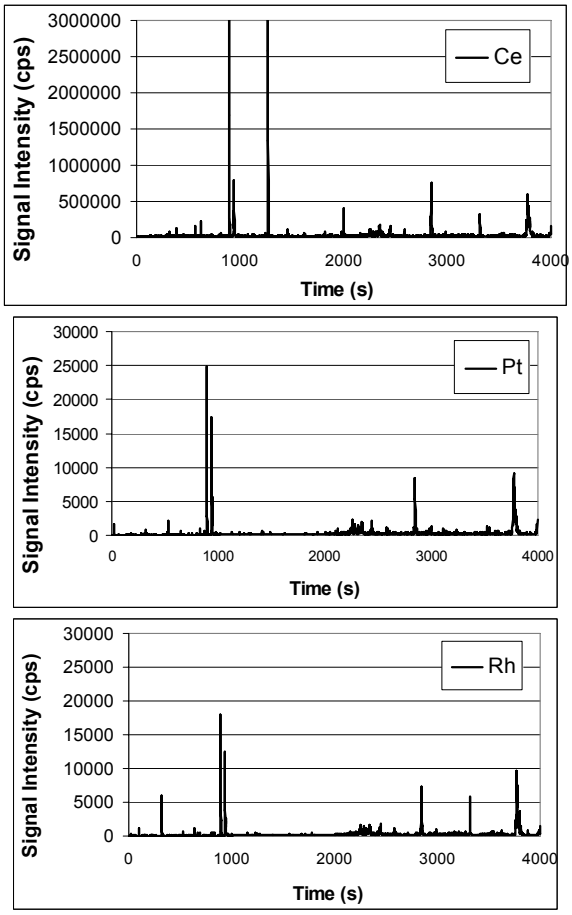
Fig. 5: Scanning laser-ablation on tunnel dust (20-63µm fraction).



3. Scanning laser-ablation on tunnel dust

Each of the two fractions obtained from tunnel dust (<20µm and 20-63 µm) were analyzed, always with a sequence of parallel lines, for a total time of 4000 seconds. The 20-63µm fraction was characterized by more Ce-PGEs peaks than the <20µm fraction (Fig. 5-6). This is a further confirmation about the assumption that defines the 20-63µm fraction the one most enriched in catalyst particles.

Fig. 6: Scanning laser-ablation on tunnel dust (<20µm fraction).

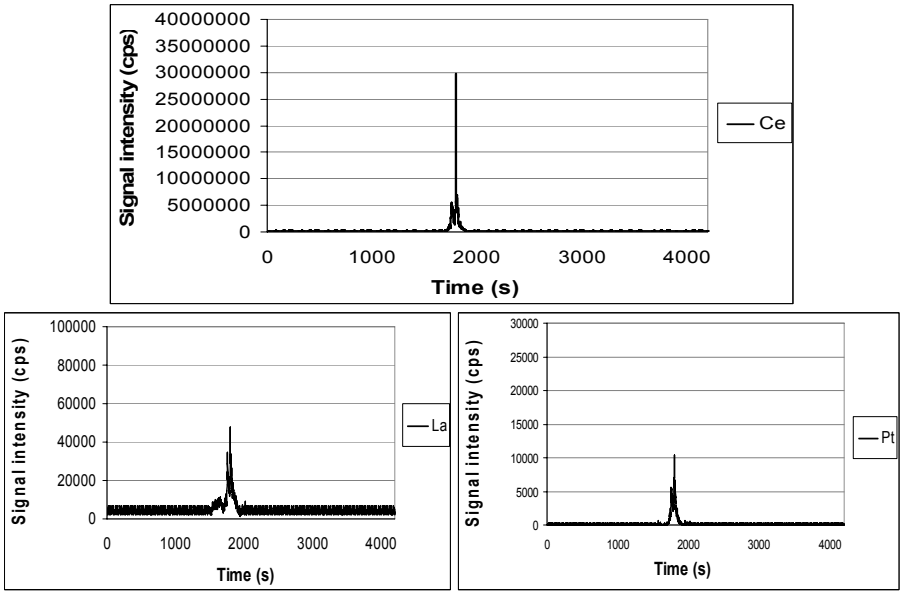


4. Other elemental association for tracking catalyst particles

Apart from Ce and PGE, there are other elements that could be abundant in a catalyst (with higher concentration regarding the “urban” background) and that could be used for tracking the catalyst particles in the environment. La, at example, is the rare earth element mainly used, after Ce, in the catalyst’s structure. However, while Ce is always present in extremely high concentrations, La presence in a catalyst is very variable (depending on the catalyst type). In fact, carrying out some scanning laser-ablation tests on

samples enriched with different type of crushed catalyst, we verified that La can't be used always to trace catalyst particles. We used two type of crushed catalyst: one with a ceramic structure (La=412 mg/Kg) and another with a metallic structure (La=78 mg/Kg). Particles from metallic catalyst didn't produce signals that were distinguishable from the baseline (background concentration of La in urban samples of Viterbo was 85.02 mg/Kg), while particles from ceramic catalyst generated well distinguishable peaks (Fig. 7).

Fig. 7: Scanning laser-ablation on enriched sample.



Conclusions

Particles rich in PGE and Ce are emitted from catalyzed automobile with the exhaust fumes. These particles are mostly deposited on the roads as road dust or on the road-side soils.

The elevated amounts of Ce and PGE in catalyst particles (that are in higher concentration compared with particles of other sources), joined to the characteristic association of these elements, make possible to distinguish them in urban solid samples with the use of LA-ICP-MS.

Although Ce-PGE is the best association for tracking catalyst particles, we verified that also the La-PGE association can be used, in some cases, for this purpose.

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Contribution à la connaissance de l'exposition en habitacle automobile
Contribution to knowledge of exposure in car passenger compartments

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Résumé

Au cours de sa journée, un citadin répartit essentiellement son temps entre son domicile, son lieu de travail et les transports individuels ou collectifs. La dose reçue à l'échelle d'une journée, est la somme des doses reçues dans ces différents micro-environnements.

Le projet présenté ici a pour objectif l'étude des niveaux et de la dynamique de polluants entrant dans un micro-environnement particulièrement important, l'habitacle automobile.

Pour ce faire, un véhicule a été équipé de deux analyseurs de NOx (TEI), d'un analyseur de CO (Maihak), d'un granulomètre (ELPI / DEKATI) et d'un compteur de particules (P-Track / TSI).

Les mesures ont porté sur l'air fourni en sortie de l'aérateur de l'habitacle.

Des « roulages » ont été effectués, dans différents milieux tels qu'une autoroute, ou le périphérique parisien, ainsi qu'au niveau d'un tunnel donné, de nuit, à la suite d'un véhicule de nature connue pour une distance connue.

Mots-clefs : *habitacle, automobile, exposition, particules ultrafines, Nox.*

Abstract

1) Objectives

During a typical day a person's time is mostly divided between their home, workplace and either public or private transport. The dose received over the timescale of a day is the sum of doses received in these different micro-

environments, which supposes knowledge of the time spent in each of them as well as the quality and variability of pollutant concentrations.

The aim of the project presented here is to study the levels and dynamics of pollutants entering a particularly important micro-environment, that of the passenger compartment. This is done by considering:

- nitrogen oxides, carbon monoxide, particle number and size;

- monitoring exposure during various trips (highway, beltways);

- taking into account factors that influence exposure, such as the distance between the source vehicle and the target vehicle.

2) Method

A vehicle was equipped with two NOx analysers (TEI), a CO analyser (Maihak), a granulometer (ELPI / DEKATI) and particle counter (P-Track / TSI).

The measurements focused on the air expelled at the outlet of the passenger compartment ventilator.

Trips were made in different environments such as a highway and the Paris beltway, as well as in a tunnel at night behind a known type of vehicle for a known distance.

3) Results and conclusions.

Orders of magnitude of concentration were determined for the pollutants considered for different exposure conditions (open and closed environments, and light and heavy traffic).

During tunnel driving tests, a clear link was established between exposure characteristics on the one hand and, on the other, factors such as the nature of the vehicle followed, its engine rating and the distance separating the target and the source.

***Keys-words**: paper presentation, proposal, conference, communication, references.*

Introduction

Au cours de sa journée, un citadin répartit essentiellement son temps entre son domicile, son lieu de travail et les transports individuels ou collectifs. Il respire donc principalement les atmosphères de locaux fermés, que nous qualifions ici de « micro-environnements ».

La dose reçue à l'échelle d'une journée, est la somme des doses reçues dans ces différents micro-environnements, ce qui suppose la connaissance d'une part du temps passé dans chacun d'entre-eux, et d'autre part du niveau et de la variabilité de la concentration en polluants.

A ce titre, et tout particulièrement en ce qui concerne le mode de vie citadin, les habitacles automobiles jouent un rôle important, puisqu'ils concernent une grande partie de la population, et qu'ils sont caractérisés par une forte exposition aux polluants issus du trafic. En effet, ce type de micro-environnement se situe dans le panache des émissions des autres véhicules. Parmi les composés issus du trafic automobile on trouve notamment le monoxyde de carbone, les oxydes d'azote et les particules.

La campagne a été menée du 28 juin au 9 juillet 2004. L'ensemble des moyens ont été basés sur le site du CERTAM, à Rouen.

Dispositif

1. Véhicule

L'ensemble des appareils de mesure a été installé dans un véhicule utilitaire Renault Kangoo appartenant au CERTAM

Une remorque adjointe à l'utilitaire a permis le transport du groupe électrogène de 3,7kW alimentant les appareils de mesure.

Le fonctionnement des divers appareils dans l'utilitaire et du groupe électrogène entraîne différents rejets qu'il a fallu prendre en compte.

Le groupe électrogène est effectivement une source de particules et de polluants gazeux. Pour supprimer leur impact, ses rejets ont été détournés tout à l'arrière de l'unité mobile. De plus, pour être certain qu'ils n'avaient aucune influence, nous avons pris en compte pour notre étude, uniquement les mesures réalisées en mouvement.

Les analyseurs d'oxydes d'azote présents dans le véhicule utilitaire sont des sources d'ozone. Pour protéger les expérimentateurs nous avons donc évacué ces émissions à l'extérieur du véhicule. Les autres rejets des appareils, non toxiques, n'ont pas fait l'objet d'une évacuation spécifique.

2. Prélèvement des échantillons

L'ensemble des résultats présentées dans notre étude est constitué de mesures réalisées sur l'air entrant dans l'habitacle, et non sur ''l'air intérieur'' au véhicule.

Ce choix se justifie en premier lieu par la contribution de l'ensemble des appareils de mesures présents dans le véhicule d'analyse à la pollution de l'habitacle. De plus, ce mode de prélèvement présente un autre avantage : il dépend très peu de la configuration du véhicule. Ainsi, les valeurs mesurées peuvent être comparées à celles d'une autre voiture. A l'inverse, des mesures directement réalisées dans l'habitacle sont spécifique d'un volume particulier, elles sont liées à une problématique plus complexe et font intervenir des paramètres tels que le nombre de personnes dans l'habitacle, leur comportement et l'équipement du véhicule (chauffage, climatisation, etc.).

3. Instrumentation

Les deux analyseurs de gaz utilisés au cours des roulages sont des analyseurs NO/NO2/NOx à chimiluminescence THERMO ENVIRONMENTAL INSTRUMENTS / MEGATEC , modèle 42-C.

Une mesure du CO a été assurée à l'aide d'un analyseur à Infra Rouge MAIHAK modèle UNOR 610.

En ce qui concerne la mesure des particules, nous avons mis en œuvre l'impacteur basse pression DEKATI ELPI (7 nm – 10 µm) ainsi que le compteur de particules CNC P-Track de TSI (20 nm – 1µm).

Résultats

1. Représentativité du point de mesure vis-à-vis de l'exposition du conducteur

L'essai présenté ici a pour objectif de comparer les résultats obtenus avec le mode de prélèvement habituel, avec les caractéristiques de l'air directement respiré par le conducteur. Nous l'avons basé sur la mesure du NO.

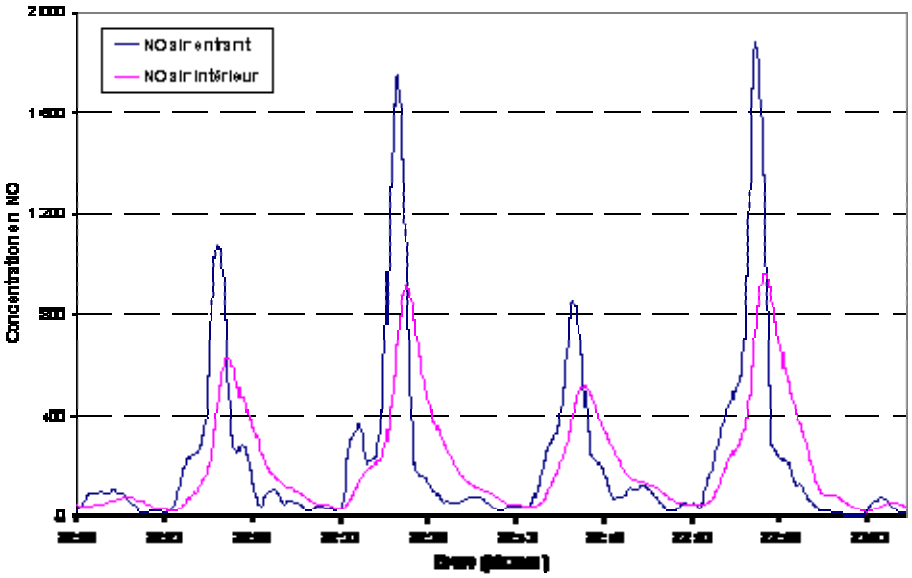
Afin de disposer d'une source continue de NOx devant le véhicule, un véhicule essence non catalysé a été suivi, sur autoroute avec passages successifs au sein du même tunnel.

La comparaison entre air entrant et air intérieur montre :

- tout d'abord une période de ''protection'' où la concentration de l'air intérieur est inférieure à celle de l'air entrant ;
- puis une phase de ''rémanence'' pendant laquelle la pollution au niveau du conducteur persiste alors qu'il n'y a plus d'entrée de NOx dans l'habitacle. Ce phénomène perdure ici 3 mn 30 après la fin de l'épisode.

Figure 1 :Profils temporels de la concentration en NO dans l'air entrant et dans l'air intérieur sur un parcours autoroutier avec passages en tunnel.

Figure 1 :NO time series for fresh air and indoor air.



L'intégration des deux pics indique une surface identique pour chacun d'eux. Ainsi, les deux points de prélèvement ont été soumis à la même quantité de polluant. Ceci suggère que les deux mesures sont équivalentes en terme de quantification des doses reçues.

2. Ordres de grandeur

Le tableau ci-dessous résume les résultats généraux obtenus à l'aide du CNC, au cours de deux roulages, l'un sur l'autoroute A13 (Rouen-Paris), l'autre sur le périphérique parisien. La figure 2 présente un exemple de mesurage de la concentration des particules.

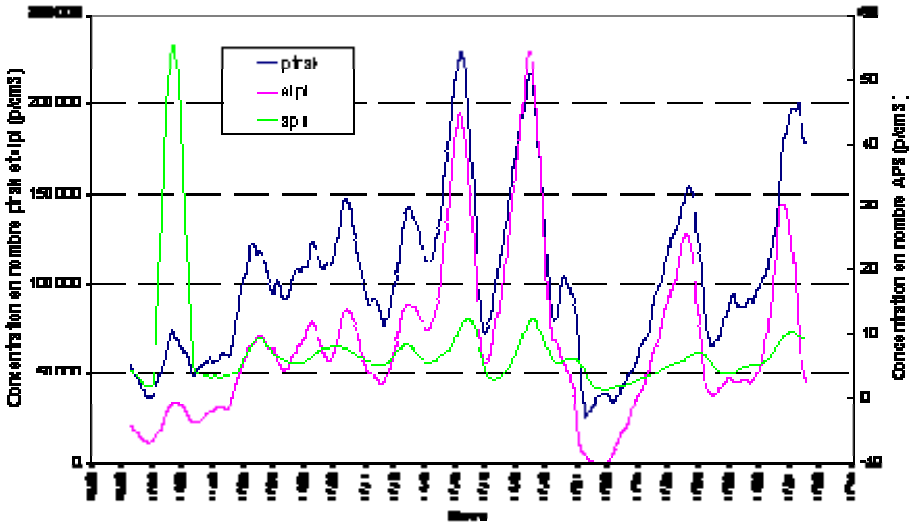
Tableau 1 :Ordres de grandeur de la concentration en nombre mesurée sur le périphérique parisien et l'autoroute A13.

Table 1 :number concentration levels during the highway A13 trip, and the « périphérique » trip.

	Valeur maximum	Valeur minimum	Niveau de fond	Niveau moyen
Périphérique parisien	230 000 p/cm3	25 000 p/cm3	110 000 p/cm3	75 000 p/cm3
Autoroute en milieu rural	220 000 p/cm3	3 800 p/cm3	64 000 p/cm3	10 000 p/cm3

Figure 2 :Profil temporel de la concentration en nombre en habitacle lors d'un parcours sur le périphérique parisien (résultats moyennés sur 60 s).

Figure 2 :example of particle concentration time serie during the « périphérique » trip (60s average)



Ces résultats montrent une variabilité très importante des concentrations observées, d'une minute à l'autre (figure 4), voire même en fait, d'une seconde à l'autre.

Le fait que l'autoroute représente majoritairement un espace « ouvert », implique que le niveau de fond est base, et l'exposition lié essentiellement à la présence dans un panache.

Dans le cas du périphérique, nous nous situons en milieu urbain, bien souvent encaissé voire semi-clos (tunnel), en présence d'une densité de voiture beaucoup plus importante, et avec une proximité plus nette.

Ceci explique un minimum et un niveau moyen beaucoup plus hauts.

3. Influence de la distance vis-à-vis du véhicule précédent

Cet essai a pour but de caractériser les variations de l'exposition aux polluants dans l'habitacle d'une voiture, en fonction de la distance au véhicule la précédent.

Le véhicule suivi est une voiture de tourisme Citroën Picasso à motorisation Diesel Hdi 2 sans FAP.

Afin de simplifier au maximum les conditions de l'expérience pour éviter l'interférence de paramètres autres que la distance au véhicule émetteur. Ainsi, les mesures ont été réalisées en tunnel. En effet, les mesures réalisées en tunnels sont beaucoup moins soumises aux facteurs de variation tels que le vent. Par ailleurs, pour limiter l'influence du trafic automobile, l'essai a été réalisé entre 23h30 et 01h30 du matin, pendant une période de trafic réduit.

Figure 3 : Exposition aux particules (7 nm - 10 µm) mesurée par l'ELPI pour différentes distances au véhicule émetteur.

Figure 3: Exposure to particles (7 nm - 10 µm) measured with ELPI for three distances between the target and the source.

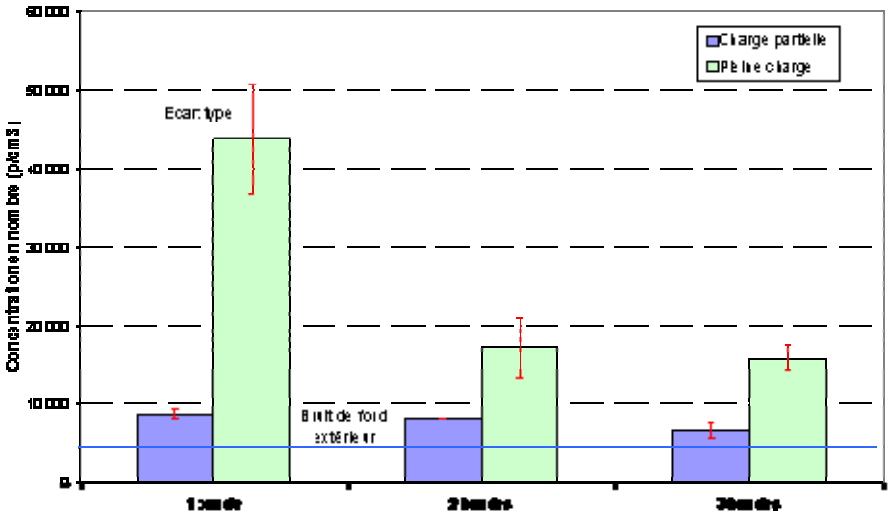
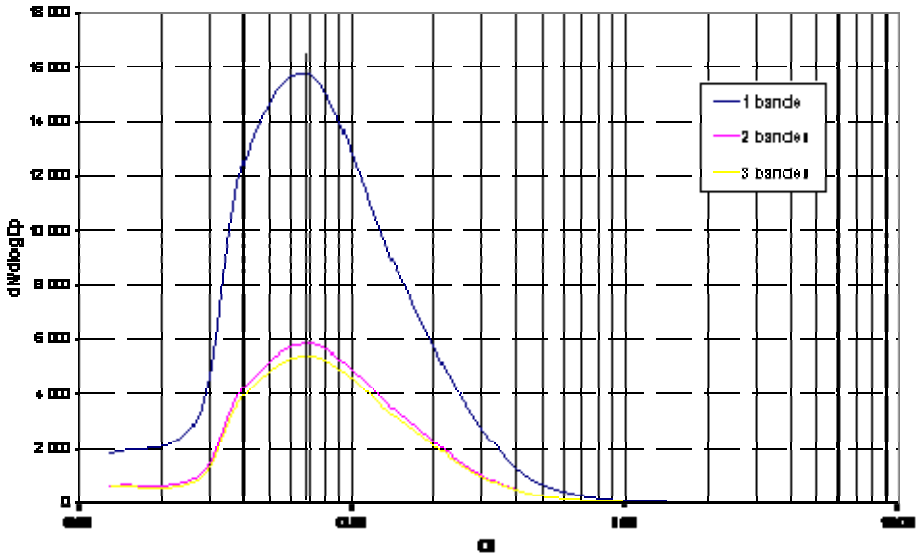


Figure 4 : Granulométries moyennes en montée pour différentes distances (diamètre en µm)

Figure 4 : size distribution for three distance separating the target and the source



La Citroën Picasso a été suivie à trois distances différentes : l'équivalent d'une, deux et trois bandes de signalisation autoroutière, soit environ 33, 66, et 100 mètres. Pour chacune de ces distances, six passages ont été effectués, dont trois en montée (fonctionnement à pleine charge) et trois en descente (charge partielle).

En passant d'une distance de sécurité de 1 à 2 bandes on diminue de façon significative (réduction de 2/3) l'exposition en habitacle.

Au delà de 2 bandes, l'augmentation de la distance de sécurité est sans effet sur l'exposition aux particules. Ceci est probablement à associer au fait de se trouver dans un tunnel.

Il est à noter que la distribution en taille mesurée par l'ELPI ne fait pas apparaître de déplacement du diamètre médian, au fur et à mesure qu'augmente la distance.

Remerciements

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Health risk assessment of transport-related air pollutants

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Abstract

This paper presents health risks assessment of chosen pollutants emitted from traffic. Recently more and more studies try to demonstrate significant effect of transport related emissions on human mortality especially in large cities. Polyaromatic hydrocarbons (PAHs) belong to group of persistent organic pollutants, which rise during imperfect combustion. Important sources of PAHs are, except transport, coal and other fossil fuels combustion and cigarette smoke. Results of air quality monitoring were used as input data in health risk assessment. Measurements have proceeded on two localities with different traffic intensity. The Guideline MŽP No. 1138/OER/94 was used for human health risk assessment to assess the possibility of carcinoma occurrence. This document is based on the methodology developed by US EPA. PM2,5 have been measured and 16 basic PAHs adsorbed on the surface of these particles were identified. Higher PAHs concentrations were determined, as it was assumed, on the locality with higher traffic intensity. Dibenz(a,h)anthracene, benzo(a)pyrene a benz(a)anthracene were chosen for assessment of PAHs negative health effects because of their high toxicity.

Keywords: *health risks assessment, PAHs, transport*

Introduction

Contamination of atmosphere with gaseous and solid pollutants is one of the most important environmental problems. Increasing number of pollutants emitted to the atmosphere demonstrably have adverse effects on human health and environment. Mainly road transport is important source of this contamination especially in large cities. Combustion processes in the vehicles engines emit very heterogeneous mixture of chemical compounds include many pollutants. Many studies bring in their conclusions clear evidences that air pollution with these pollutants significantly contributes to an increase the risk of respiratory symptoms and diseases and risk of death because of cardiopulmonary cases, especially in population of children under five years. The most life-threatening group of people are those living near the streets with intensive road transport.

Health Risks of PAHs

Benz(a)anthracene, benzo(a)pyrene and dibenz(a,h)anthracene belong to group B2 and are classified by US EPA as possible human carcinogens. The arrangement of the aromatic rings in the PAHs molecule structure gives it a "bay region" that is known to react with cellular macromolecules, including DNA, which may account for both their toxicity and carcinogenicity. These compounds arise from imperfect fossil fuel combustion processes, are components of exhaust gases, cigarette smoke, coal tar and asphalt. Primarily are released to the air where can be adsorbed on PM surface and than removed from the atmosphere by photochemical oxidation and dry deposition to land or water. So these compounds were detected in the air near power plants, heavily travelled roads and highways. They can be adsorbed following inhalation, oral, and dermal routes of administration and are rapidly distributed to several tissues. The metabolism of these compounds is complex and includes the formation of a proposed ultimate carcinogens (e. g. benzo(a)pyrene 7,8 diol-9,10-epoxide). No conclusive data are known on effects of these pollutants in humans but accomplished animal studies indicate that exposure to these compounds can cause malfunctions in reproduction, blood circulation, lymph tissues and also tumours and cancer of pulmonary alveoli can occur.

Many epidemiological studies indicate clear connection between exposure to PAHs mixture (e.g. coking plant emissions, cigarette smoke and gasoline engine exhaust emissions) and higher risk of lung cancer and other tumour diseases occurrence. However determination of proportion of each compound to total toxicity of whole chemical mixture is not possible.

Input data for assessment

84 samples of the ambient air were taken and analysed during the year 2005. Measurements were carried out in seven days campaigns in regular interval of five weeks on two localities. Selected sites represent urban neighbourhoods with the different morphology and burden with transport. Transport intensity is quite high on both localities, but is higher on locality Kotlářská. Arboretum represents wide opened site with a lot of trees. Houses stand only on the opposite site of the sampling place. Sampling instruments were about 25 m far from the intersection behind the belt of trees (booth spruce and deciduous). Sampling instruments on locality Kotlářská were located about 3 m far from intersection surrounding with 5 floor houses. This street could be considered “street canyon”. $PM_{2.5}$ have been measured and 16 basic PAHs adsorbed on the surface of these particles were identified. Benz(a)anthracene, benzo(a)pyrene and dibenz(a,h)anthracene were chosen for assessment of negative health effects because of their high toxicity.

Health risk assessment

Health risk assessment was implemented according to Methodical guideline MŽP č. 1138/OER/94. This document is based on the methodology developed by US EPA. It is the main tool exploited for decision-making process for environment conservation and public health protection to specify priorities, prepare proposals and inform public about risks in the environment where they live. The term “health risk” is defined by the incidence of health damage, disease or death resulting from a risk factor being present in the environment. Risk analysis main goal is to define the level of hazard posed to both individual human health and the health of whole population in the selected area.

Risk assessment itself consists of the following concurring steps. The first one includes the data collection and evaluation, thus determination of hazardous chemical substances and evaluation of their potential to have harmful impact on human health. Measured data and data from RAIS and US EPA databases were used for calculations in presented case study. Dose-response relationship definition is the second step. Slope factor (SF) is used as a characteristic parameter for carcinogenic (non-threshold) responses where probability of a negative response increases with the dosage. It represents biologically possible edge of evaluation of tumour occurrence possibility related to an average lifetime daily dose and is determined separately for inhalation exposure (IUR) and oral exposure (OSF). SF values are available in famous on-line databases. Exposure assessment is the most important and also the most difficult step in whole process. Determination and detailed characterization related to population of all possible entrances for each compound is the most important process for right exposure assessment. Specific equations and scenarios are composed for calculation of accepted compound amount within different pathways. Inhalation exposure was only considered in this case study. LADD (lifetime average daily dose) is used for this purpose for carcinogenic compounds. Risk characterization represents the final step of Health risk assessment process. Lifetime probability increase in cancer ratio above the general population average both for individuals (CVRK) and population (CVRP) quantitatively express the risk of carcinogenic responses.

Inhalation exposure was only considered as the entrance of chosen pollutants to human body in this case study so following scenario was used in calculations both for children younger than 6 years and adults:

$$\text{LADD} = \frac{CA \cdot IR \cdot ET \cdot EF \cdot ED}{BW \cdot AT}$$

CA contaminant concentration in inhaled air ($mg.m^{-3}$)

IR inhalation rate ($m^3.day^{-1}$)

ET exposure time ($hod.day^{-1}$)

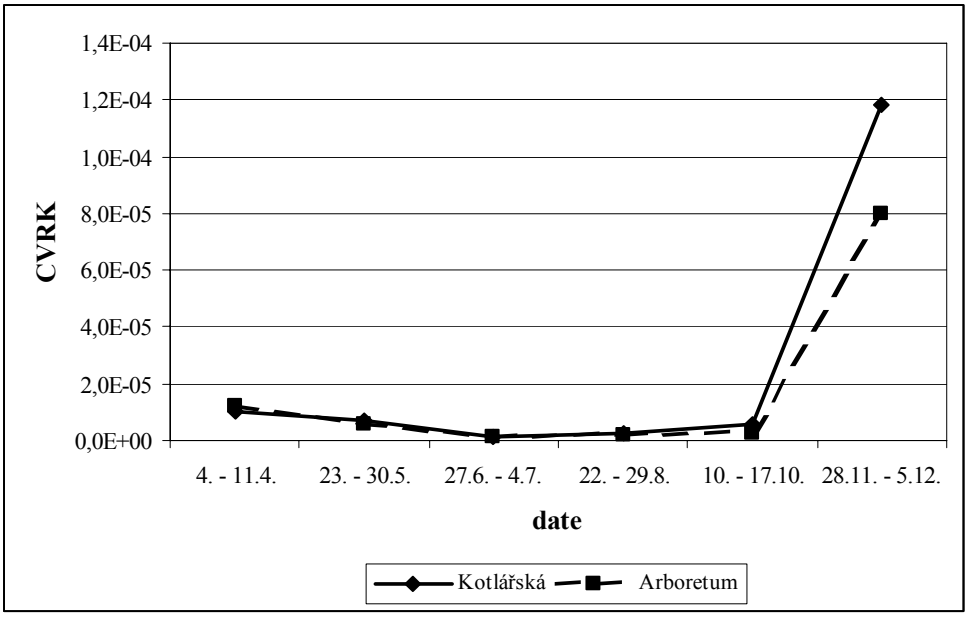
EF exposure frequency ($day.year^{-1}$)

ED exposure duration (years)

BW body weight (kg)

At averaging time (time during which concentration CA is considered constant

Figure. 1: Progress of benzo(a)pyrene CVRK for children during observed period.



Results and discussion

Obtained results show that the highest possibility (1,18.10-4) of carcinoma occurrence due to exposure to benzo(a)pyrene was assess for children in autumn (turn of November and December) on Kotlářská locality where was exceeded the barrier of socially assumed point of individual risk for carcinoma occurrence (1.10-4). The highest values for other pollutants were also in this season but the barrier was not exceeded in any other case (see fig. 1). The lowest possibilities of carcinoma occurrence were identified in summer (turn of June and July). The cause of this trend could be the difference in vertical stabilization of the atmosphere. Better ventilation in warmer season (convection) amuse pollutants further from the sources whereas in colder season ventilation is limited and pollutants cumulate near the source. Local furnace could be another important source of these compounds in colder period.

Children younger than 6 years are 3,3times susceptible to carcinoma occurrence cause to exposure to chosen pollutants than adults on both model sites (see tab.1).

Benz(a)antracene and benzo(a)pyrene represent 1,3times respectively 1,4times higher possibility of carcinoma occurrence on the locality Kotlářská

both for children and adults than on locality Arboretum. The possibility of carcinoma occurrence due to dibenz(a,h)antracene exposure is almost the same on both localities (see tab. 2).

Table. 1: Comparison of CVRK for adults and children.

Locality	Pollutant	CVRK	
		Adults	Children <6 years
Kotlářská	Benz[a]anthracene	5,41E-07	1,77E-06
	Benzo[a]pyrene	7,51E-06	2,42E-05
	Dibenz[a,h]anthracene	8,33E-07	2,72E-06
Arboretum	Benz[a]anthracene	4,19E-07	1,37E-06
	Benzo[a]pyrene	5,25E-06	1,72E-05
	Dibenz[a,h]anthracene	8,78E-07	2,76E-06

Table. 2: Comparison of CVRK for both localities.

Population	Pollutant	CVRK	
		Arboretum	Koltlářská
Adults	Benz[a]anthracene	4,19E-07	5,41E-07
	Benzo[a]pyrene	5,25E-06	7,51E-06
	Dibenz[a,h]anthracene	8,78E-07	8,33E-07
Children <6 years	Benz[a]anthracene	1,37E-06	1,77E-06
	Benzo[a]pyrene	1,72E-05	2,42E-05
	Dibenz[a,h]anthracene	2,76E-06	2,72E-06

Conclusion

Obtained results confirm conclusions shown in literature namely higher children susceptibility to possibility of carcinoma occurrence. Higher burden of inhabitants living near the locality with higher transport intensity was also confirmed in this study.

Acknowledgment

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L'évolution des systèmes d'indicateurs en environnement

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Résumé

Nous considérons les grands systèmes d'indicateurs mono-nuisances de l'OCDE, de l'AEE et de l'OMS. Ils sont sous forme de cycles qui rangent les indicateurs en différentes classes, nous examinons ici l'évolution de ces différentes versions successives.

Mots-clefs *: pollutions, nuisances, indicateurs d'environnement, cycles et systèmes d'indicateurs*

Abstract

Here we consider the most well known environmental indicators systems or cycles, used by OEDC, EEA and WHO. These systems are collections of elementary pollutions (mono-nuisances) sorted in different categories. They are not quite identical, but they followed a slight progression with some subdivisions of previous categories. Here we examine this evolution (in part 3.i to iii, figures 2 to 4) and observe that it is focusing on a diagram reflecting the development of almost every mono-nuisance (in part 2, figure 1, and recovered in part 3.iv, table 1). This is in good compliance with a general an necessary need for structuring and rendering clearer the wide field of environmental indicators as we do in EIP project INRETS.

Key-words *: pollutions, nuisances, environmental indicators, indicators cycles and systems*

Introduction, l'état de l'environnement et sa description

Les préoccupations environnementales ont pris de plus en plus d'importance auprès de la population dans son ensemble et de ses diverses composantes, particuliers, milieu scientifique, instances politiques, économiques, décisionnelles, … . Cela a donné lieu dès les années 60 au développement de nombreuses batteries d'indicateurs pour suivre l'irruption du nouveau phénomène de la pollution, au niveau des émissions comme de de leurs conséquences. Pour simplifier ces outils sont apparus en deux temps, (Maurin 2005). Dans le premier il s'est agi de la caractérisation des principales

nuisances, en particulier du bruit et de la pollution de l'air dus aux transports, et il s'est produit une forte et pléthorique production d'indicateurs sans guère de souci d'harmonisation.

En second on a assisté à l'avènement de collections des indicateurs précédents dans une nouvelle gamme d'outils, à savoir des paniers ou tableaux de bord qui rassemblent un grand nombre d'indices ou indicateurs mono-nuisances. C'est le cas du cycle des indicateurs PER de l'OCDE, du cycle DPSIR de l'AEE, et plus récemment du cycle DPSEEA de l'OMS-WHO, (Rodrigues & al. 2002). On peut y voir aussi la première manifestation de l'approche globale multi-nuisances.

Tout ceci a conduit à de volumineuses productions d'indicateurs sans guère de stratégie ni de coordination, et il est devenu nécessaire de clarifier ce domaine. Le projet de recherche PIE de l'INRETS s'est engagé dans une démarche de structuration des indicateurs ; ici nous montrons comment cela permet de suivre l'évolution qu'ont parcourue les cycles ou paniers d'indicateurs mono-nuisances.

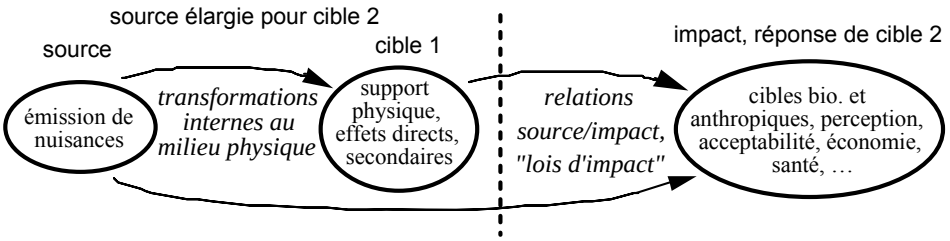
Un rappel de l'analyse structurelle des indicateurs mono-nuisances

Pour la plupart chaque pollution suit un enchaînement commun qui se développe depuis la création de la pollution jusqu'à ses divers effets qui se font sentir dans les milieux receveurs ou cibles. Il y a tout d'abord le milieu physique lui-même (cible 1) qui est à la fois le siège des émissions et le premier milieu touché, et la biocénose ou le milieu vivant comme cible finale (cible 2), figure 1.

Entre l'émission et chaque impact il y a une suite de transformations. Cet enchaînement commun à de nombreuses nuisances permet de cerner deux pôles structurants importants, d'une part l'identification des familles de grandeurs qui interviennent, et de l'autre l'identification des étapes majeures de construction des indicateurs d'impact sur la cible 2.

Figure 1 : l'enchaînement des conséquences des pollutions (commun à beaucoup de situations),

Figure 1: the effects' sequence, (common to many pollutions)



1. Le premier pôle, les familles de grandeurs

Parmi celles-ci on distingue :

- pour mémoire les grandeurs de zone ou de support territorial qui précisent la zone considérée ;
- les grandeurs de source de nuisances. Ce sont pour l'essentiel des variables physico-chimiques à l'origine de la pollution, elles sont naturellement objectives et mesurables selon des métrologies bien définies, ou accessibles par des modélisations et simulations. Ces grandeurs subissent plusieurs transformations et produisent des effets directs et secondaires (Lerond & al 2003). Celles qui demeurent du ressort physique objectif après réactions, propagations (la cible 1), … constituent une source élargie pour produire les impacts sur la cible 2. Ces grandeurs sont extensives ou additives dans l'espace et le temps (les émissions), ou intensives pour caractériser l'intensité de l'exposition, comme les teneurs en gaz polluants et les niveaux de bruit. En pollution les indicateurs dits "d'émission" et "de qualité de l'air" soulignent cette dichotomie naturelle (Goger 2005).
- les grandeurs d'impact. Les grandeurs de source ne décrivent pas directement l'impact sur la cible 2 ; pour en rendre compte il faut introduire de nouvelles grandeurs dites d'impact qui sont aussi les réponses de la cible. Cela concerne des observations collectives comme l'éthologie, le comportement de la faune et de la flore, ainsi que le volet humain lui-même très vaste. Ce dernier comprend également des réponses statistiques de populations avec les aspects sociétaux, sanitaires, économiques, et des réponses individuelles. Les grandeurs sont objectives ou subjectives, elles touchent à un grand nombre de champs disciplinaires, elles sont originales ou déjà connues, et elles doivent être cernées avec un regard renouvelé plus ccordonné.
- les grandeurs de cible. Les milieux affectés par la pollution sont caractérisés par des grandeurs dites de cible. Dans la cible bio ce sont des variables identifiantes comme toute population et sous-population particulière, (le milieu humain, la faune, la flore), des sites particuliers et sensibles, des grandeurs économiques et patrimoniales. Elles sont pour l'essentiel extensives et objectives.

2. Le second pôle, les étapes majeures de conception d'indicateurs

A ce titre on identifie les étapes suivantes :

- les transformations physico-chimiques internes au sein du seul milieu physique ou cible 1, (Goger 2006), à la fois milieu de source et de cible ;
- la transformation entre les grandeurs de source élargie et "la" réponse de la cible bio. C'est la correspondance qui transcrit l'information que

l'on connaît sur l'impact des expositions. Il y en a autant que de couples potentiels "source - cible", on peut l'appeler "loi d'impact" ou "loi de réponse" de manière générique, elle conceptualise les relations dose/réponse, dose/effect, exposition/ risque, …, et elle constitue une clé pour la connaissance des d'impacts et la construction des indicateurs associés. Si l'acoustique de l'environnement ne se positionne pas clairement vis-à-vis de cette étape, (Maurin 2004), la pollution de l'air y souscrit davantage avec sa double approche "problème" et "dommage", (Goger 2006) ;

- le croisement entre couples de données de source et de cible, ou d'impact et de cible, pour des indicateurs indiquant par exemple le nombre de riverains par niveau d'exposition.

Ici nous laissons de côté l'étape de l'agrégation des informations mononuisances au sein de la démarche globale multi-nuisances, (Maurin 2005, Rousval 2005), ainsi que l'adéquation entre la production des indicateurs et leur utilisation, (Rousval 2005).

L'application aux cycles d'indicateurs multi-nuisances

Ces grands cycles ou systèmes d'indicateurs sont désignés par les initiales des classes d'indicateurs mononuisances qu'ils contiennent. Nous considérons ici les cycles PER, DPSIR et DPSEEA avec leurs points communs et leurs différences. C'est ainsi, quand on met l'accent sur les différences, l'occasion d'oberver que ces cycles suivent une progression qui précisément s'ajuste aussi sur les éléments structurants précédents (familles de grandeurs, étapes de construction).

1. L'examen des cycles

i) Le premier cycle à avoir été bien diffusé est celui de l'OCDE qui comprend les trois classes d'indicateurs notées P, E et R. Le P correspond aux indicateurs qui rendent compte de la "pression" qui est faite sur l'environnement, les deux mots pression et *pression* sont les mêmes en anglais comme en français ; le E correspond aux indicateurs qui rendent compte de l'état de l'environnement, c'est le mot français état qui correspond à l'anglais *state* ; et le R correspond aux indicateurs qui s'appliquent à la réponse du système économico-social qui est faite pour améliorer la situation de l'environnement, c'est l'initiale du mot français réponse qui correspond aussi à l'anglais *response*, figure 2. La classe R est plus ou moins hors champ des indicateurs d'impact sur l'environnement, alors que P et E concernent pleinement la description d'une situation environnementale et sa position dans l'enchaînement des conséquences.

Figure 2 : le cycle OCDE

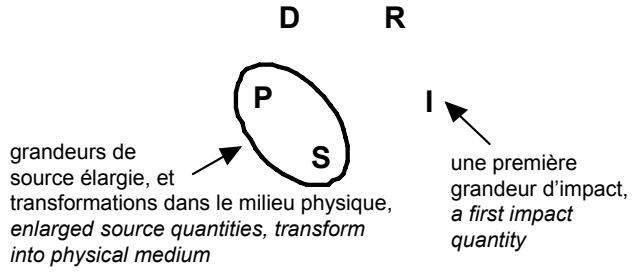
Figure 2 : the OEDC cycle

(**D**) **R**

P **E**

Figure 3 :le cycle AEE

Figure 3: the EEA cycle



ii) Ce cycle a été complété par le cycle DPSIR repris par l'Agence Européenne pour l'Environnement (AEE, *EEA* en anglais). Par rapport au précédent il contient la nouvelle classe D (pour *drive* ou moteur) qui précise les principales causes et origines des nuisances. Cette nouvelle classe, comme R, est davantage de ressort économique qu'environnemental proprement dit ; avec ces deux volets le cycle est présenté comme une sorte de bouclage entre la réponse apportée (R) et le moteur (D) des nuisances dans l'environnement plus qu'une simple succession d'étapes, figure 3.

L'autre grande innovation est le découpage de l'ancienne classe E en classe S (pour *state* ou état) et en classe I comme impact ou *impact*. Ici ce sont les trois temps P, S et I qui constituent le coeur du phénomène des nuisances et de l'altération de l'environnement proprement dite, en laissant de côté ce qui les provoque (D) et les réponses auxquelles elles donnent lieu pour les combattre (R).

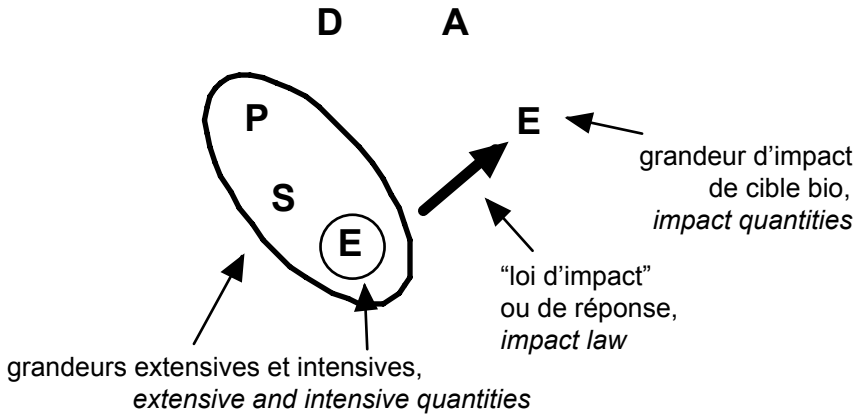
Ce système est un affinement du précédent, et il commence à préfigurer la différence entre grandeurs de source et grandeurs d'impact ; malgré cela on peut lui adresser deux critiques notables, (qui sont applicables au cycle PER à plus forte raison),

- une certaine confusion ou chevauchement entre les deux classes P et S, et partiellement I, à propos des grandeurs physiques et qui sont dus à la couverture de la source élargie,
- un défaut d'analyse et de finesse dans la classe I à cause des deux cibles physiques et bio non parfaitement distinguées.

iii) Une solution à ces objections est apportée par le cycle DPSEEA de l'OMS (*WHO* en anglais). Il y a pour commencer une différence de forme au niveau du vocabulaire, avec l'ancien R qui est à présent remplacé par le A de "action", aussi bien en français qu'en anglais. Après quoi il y a une différence de fond avec un nouveau découpage de classe. Cette fois-ci c'est la classe I qui est à sous-divisée en deux, et qui permet ainsi de détailler le domaine des effets sur la cible 1 et des impacts sur la cible 2, avec une première nouvelle classe E, ou E_x, comme *exposure* (exposition en français) et une seconde classe E, ou E_f, comme *effect* (effet en français), figure 4.

Figure 4: le cycle OMS

Figure 4: the WHO cycle



Sur le plan sémantique, le remplacement du R de *response* par un A libère le vocable "réponse", ce qui permet de l'affecter plus naturellement à la réponse de la cible plutôt qu'à la réponse du système économique et sociétal pour contrôler les nuisances, laquelle réponse est tout à fait bien représentée par action. Ce changement de vocabulaire est indépendant de l'analyse précédente du § 2, mais c'est une circonstance fortuite et bienvenue qui peut aider à éviter des malentendus à propos du vocable "réponse" (comme c'est souvent le cas avec des vocables polysémiques, y compris dans les domaines scientifiques, "objectif" par exemple selon qu'il est substantif ou adjectif).

2. Un aboutissement de l'évolution.

Par conséquent ces systèmes d'indicateurs figurent davantage comme des instants particuliers dans une évolution que des systèmes définitifs. Ils font état d'une progression avec des aménagements successifs pour mieux se caler sur les états de l'enchaînement général commun à la plupart des nuisances (figure 1).

On remarque cependant combien les aménagements qui leurs sont successivement apportés sont reliés aux constituants de l'analyse structurelle des indicateurs rappelée en § 2, avec les familles de grandeur d'une part et les étapes de conception de l'autre. La prise en compte de ces deux éléments permet un recadrage des classes d'indicateurs des cycles, et cela conduit assez naturellement à une version iv).

iv.1) Le découpage de l'ancien I avec la distinction des deux nouvelles classes E_x et E_f permet de mieux attribuer des grandeurs de même nature par classe. En l'occurence la classe E_x ne comprend que des grandeurs physico-chimiques qui appartiennent encore à la source élargie et qui caractérisent l'exposition de la cible bio, tandis que la classe E_f est réservée aux grandeurs d'impact ou de réponse de la cible bio, des grandeurs hors du champ physique par construction et définition ;

iv.2) Les trois classes P, S et E_x qui ne concernent que le milieu physico-chimique se partagent mieux la description des pollutions de la source élargie en tant que siège et support des pollutions.

- Les émissions et générations de nuisances sont du domaine des grandeurs de source originelle, c'est la classe P des cycles avec des grandeurs extensives.
- La cible 1 demeure du ressort du milieu physique avec ses transformations internes qui produisent des effets directs et secondaires au gré de transformations bien connues ou en cours de découverte. Cela peut être des grandeurs de source ou des grandeurs d'effet sur la cible 1, mais communauté de milieu physique aidant elles sont regroupées dans la classe S, et il peut y avoir des indicateurs ayant les mêmes unités physiques.
- Vis-à-vis de la cible 2 il importe d'isoler les variables physiques qui donnent lieu aux impacts que celle-ci subit ou aux réponses qu'elle fournit, c'est à dire les variables objectives qui après mécanismes divers sont des données intensives d'exposition. C'est le contenu de la classe E_x.

iv.3) Cela permet corrélativement de bien expliciter la présence de la correspondance ou loi d'impact qu'il y a entre une exposition physique et la réponse de cible bio, figure 4. La première classe E_x comprend les arguments d'entrée et la seconde E_f les arguments de sortie de la transformation pour toutes les cibles du milieu vivant.

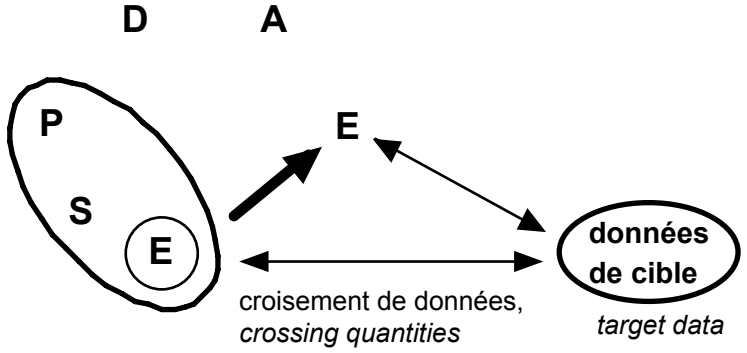
Ce n'est d'ailleurs sans doute pas une simple coïncidence si une aussi nette distinction des cibles physiques et vivantes d'une part, et l'analyse fine de l'impact sur la cible non physique de l'autre sont dues à une institution qui s'intéresse en priorité à l'individu humain et à sa santé. Plus généralement c'est l'entrée en scène explicite du milieu réceptif bio et de ses réponses avec une étape spécifique de construction.

iv.4) Les classes E_x et E_f de grandeurs intensives se prêtent aussi au croisement des données avec des grandeurs extensives de cible pour former d'autres indicateurs d'impact très classiques par ailleurs, figure 5, dans une construction qu'il vaut mieux mettre en marge des cycles précédents par souci de clarté. Vis-à-vis du croisement les données des classes E_x et E_f sont équivalentes.

Cette évolution peut être facilement reprise dans un tableau où les 3 grands cycles-paniers "historiques" i), ii), iii) ainsi que leur aboutissement iv) sont en colonne, et où les différentes classes d'indicateurs et de grandeurs sont disposées en ligne (tableau 1). Cette présentation permet de figurer les découpages successifs de classes qui ont eu lieu, de E en S et I, puis de I en E_x et E_f ; quant à la dernière colonne iv) elle se prête à l'interprétation des lignes avec les pôles structurants que sont les familles de grandeurs et les étapes de construction (Maurin 2005) rappelés au § 2.

Figure 5 : cycle OMS et ouverture au croisement des familles de données

Figure 5 : the WHO cycle, the opening to data families crossing



Naturellement il subsiste une différence entre les objets des colonnes. Alors que les paniers i) à iii) ne sont que du ressort de la collection d'indicateurs, l'approche en iv) s'inscrit dans la problématique de conception et de construction structurelles qui implique une véritable étape d'agrégation après le rassemblement des informations mono-nuisances, (Maurin 2005, Rousval 2005).

i)OCDE ii) AEE iii) OMS iv) approche en termes de grandeurs et d'étapes de construction, projet INRETS PIE

Tableau 1 : l'évolution des grands cycles ou systèmes d'indicateurs d'impact environnementaux, recentrage autour des grandeurs et des étapes de construction, les deux pôles structurants du § 2.

Table 1: the major cycles of environmental indicators impact's evolution, the refocusing towards the two founding poles of § 2: families of quantities and major steps of construction.

	D	D	(moteurs économiques, causes des nuisances)
P	P	P	grandeurs de source physiques, émissions extensives
E	S	S	transformations internes au milieu physique, effets directs et secondaires
	I	E_x	grandeurs de source physiques intensives d'exposition *
		E_f	grandeurs d'impact, réponse de cible bio après "loi d'impact" *
R	R	A	(action en réponse du milieu économique sur les causes et moteurs divers)

* possibilité de croisement avec les grandeurs de cible extensives, (figure 5).

Conclusion

Le toilettage de la double production d'indicateurs d'impact environnementaux et de paniers d'indicateurs est nécessaire. Il est possible, avec des familles de grandeurs et des étapes de construction de proposer une structure qui se cale convenablement sur le mécanisme des pollutions mono-nuisances en général, et qui en rend compte d'une manière satisfaisante.

Les paniers-collections d'indicateurs mono qui ont jalonné l'histoire de l'approche multi-nuisance ont suivi, malgré leurs ressemblances, une évolution. Et au cours de celle-ci il s'avère que les mêmes pôles structurants que ceux qui interviennent pour les indicateurs mono-nuisances permettent de poser un aboutissement à la progression de ces paniers, même s'ils n'abordent pas l'agrégation à proprement parler.

Cette observation à partir de paniers d'indicateurs confirme à sa manière l'intérêt de ces deux pôles de structuration pertinents et d'un souci formel associé dans l'approche globale multi-nuisances.

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Environmental performance of new car fleet – Well to wheel analysis for Belgium 2002-2004

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Abstract

The objective of the presented paper is the analysis of the evolution of the environmental performance of the new passenger car fleet registered in Belgium from 2002 to 2004. The Ecoscore is used as a well to wheel indicator for the global environmental performance of vehicles. The environmental performance of new passenger cars registred in Belgium has improved with 2.1% from 2002 to 2004. The most substantial improvement is noticed for diesel cars, as the market penetration of Euro 4 petrol cars was allready high in 2002 and the average fuel consumption of the diesel cars decreased more due to downsizing. The present car taxation is not well correlated with the global environmental performance of the vehicle. With a fiscal regime based on Ecoscore, market demand might shift with a substantial potential for increased improvement of the environmental performance of the new car fleet.

Keys-words*: environmental performance passenger cars, well to wheel analysis, time analysis, car taxation*

Introduction

To reduce the impact of traffic on the environment, policy makers have different options like stimulate a modal shift from road transport to other modes or reduce traffic volume. The introduction of 'clean vehicles' is a promising contribution for a significant reduction of energy use and pollutant emissions. A consistent policy mix to support the market introduction and use of clean vehicles should be based on a coherent definition of a 'clean vehicle' that takes the several impacts of the vehicle into account and that allows to compare vehicles of different fuel types and drive trains.A well-to-wheel framework is used to compare the harm to humans and to the environment. Three major impact categories (global warming, air quality and noise pollution) are combined through a weighting system into a single indicator, named Ecoscore. This allows an environmental assessment of road vehicles, including the impact of

different types of pollutions through their effect on several receptors (climate, human health, ecosystems).

The Ecoscore indicator can be used as a monitoring indicator of the environmental performance of the vehicle fleet and as a basis for policy instruments for the support of clean vehicles.

Objectives

The presented paper analyses the environmental performance of the new passenger car fleet registered in Belgium with the use of the Ecoscore indicator as monitoring tool for the global environmental performance. The statistical analysis results in correlations of environmental performance with technical, economical and market parameters. A time analysis investigates the evolution of the environmental performance and correlated parameters from 2002 until 2004. The second objective is to present an approach how the Ecoscore indicator could be used as a basis for car taxation and what the impact could be of the new fiscal scheme compared to the present scheme in Belgium.

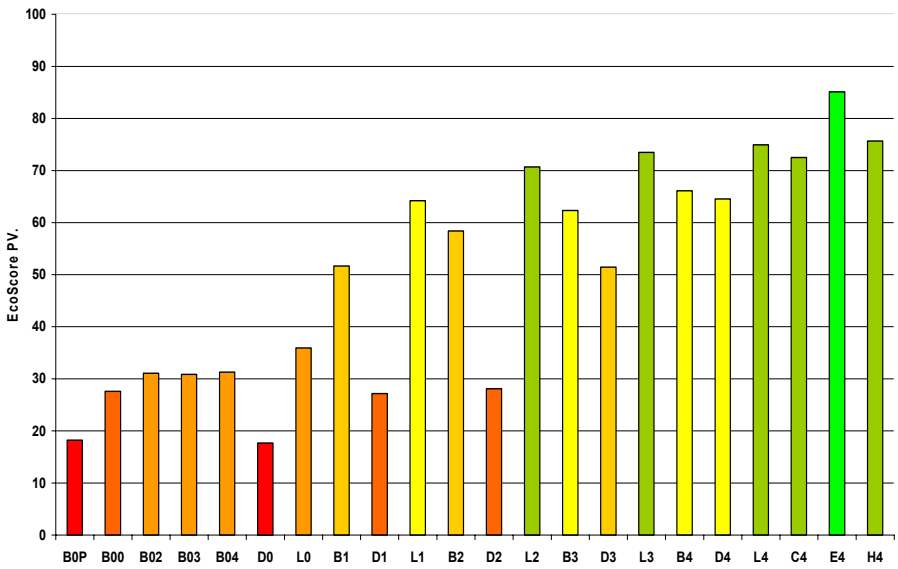
Ecoscore indicator

The Ecoscore indicator (Timmermans, 2005) is an environmental rating methodology that has been developed to have a consistent definition of the environmental performance of vehicles that allows to compare vehicles of different drive trains and fuel types. For this purpose, a well-to-wheel approach has been followed so the indicator takes emissions from fuel production and distribution (well-to-tank) and from vehicle use (tank-to-wheel) into account. In the Ecoscore methodology, the following damages are considered together: global warming, air quality and noise pollution. For each of the three impact categories, the related emissions are combined in a single unit. Emissions related to greenhouse effect are summed up based on the global warming potential. For air quality emissions, the external damage costs expressed in monetary terms from the EU 'ExternE' project (ExternE, 1997), are used to establish the relative weight of different emissions and calculate their impact on air quality. In order to measure the relative extent of the different damages, the formerly evaluated damage has been "normalised" according to a specific reference value for each category of damage. The reference emission values correspond are the values imposed by the Euro 4 standard for petrol cars, so reference value for PM = 0. As far as CO_2 emissions are concerned, the value of 120g/km is taken as reference, as this value is the objective for new car registrations, the automobile industry has accepted to aim. For noise, a reference value of 70 dB(A) is taken as this is the median for new registered passenger cars in Belgium. As a last step, the different impact categories are weighted into a single indicator. The weighting is determined based on other environmental rating methodologies combined with an expert panel of stakeholders in Flanders. In the total Ecoscore, greenhouse effect has a share of 50%, air quality of 40% and the resulting 10% for noise pollution. For communication purpose, the damage indicator is transformed to a Ecoscore

from 0 to 100, the higher the score the better the environmental performance of the vehicle.

The Ecoscore has to objective to be used in policy measures so it should be applicable to a large set of vehicles. Availability of input data is crucial for that objective, so emission data of the homologation test cycle are used. These data do not reflect entirely the emissions under real traffic conditions but provide a useful indication for relative comparison between vehicles.

Figure 1 : examples Ecoscore passenger cars



The Ecoscore methodology can be applied for light duty vehicles, heavy duty vehicles and two wheelers. This paper focuses on application for passenger cars. Figure 1 presents the results of the Ecoscore of comparable passenger cars of different ages, fuel and vehicle types. The main characteristics of the cars included in Figure 1 are given inTable 1.

Table 1 : passenger cars included in example figure Ecoscore

	Category	Fuel type	Engine capacity	Consumption per 100km
B0P	Pré ECE	Petrol	1,4 - 2,0l	14.3 L
B00	Pré Euro ECE 15/00	Petrol	1,4 - 2,0l	10.1 L
B02	Pré Euro ECE 15/02	Petrol	1,4 - 2,0l	9.3 L
B03	Pré Euro ECE 15/03	Petrol	1,4 - 2,0l	9.3 L
B04	Pré Euro ECE 15/04	Petrol	1,4 - 2,0l	8.8 L
D0	Pré Euro	Diesel	< 2,0l	7.6 L
L0	Pré Euro	LPG	> 2,0l	9.1 L
B1	Euro I	Petrol	1595cm³	8.4 L
D1	Euro I	Diesel	1974cm³	6.5 L

L1	Euro I	LPG	1598cm³	9.4 L
B2	Euro II	Petrol	1595cm³	7.6 L
D2	Euro II	Diesel	1700cm³	5.9 L
L2	Euro II	LPG	1598cm³	7.4 L
B3	Euro III	Petrol	1595cm³	6.9 L
D3	Euro III	Diesel	1686cm³	4.7 L
L3	Euro III	LPG	1598cm³	7 L
B4	Euro IV	Petrol	1598cm³	6.3 L
D4	Euro IV	Diesel	1686cm³	4.6 L
L4	Euro IV	LPG	1598cm³	7.2 L
C4	Euro IV	CNG	2435cm³	11.2 L
E4	Electric	Electricity		0.17 kWh
H4	Euro IV	Hybrid	1497cm³	4.3 L

1. Belgian car fleet

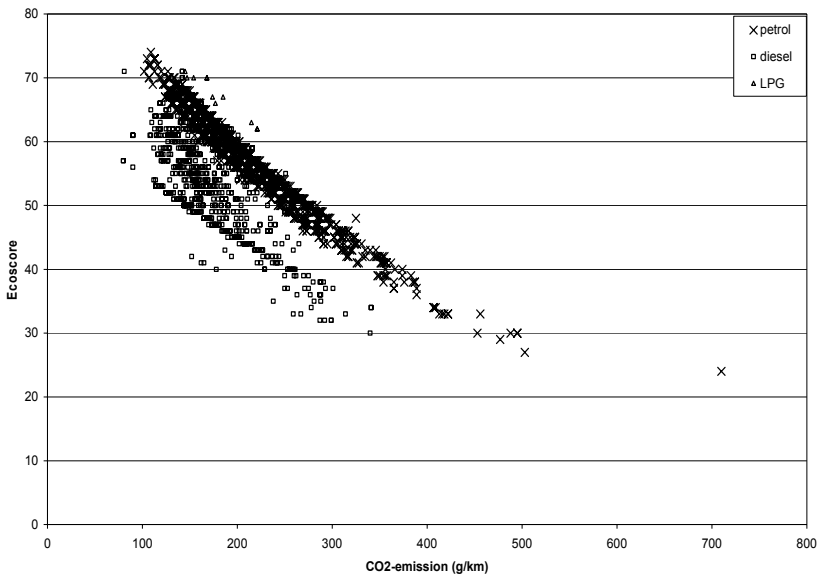
A first analysis that is done on the new passenger cars that are for sale on the Belgian market, the sales figures not taken into account. In Table 2 a summary of the main correlations between the Ecoscore and technical parameters is given. The correlations for petrol cars and the Ecoscore are higher than for diesel cars. The reason for this is that the Ecoscore for petrol cars is mainly determined by CO_2-emission, thus fuel consumption because of the rather low impact of petrol car emissions related to air quality (HC and CO). The diesel emissions of NO_x and PM that have a serious health impact have a more important weight in the Ecoscore, which results in a lower correlation between the Ecoscore and technical parameters that influence fuel consumption. The footprint of the car, defined as length multiplied by width of the base of the car has the smallest correlation with the Ecoscore.

Table 2 : correlation between Ecoscore and technical parameters

	Petrol	Diesel
cylinder capacity	-0,87	-0,54
power	-0,85	-0,36
footprint	-0,52	-0,39
weight	-0,83	-0,64
emission standard	0,23	0,46
CO2-emission	-0,97	-0,76

On the other hand, the positive correlation with the emission standard (euro 2, 3 or 4) is higher for diesel cars compared to petrol cars for the same reason that the Ecoscore of petrol cars are more dominated by fuel consumption and CO_2-emissions, while the Ecoscore for diesel cars are more influenced by regulated emissions, especially PM and NO_x. In Figure 2 the relation between the Ecoscore and the CO_2-emission of petrol, diesel and LPG cars is illustrated, the close correlation for petrol cars is clear. This figure indicates the range of the Ecoscore of the new car fleet. Petrol cars have the possibility to be very clean providing they have a low fuel consumption.

Figure 2 : relation Ecoscore – CO_2 emission Belgian car fleet



The analysis of the environmental performance of the car market is also done per market segment. The segmentation is made up by the Belgian car manufacturers and importers association FEBIAC based on their expertise of the car market and has proved to be a solid base for a market oriented analysis of the car market. The Ecoscore per segment is illustrated in Table 3 which indicates the minimum, maximum and average Ecoscore per segment. The segments of smaller cars have on average a better environmental performance compared to larger cars. The relation with the Ecoscore and relevant technical parameters (fuel type, fuel consumption, emission standard, …) is analysed in the following chapter.

Table 3 : Ecoscore per segment

	Ecoscore		
	Avg	**Min**	**Max**
Supermini	64	50	74
Small family car	59	42	69
Large family car	55	41	72
Mini multi purpose vehicles	64	51	72
Multi purpose vehicles (MPV)	50	40	62
Executive car	53	30	73
Roadster	51	24	73
Off roader	46	30	63

2. Time analysis 2002-2004

The next step in the analysis is to look at the sales figures and the evolution of the environmental performance of the car fleet taking market demand into account. An overview of sales figures taken into account for the analysis is given inTable 4. For data availibility reasons, the analysis can not be done on the total car sales in Belgium. The sales figures taken into account cover 66% of the car sales in 2002, 76% of 2003 and 75% of 2004.

The 3 main segments (supermini, small and large family car) cover 86% of the car market in Belgium. The off road segment is small in comparison with the main three segments, but it's market share is rising from 2002 to 2004. Regarding the share of the different fuel types, a constant increase of the share is diesel cars can be seen. The sales of LPG fuelled cars are not included in the further analysis because of the insignificant market share of 0.03%.

Table 4 : Overview passenger car sales 2002-2004 Belgium

-	-2002	-2003	-2004
-Total sales	**-309604**	**-348082**	**-360173**
-Market share per segment (%)			
- S11 SUPERMINI	- 27.1	- 24.5	- 24.1
- S12 SMALL FAMILY CAR	- 27.9	- 32.6	- 29.7
- S13 LARGE FAMILY CAR	- 32.9	- 30.0	- 32.6
- S14 MINI MPV	- 2.2	- 1.9	- 2.2
- S15 MPV	- 2.6	- 2.8	- 2.3
- S16 EXECUTIVE CAR	- 2.1	- 2.5	- 3.0
- S17 ROADSTER	- 0.6	- 0.5	- 0.6
- S18 OFF ROADER	- 4.6	- 5.2	- 5.4

The evolution of the environmental performance of the new car fleet sold in Belgium is given in Table 5 with detail per fuel type and Table 6 with detail per market segment.

The global environmental performance of the new car fleet improved with 2.1% from 2002 to 2004. This is mainly due to the improvement of the environmental performance of diesel cars in this period, combined with the increasing market share of diesel cars uptil 71% in 2004. The environmental performance of the average diesel car is poorer compared to petrol cars (Ecoscore of 54.8 compared to 64.5 in 2004), but the improvement in the analysed period is better. The market penetration of petrol cars that met the Euro 4 emission standard was in 2002 already rather high (60%) and increased to 73% in 2004, while the market penetration of diesel Euro 4 cars was only 2% in 2002 and increased to 20% in 2004. At the same time, the average fuel consumption of diesel cars decreased with 3.4% while petrol cars only achieved a fuel consumption reduction of 1.4%. The downsizing trend for diesel cars

(lower cylinder capacity, no weight increase) does not apply for petrol cars (smaller reduction of average cylinder capacity and weight increase of 2%).

Table 5 : Indicators environmental performance 02-04 per fuel type

-	- 2002	- 2003	- 2004	- '02-'04
		- TOTAL		
- ECOSCORE	- 56.7	- 57.0	- 57.9	- 2.1
- FUEL CONSUMPTION	- 6.2	- 6.1	- 6.0	- -3.2
- CYLINDER CAPACITY	- 1748	- 1739	- 1721	- -1.5
- POWER	- 74	- 73.6	- 74.5	- 0.6
- WEIGHT	- 1216	- 1235	- 1250	- 2.7
- PETROL/DIESEL	- 35 / 65	- 32 / 68	- 29 / 71	-
- EURO 3 / EURO 4	- 78 / 22	- 74 / 26	- 65 / 35	-
		- PETROL CARS		
- ECOSCORE	- 63.9	- 64.3	- 64.5	- 0.9
- FUEL CONSUMPTION	- 7.0	- 7.0	- 6.9	- -1.4
- CYLINDER CAPACITY	- 1497	- 1466	- 1452	- -3.0
- POWER	- 69.6	- 67.9	- 67.4	- -3.1
- WEIGHT	- 1055	- 1066	- 1077	- 2.0
- EURO 3 / EURO 4	- 40 / 60	- 33 / 67	- 27 / 73	-
		- DIESEL CARS		
- ECOSCORE	- 52.7	- 53.5	- 54.8	- 2.1
- FUEL CONSUMPTION	- 5.8	- 5.7	- 5.6	- -3.4
- CYLINDER CAPACITY	- 1885	- 1863	- 1813	- -3.8
- POWER	- 76.5	- 76.1	- 76.5	- 0
- WEIGHT	- 1304	- 1310	- 1305	- 0
- EURO 3 / EURO 4	- 98 / 2	- 93 / 7	- 80 / 20	-

Table 6 : Indicators environmental performance 02-04 per segment

-	2002	2003	2004	'02-'04
S11 SUPERMINI				
ECOSCORE	63.6	63.6	63.9	0.5
FUEL CONSUMPTION	5.5	5.4	5.3	-3.6
CYLINDER CAPACITY	1338	1325	1304	-2.5
POWER	51.5	51.7	52	1.0
WEIGHT	922	944	972	5.4
PETROL/DIESEL	62 / 38	60 / 40	56 / 44	-
EURO 3 / EURO 4	62 / 38	60 / 40	53 / 47	-
S12 SMALL FAMILY CAR				
ECOSCORE	57.3	57.4	58.6	2.3
FUEL CONSUMPTION	5.8	5.7	5.6	-3.4
CYLINDER CAPACITY	1714	1676	1656	-3.4
POWER	67.6	66.3	67	-0.8
WEIGHT	1185	1180	1175	-0.8
PETROL/DIESEL	30 / 70	26 / 74	26 / 74	-
EURO 3 / EURO 4	84 / 16	75 / 25	58 / 42	-
S13 LARGE FAMILY CAR				
ECOSCORE	52.4	53.7	55	5.0
FUEL CONSUMPTION	6.6	6.5	6.3	-4.5
CYLINDER CAPACITY	1994	1997	1938	-2.8
POWER	90.1	89.7	87.9	-2.4
WEIGHT	1397	1425	1424	1.9
PETROL/DIESEL	15 / 85	14 / 86	11 / 89	-
EURO 3 / EURO 4	87 / 13	84 / 16	79 / 21	-
S18 OFF ROADER				
ECOSCORE	46.2	45.7	47	1.7
FUEL CONSUMPTION	8.7	8.7	8.4	-3.4
CYLINDER CAPACITY	2294	2279	2265	-1.2
POWER	103	102	105	1.9
WEIGHT	1648	1675	1699	3.1
PETROL/DIESEL	32 / 68	26 / 74	20 / 80	-
EURO 3 / EURO 4	89 / 11	88 / 12	86 / 14	-

The analysis of the results per segment confirm the results of the analysis per fuel type. The improvement in the segment of large family cars which has the largest market share is better than the general improvement of the environmental performance of the new car fleet, and this segment has a very

large diesel share of 89%. The segment of supermini's hardly improved their environmental performance in the analysed time frame because of the already high share of Euro 4 cars in 2002, allthough also a substantial fuel consumption reduction was achieved in this segment. The segment of off road vehicles achieved a smaller improvement of environmental performance than the average new car fleet. The market penetration of Euro 4 cars in this segment almost stagnated and the diesel share in this segment is also very high (80%). Although the average power and weight of off road vehicles increased more then average, the fuel consumption was reduced due to the high increase of the diesel share.

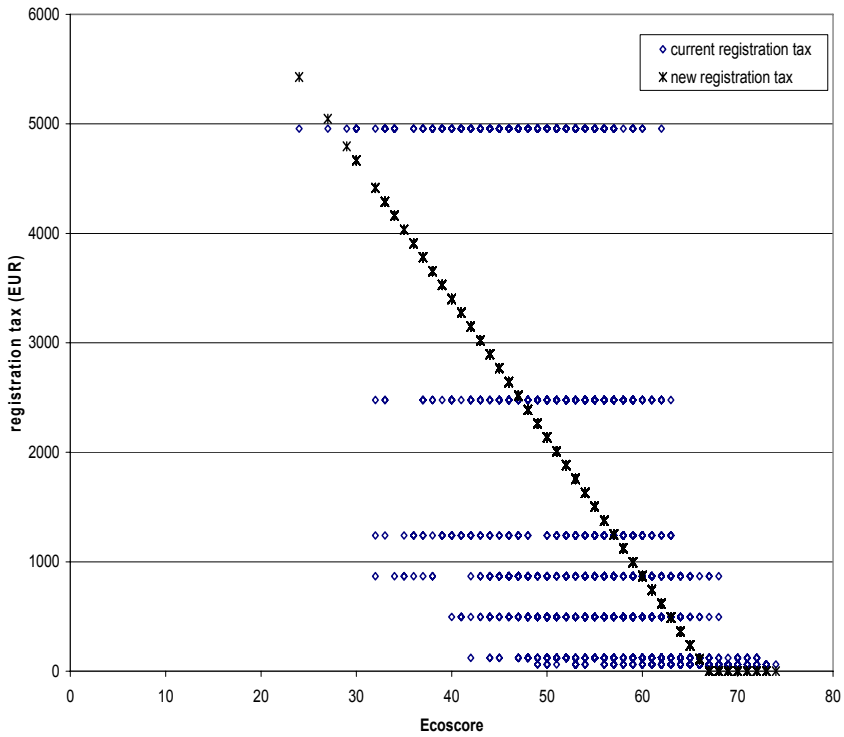
An important remark to make for the interpretation of the results is that only passenger cars registered as M1 vehicle are taken into account in the analysis because of data availability of sales figures and technical and emission data. Before 2006, car owners had the possibility to register large passenger cars (mostly off road vehicles) as light commercial vehicles (N1) which is much more interesting for fiscal reasons. The results of the analysis done in this paper are not applicable to this share of the car market. From 2006 it is made much more difficult to register passenger cars as light commercial vehicles.

3. Car Taxation

The Ecoscore is currently used only for communication purposes to inform consumers on the global environmental performance of vehicles. On behalf of the Flemish environmental administration, implementation pathways for an effective policy instrument mix for the promotion of purchase and use of environmentally friendly vehicles has been developed. Most effective instrument is green car taxation. A system of the car taxation based on the Ecoscore is under development in Flanders that will replace the current system based on cylinder capacity and horse power. The new car taxation will be based on the Ecoscore, both registration tax for new cars and circulation tax for the total car fleet.

In Figure 3 the relation between the current tariffs of registration tax and the environmental performance is illustrated. There is a large range of Ecoscore per tariff category of the current registration tax and the correlation between the Ecoscore and the registration tax is low (-0.57). A proposal for a new system is illustrated where the registration tax is a linear function of the Ecoscore, which the European Commission has approved. Important element is to investigate how the Ecoscore based taxation would influence purchase behaviour. A European study on the effectiveness of CO_2-based taxation showed that the average CO_2-reduction for Belgium would be 3.5 to 8.5% (EC, 2002). Compared to the average yearly improvement of the global environmental performance of 1%, the potential for further improvement is substantial if the effectiveness of the CO_2-based taxation can be applied to the Ecoscore-based taxation.

Figure 3 : Registration tax in function of Ecoscore



When using Ecoscore as a basis for policy instruments, data accuracy is an important topic. Homologation data are used as input because of data availability reasons, so it's important that homologation data reflect to a maximum extent the environmental performance of vehicles in real traffic conditions.

Conclusion

The Ecoscore indicates the global environmental performance of vehicles. For petrol cars, this is mainly dominated by the greenhouse gas emissions. For diesel cars, harmful NO_x and PM emissions are also very important.

There is a small positive evolution of the environmental performance of new cars for 2002 to 2004, mainly due to the improvement of the environmental performance of diesel cars. An average reduction of the fuel consumption of 3.2% has been achieved, for diesel cars even a reduction of 3.4%. The time frame of the analysis is the period of market introduction of Euro 4 vehicles, the share of Euro 4 increased from 22% to 35% in 2004, the Euro 4 cars in 2002 were almost exclusively petrol cars. For 2005-2006, the further introduction of Euro 4 diesel cars will lead to further improvement of the environmental performance of the new car fleet.

The current car taxation in Belgium has a low correlation with the global environmental performance of cars. A revision of registration and circulation tax is being prepared by the Flemish administration and the principle to base car

taxation on Ecoscore has been approved by the EC. This system has a large potential for creating a market shift to more environmentally friendly vehicles. A debate on data accuracy in important in this respect.

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Environment and transport indicator system in Spain. Are we tending towards sustainability?

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Abstract

Transport growth demand, both passengers and freight, is analysed together with its linkage with socioeconomic and environmental parameters: atmospheric pollution, green house gases, GDP, energy consumption, vehicle population, etc.. The results of analysis indicate that, even though technological improvements allow to reduce the emissions of pollutants, the rest of parameters follow unsustainable patterns. There is need to manage transport growth in terms of a comprehensive approach involving transportation planning, pricing, management innovations, technology and land use. This study reviews interurban transport trends in Spain and discusses if the current transport system tends towards sustainability. This discussion is supported by the results of an environment and transport indicator system: TRAMA.

Keys-words*: sustainability, growth pattern, instruments, Spain.*

Introduction

During last thirteen years transportation in Spain, infrastructures and services, has experienced a big change in response to the increasing demands of society in a context of an economic growth. Positive transport growth trends, of both passenger and freight transport, have contributed to increases in energy use and CO_2 emissions. The current transport system, based on high energy intensity forms of road transport such as passenger cars and heavy duty vehicles, causes serious environmental impacts including air and noise pollution in the environment together with global warming (Sperling, 2004).

Whereas the general increase of transport activities has resulted in a constantly increasing vehicle population, the concern about the potential threat to the environment and human health posed by the life-style of present-day society is also growing (Lenz *et al.*, 2003). Consequently, attention must be

paid to social and environmental sustainability. The term sustainability covers a wide range of issues and a sustainable transport system must be cost-effective (economic and financial), environmentally friendly (pollution, land use, energy consumption, and wildlife), safe and provide an adequate service to all segments of society (Sinha, 2003).

TRAMA

The indicator system, TRAMA, is developed to assess the sustainability of the Spanish transport system. TRAMA is based on a database of key sustainability indicators for the period 1990-2003 and follows the guidelines and methodology from the TERM indicator system of the EEA (European Environment Agency, 2001). The database was augmented by data on transport, environment, economy and demography from national databases (Pérez-Martínez & Monzón de Cáceres, 2005). The time period includes years when the economical growth coupled the massive adoption of motorized transport.

TRAMA provides a comprehensive picture of the environmental pressures and impacts from transport and identifies the causal factors (mainly technological and socio-economics). The system measures the efficiency of the adopted policies, commitments, objectives, and targets on regards transport and environment. Therefore, TRAMA links environmental pressure indicators to relevant sustainability reference values and targets.

Transport pattern and trends

Table 1 summarizes data per capita per year on green house gas emission (GHG), acidifying substances emission (AS), ozone precursors emission (OP), particles emission (P), passenger kilometres of travel (pkm), tonne kilometres (tkm), Gross Domestic Product (GDP), motorization (MI), transport investments (TI) and high capacity road length (HCRLC), for 1990 and 2003 and how they have changed relatively to 1990. Table 1 presents also data index on transport prices (TP), harmonized consumer prices (HICP) and road energy efficiencies (EEs), in terms of passenger kilometres of travel per kilogram oil equivalent (pkm/koe) or tonne kilometres per kilogram oil equivalent (tkm/koe). From 1990 to 2003, GHG has increased 47% coupled with pkm (76%), tkm (50%), GDP (31%) and MI (46%) increases. AS, OP and P had a decrease during the 13-year period: 7%, 22% and 2% respectively, due to technological improvements of combustion engines and developments in fuels. Furthermore, the means of transportation are becoming more efficient from the energetic point of view (smaller consumptions) and EEs show reductions, 16% and 6% for road passengers and road freight respectively. From the offer point of view, TI and HCRLC experienced a change of 27% and 119%. Referred to offer-demand adjustment, the TP is increasing at a faster rate than the HICP, 94% and 80%.

Table 1: Selected transport and environment indicators in 1990, 2003, corresponding percentage growth relative to 1990 and annual growth.

Tableau 1 : Indicateurs du transport et de l´environnement en 1990, 2003, pourcentages de croissance relative à 1990 et croissance annuelle.

Tracking indicator	1990	2003	Mean	Change 1990-2003 (%)	Change (%/year)
Environment					
reen house gases (kg CO2 eq./capita/year)	1.760	2.589	2.174	47	**3,0**
lifying substances emission (kg/capita/year)	0,51	0,47	0,51	-7	-0,6
ne precursors (kg NMVOC eq./capita/year)	42	33	40	-22	-1,9
articles emission (kg PM eq./capita/year)	20	20	21	-2	-0,2
Transport					
Passenger-km of travel/capita/year	5.832	10.262	8.194	76	4,4
Tonne-km/capita/year	6.261	9.387	7.620	50	3,2
d energy efficiency, passengers (koe/pkm)	0,046	0,039	0,040	-16	-1.3
.oad energy efficiency, freight (koe/tkm)	0,045	0,042	0,043	-6	-0.5
otorization index (vehicles/1000 people)	404	589	506	46	2,9
Transport investments (€/capita/year)	134	170	145	27	1,9
ligh capacity road length (km/100000 people)	13	28	22	119	6,2
P- Transport price index (1990=100)	100	194	161	94	5,2
Economy and society					
Gross Domestic Product (€/capita/year)*	10.183	13.304	11.729	31	2,1
Population (1000 people)	39.887	42.717	40.288	7	0,5
Harmonized consumer prices (1990=100)	100	180	148	80	4,6

*constant price (1995)

Figure 1: Trends in transport and environment in Spain, 1990-2003.

Figure 1 : Tendances du transport et de l´environnement en Espagne, 1990-2003.

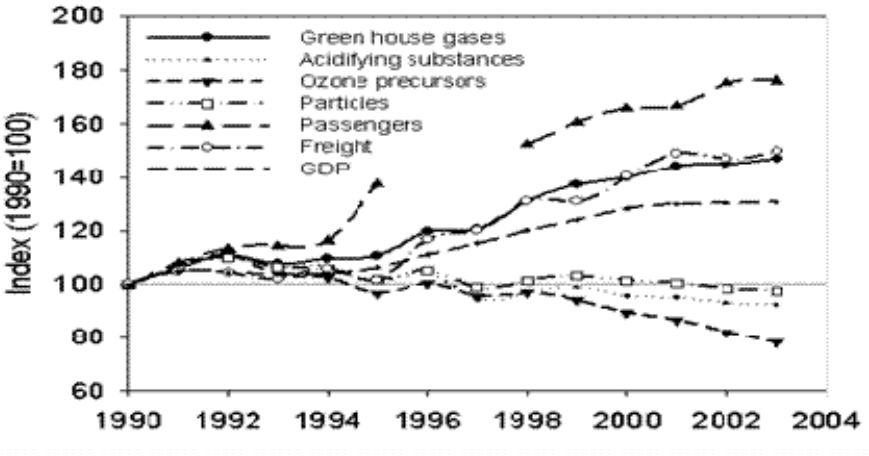

Figure 1 shows GDP, AS, OP, P, pkm, tkm, and GDP trends during the period 1990-2003. There is a direct association between transport pattern, emissions and economic development. Growth in transport demand has been tied to income growth as is found in several international trends. This association is more evident for freight. It is significant that passengers growth is the highest due to the income increase and to the general desire for mobility posed by the life-style of society.

Sustainability indicators

We made bivariate regressions analysis to show consistent relationships, across time, between the key sustainability indicators. Table 2 shows Pearson correlations for the indicators and all values were statistically significant at the 99% confidence level. Transport demand, passengers and freight, GDP and motorization were positively correlated with GHG, as identified by Pearson coefficients of 0.98, 0.99, 0.94 and 0.9, respectively. As for the GDP per capita per year, it was positively correlated with passenger transport demand (0.97), freight transport (0.99), motorization (0.99). HCRLC (a proxy for road capacity) was positively correlated with MI (0.98) indicating an induced demand associated to new mobility habits.

Table 2: Pearson coefficients for correlations for ecoefficiency variables (transport, environment, society, economy) and for the period 1990-2003.

Tableau 2 : Coefficients Pearson de corrélation pour des variables "d´écoefficience" (transport, environnement, société, économie).

Tracking indicator	Correlated with	Pearson coefficient
GHG (kg CO2 eq./capita/year)	Passenger-km of travel/capita/year	**,976(**)**
	Tonne-km/capita/year	,986(**)
	GDP (€/capita/year)	,994(**)
	MI (vehicles/1000 people)	,990(**)
AS (kg/capita/year)	OP (kg NMVOC eq./capita/year)	,903(**)
GDP (€/capita/year)	Passenger-km of travel/capita/year	**,972(**)**
	Tonne-km/capita/year	**,989(**)**
	MI (vehicles/1000 people)	**,988(**)**
HCRLC (km/100000 people)	MI (vehicles/1000 people)	**,981(**)**

** Correlation is significant at the 99% confidence level.

Table 3 shows regression equations, corresponding coefficients of determination, and elasticity values obtained from trend analysis for key sustainability indicators during the studied period. All the coefficients were high, and especially GHG explained a large amount of variation when regressed against other variables. Figure 2 shows the curves obtained when regressing GHG against passenger of travel per capita per year, freight, GDP and motorization. The elasticity or semielasticity values associated to these regression equations indicate that, for instance, a 10% increase in pkm could increase GHG per capita per year by 7%, and a 10% increase in tkm could increase GHG per capita per year by 8,4%. Similarly, 10% increases in GDP and MI could increase GHG by 13.4% and 10% respectively (table 3). At the same time, a 10% increase in GDP per capita per year could increase pkm per capita per year by 18,2%, and tkm per capita per year by 14.9%. These values are significant higher than those of our European context, where the three variables follow similar growth patterns.

It is interesting to analyze the variation of the GHG emission elasticity against different levels of GDP. The elasticity tends to decrease as country's income level is higher. With high income levels energy efficiency mechanisms are introduced which reduce emissions. In Spain, elasticity reaches its maximum value (1,41) at 8.565€ per capita and it happens during mid-eighties.

Figure 2: Green house gases, passenger kilometres, tonne kilometres, income and motorization.

Figure 2 : Gaz à effet de serre, voyageurs kilomètre, tonnes kilomètre, revenus et motorisation.

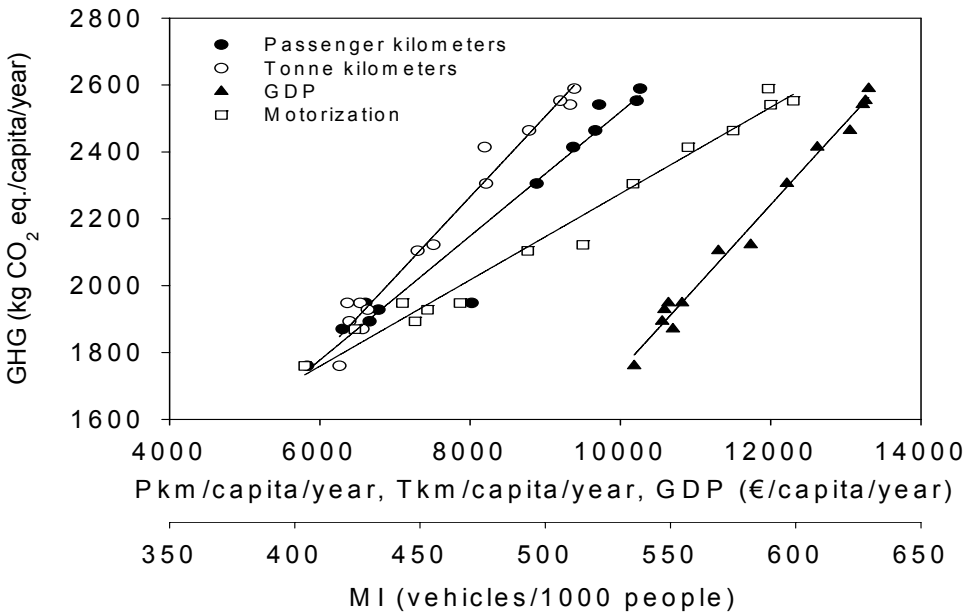

Table 3: Regression results and elasticity values for selected tracking indicators.

Tableau 3 : Résultats de la régression et valeurs de l´élasticité pour les indicateurs sélectionné.

X	Y	Equation	R2	Elasticity (mean)	Semielasticity (A), Elasticity (B)
Passenger kilometers of travel/capita/year	Green house gases (kg CO2 eq./capita /year)	$y = 663.5 + 0.1856X$	0.9524	$\frac{0.1856X}{(663.5 + 0.1856X)}$ (0.70)	At the mean, a 10% increase in pkm per capita increases GHG by 7% (A)
Tonne kilometres/capita /year	Green house gases (kg CO2 eq./capita /year)	$y = 341.15 + 0.2405\ X$	0.9725	$\frac{0.2405X}{(341.1 + 0.2405X)}$ (0.84)	At the mean, a 10% increase in tkm per capita increases GHG by 8.4% (A)
GDP (€/capita/ year)	Green house gases (kg CO2 eq./capita /year)	$y = -5775.91e^{-e(-(x-11527.35)/8565.24))}$	0.9879	α* (1.34)	A 10% increase in GDP increases GHG emissions by 13,4% (A)
MI (vehicles/ 1000 people)	Green house gases (kg CO2 eq./capita /year)	$4.235X^{1,002}$	0.9804	1.00	A 10% increase in MI per capita increases GHG by 10.0% (B)
AS (kg/capita /year)	OP (kg NMVOC eq./capita /year)	$y = 81.99+61.78Ln(X)$	0.8121	$(Ln(X)+1.3271)^{-1}$ (1.53)	A 10% increase in AS increases OP by 6.2% (A)
GDP (€/capita/ year)	Passenger kilometres of travel/capita/year	$y = -132276.36+14995.71Ln(X)$	0.9484	$(Ln(X)-8.8209)^{-1}$ (1.82)	A 10% increase in GDP increases p-km 18,2% (A)
GDP (€/capita/ year)	Tonne kilometres/capita/year	$y = -16129.48 + 5.217X - 4.5610^{-4}X^2 + 1.5610^{-8}X^3$	0.9814	β** (1.50)	A 10% increase in GDP increases t-km 14.9% (A)

$$^{*}\ \alpha = 0.000116751Xe^{(0.000116751(11527.4-x))}$$

$$^{**}\ \beta = \frac{(5.217X - 0.000912X^2 + 4.6810^{-8}X^3)}{(-16129.48 + 5.217X - 4.5610^{-4}X^2 + 1.5610^{-8}X^3)}$$

Conclusion and discussion

Trends in transport activity and GHG emissions are rising steadily. The data clearly indicate that GHG and transport demand are increasing at a faster rate that the GDP. On the contrary, air pollution, AS, OP, P, is decreasing but at smaller rate. Unless transport activity and income can be decoupled, energy use in the transport sector will continue growing (Caid, 2003). Nevertheless, the maximum GDP elasticity respect to GHG has been already reached and this implies that future increases in the GHG in Spain will bring smaller changes in incomes.

Technological innovations contribute to create a sustainable transportation system and there is evidence of an improvement in energy efficiencies and great advances in curving pollution. However, to rely solely on technology in achieving a sustainable transportation system is not realistic and profound changes are needed in current policies and regulations (Rodenburg *et al.*, 2002).

The direct utility of the indicator system is to feed information back into the processes where mobility relevant policies are formulated and implemented (Acutt & Dodgson, 1997). A direct link between the indicator system and policies provides a strong mechanism to integrate environmental sustainability criteria in transport decision making. This linkage is important for implementing policies and not just monitoring trends (Gudmundsson, 2003). The indicator system, TRAMA, supervises the degree of the environmental integration of the transport sector in Spain and can be used as a reference in the formulation of long-term future policies to reduce external costs.

Acknowledgments

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An Updated Version of the Environmental Quality cartography: a GIS-based solution to assess spatial impacts on the environment

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Abstract

An Environmental Quality map of the Spanish Peninsular area and Balearic Islands was developed in 2004 in order to assist the need of better techniques and instruments for developing spatial environmental assessments of plans and programmes. A number of environmental thematic datasets were valuated to obtain 12 Environmental Quality values, which were combined through Multicriteria Analysis in order to obtain the final map. One of the main sources was the Corine Land Cover map of 1990. With the recent release of the Corine Land Cover map of 2000, the Environmental Quality Map has been updated. The methodology was not modified, bearing in mind the possibility of comparing both Environmental Quality Maps. In this paper, this new map is presented, as well as the analysis of the differences encountered between both maps.

Keys-words*: Strategic Environmental Assessment, Screening, Geographic Information Systems, Multi Criteria Decision Analysis.*

Introduction

The Surveying Department and the Transport Research Centre of the Polytechnic University of Madrid (TRANSyT) co-operated on a research project (MIFO, 2005), where the generation of a Environmental Quality map for the Spanish Peninsular area and Balearic Islands was one of the main outcomes. The main purpose of the creation of this dataset was to assist on the development of Environmental Reports for Strategic Environmental Assessment procedures (Mancebo, 2005). This map summarizes the attributes of a set of

environmental qualities such as habitat naturalness, vegetation coverage, soil, landscape, etc. Thus, this cartography accounts for both nature inherent values and nature human-perceived values. These qualities are complemented by taking account of fragility characteristics such as singularity and fragmentation. The knowledge of the quality and fragility spatial characteristics is useful not only to assess environmental impacts but also to help in developing less environmentally harmful plans and programs.

Taking advantage of the recent publication of the new Corine Land Cover 2000 cartography (EEA, 2005), an updated version of the Environmental Quality map was yielded. The Corine Land Cover dataset accounts for up to three of the twelve variables considered, being one of the main sources involved in the development of the map. The new Environmental Quality map has not only been improved in spatial and attribute accuracy, but also the methodology applied was enhanced by programming the computation of more complex variables, that is, fragmentation and singularity. However, this methodology remains mainly intact, as well as the valuation scheme in order to analyse the differences between both Environmental Quality pictures.

Methodology

As already stated, the methodology used to obtain the Environmental Quality map remains mainly intact. The process begins with the collection of a set of datasets from different sources, as indicated below:

- Corine Land Cover 2000, from the European Environmental Agency (EEA, 2005)
- Landscape map, from the Spanish Environmental Ministry (MMA, 2004)
- Habitats map, from the Spanish nature data bank (DGCN, 2004a)
- Soil map, from the Spanish nature data bank (FAO, 2000)
- Vegetation Spanish Forestry map, from the Spanish nature data bank (DGCN, 2004b)

Although recent efforts to offer comprehensive spatial data catalogues, such as INSPIRE or the Spanish infrastructure of spatial data (IDEE, 2004), the knowledge and attainment on available datasets was mainly based on self experience, as these catalogues still need to be improved.

The next step is the integration and standardisation of data format, data accuracy, projections and datum transformations, with the aim of homogenising spatial datasets. Lambert Azimuthal Equal-Area (LAEA) projection was selected as it is recommended by European organization Eurogeographics (Eurogeographics, 2004; European Commission, 1999) for transnational projects. This projection offers advantages with regard to other projections often used in Spain, such as the Lambert Conformal Conic (LCC) or the Extended zone 30 UTM, in terms of area and length precision. The Extended zone 30 UTM projection consists on the use of zone 30 for the whole Spanish peninsular area, even though east and west territories should be projected

using zones 29 and 31. The European Terrestrial Reference System – 1989 Datum (ETRS-89) was the one selected following Eurogeographics recommendations (Eurogeographics, 2004; European Commission, 2000). As most cartographic data in Spain has been created on the European 1950 datum, datum transformations are a common step in harmonization processes. Again, Eurogeographics reports the type of transformation that should be used, detailing the parameters needed for each transformation (7-parameter Helmert transformation). In the light of the present study, all layers were imported to a unique digital format. For procedural reasons, the digital format chosen was Arc/Info coverage for vector data and ESRI Grid for raster layers, respectively.

Scale was discarded as a standardisation objective, being part of a comprehensive precision harmonization. Considering the precision of source layers and taking account of the likely uses of this cartography, precision threshold was established in 100 m RMS, and the minimum cartographic unit in 1 ha. These values cannot be reached by the integrated Environmental Quality map because some sources exceed these requirements. A fuzzy logic approach should then be considered in order to obtain a valid estimation of precision.

Several assessments of original datasets were made within the framework of this project in order to obtain values for each variable to be included in the development of the final map:

- Valuation of Landscape Quality performed by a group of experts
- Landscape singularity
- Multicriteria valuation of Soil Quality based on soil characteristics and productivity
- Soil singularity
- Valuation of Flora and Fauna richness
- Vegetation fragmentation
- Habitat fragmentation
- Habitat naturalness
- Habitat singularity
- Land cover vegetation percentage
- Land cover naturalness
- Land cover singularity

Singularity valuations were based on total area occupied, giving a larger weight to small-sized units., while fragmentation was valuated using patch size. All assessments were based on objective measurable characteristics, except the valuation of Landscape Quality, which is subject to the perception of the experts.

A number of multicriteria assessment methods were tested (Barredo, 1996; Malczewski, 1999), choosing the “Euclidean distance from the origin” as the final method for the integration of different valuations. This method is half-

compensatory, that is, high values in a certain criteria compensates partially low values in another one. Besides, it is a positivist method, measuring “what we have” instead of “what we lack”. These considerations are specially important regarding the expected use of this Environmental Quality map.

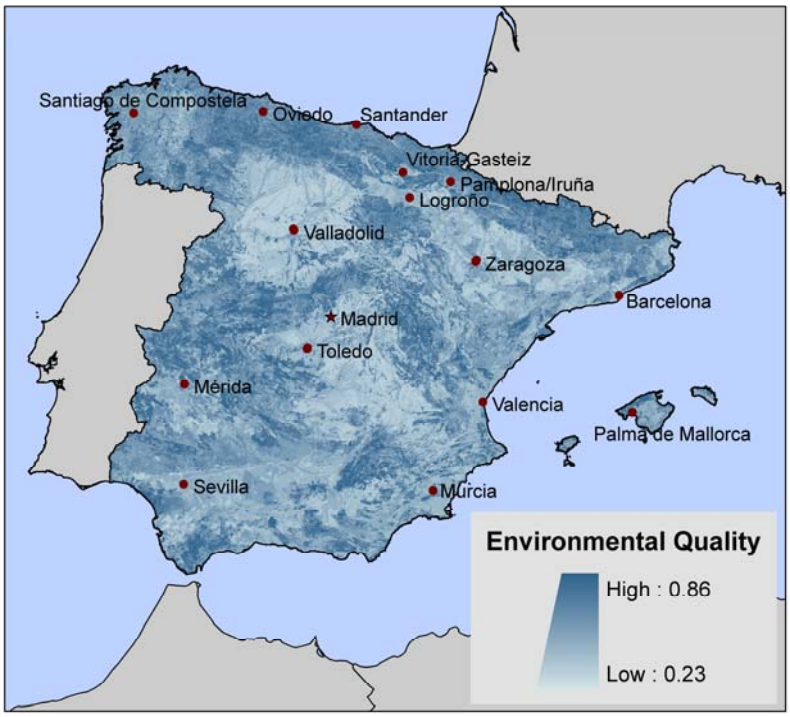
As the intention was to get a vector were all previous assessments are represented, the computing process can be performed through vector layer algebra (ESRI, 2004) . The generation of this Environmental Quality map implies the combination of a significant number of maps, eventually 12. This high number of variables resulted in a very complex methodology, which forced researchers to work with raster data instead of vector. Raster combination of data has proved to be an efficient way of simulating a vector approach for a high number of datasets. The result is a raster map where the attributes are present in its associated table, comprising information on 12 environmental variables and environmental quality.

Finally, both versions of the Environmental Quality map were statistically compared. Average and median quality as well as quality distribution were obtained in order to report general differences throughout the study area. Spatial differences were yielded subtracting these maps.

Results

The main result is the Environmental Quality Map itself (see Figure 1).

Figure 1:Environmental Quality map



The average quality is 0.488 (measured in a 0-1 scale), being 0,48 its median, while range expands from 0.23 to 0.86. Both quality distributions (Figure 2) and the coincidence of average and median quality, shows a rather homogeneous distribution of the variable.

Figure 2: Area distribution of environmental qualities.

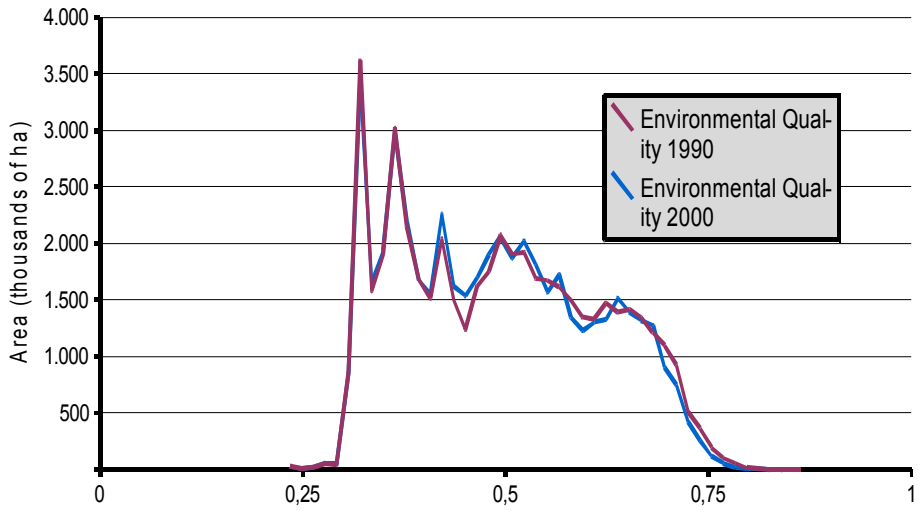
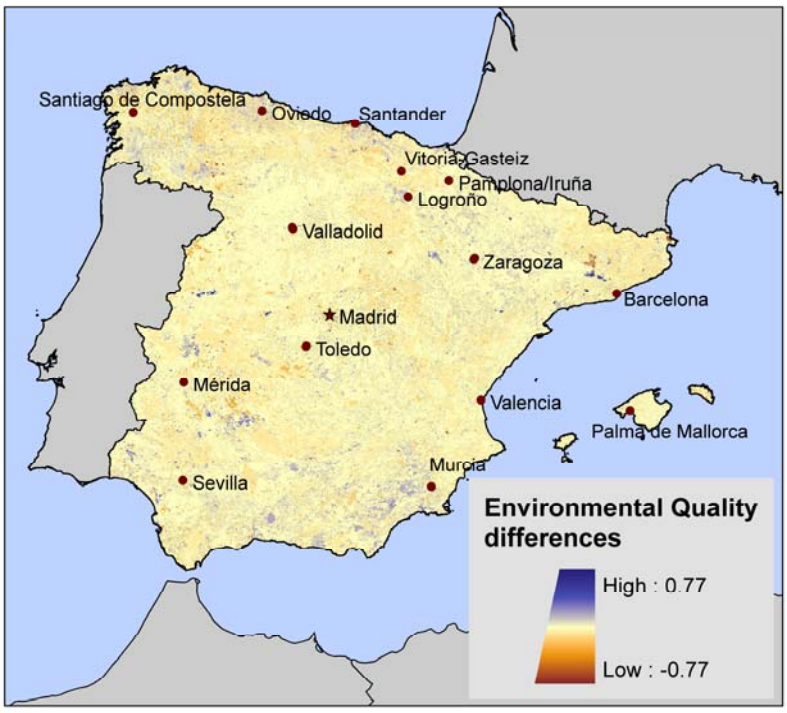


Figure 3: Environmental qualities subtraction map.

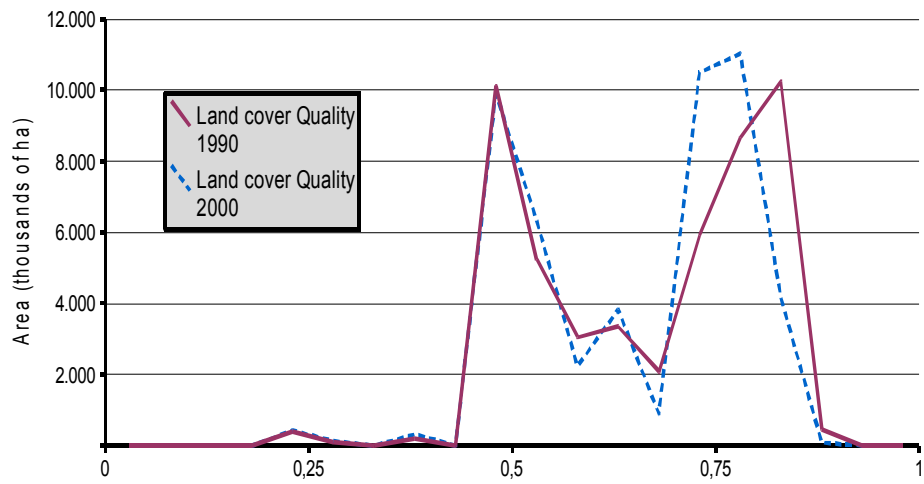


The results obtained for the old Environmental Quality Map, based on Corine Land Cover 1990, are very similar, with an average of 0.492, a median of 0.48 and a range from 0.23 to 0.87. Quality distributions of both maps can be compared in figure 2.

The arithmetic subtraction of both maps (figure 3) reported an average difference of -0.004.

Taking into account that differences between both situations could be masked by the nine criteria that remain constant in both maps, a final comparison was obtained using the three variables based on land cover. The difference was -0.012 in the same 0-1 scale, that is, three times greater than the previous reported difference. Land cover quality distributions of 1990 and 2000 can be compared in figure 4.

Figure 4: Area distribution of land cover qualities.



Conclusions

Although the advantages of using this cartography was not the aim of this paper, it has already being tested successfully in a former research project (MIFO, 2005) and is currently being used to assist in environmental assessments of the recent Spanish Transport Infrastructure Plan, which means that can be used for various and significant purposes.

Comparison of both map versions reports an environmental degradation of 0.4 % in a ten year period. This result is reached maintaining the hypothesis that habitats, landscape, soil and vegetation have remained unaltered during the period of time studied, just varying land cover. This hypothesis cannot be verified, but it is believed to be false, as a strong correlation is perceived between the different nature variables and the land cover.

In order to avoid latter assumption, an extended comparison was performed taking into account only those three criteria that were extracted from the Corine

Land Cover Map (land cover map). This analysis reports an environmental degradation of 1.2 % in ten year period.

This environmental quality loss cannot be considered an accurate measure, but rather an indicator suitable for sustainable development assessment.

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Environmental Mobility Check and EcoTransIT: Online tools for information on environmental impacts of individual trips and transports

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Abstract

This paper describes the two online tools 'Environmental Mobility Check' and 'EcoTransIT', which have been developed for clients and interested people to compare energy consumption and emissions of individual journeys with different modes of transport.

Keys-words*: Environmental information tool, goods transport, passenger transport, specific emissions, specific energy consumption.*

Introduction

Mobility is not only an important and indispensable component of our society; it is also associated with negative impacts on the environment. Traffic, for example, is one of the main causers of the greenhouse effect. Therefore the individual choice of a means of transport with less pollution can lead to a clear discharge of the environment and contribute to the development of a sustainable transport system. To be able to select means of transport under consideration of environmental criteria, different road users (enterprises, feeders, private people) need suitable information.

Two tools have been developed in the past years in order supply such information: Environmental Mobility Check (UMC) for passenger transport and EcoTransIT for goods transport. Both tools are freely available online via internet and supply specific energy and emission data for transportation relations which can be defined by the user. UMC was developed on behalf of the German Railway (DB AG), EcoTRansIT by different European Railways.

The UMC for passenger transport is a component of the timetable information and booking system of German Railways which provides extensive

information for the specific journey of the user: Travel time, costs and environmental effects (resources consumption, energy consumption, emissions) of the journey by railway and alternatively by passenger car or airplane (planned) The system is currently still limited to relations within Germany.

With EcoTransIT, environmental effects of goods transport by truck, railway, ship and airplane can be computed for concrete relations within Europe.

The following paper gives a short overview of the tools, their methodology, input data and results.

EcoTransIT

As the quantity of freight for transportation rises, also the environmental impacts continuously increase. This leads to more pressure on companies to act in an ecologically responsible way. For this purpose Stinnes (Germany), Green Cargo AB (Sweden), Schweizerische Bundesbahnen (SBB Switzerland), Societé Nationale des Chemins de Fer Francais (SNCF France) and Trenitalia S.p.A. (Italy) have decided to develop a methodology for an environmental database and an internet tool for environmental impact calculations. This tool is named EcoTransIT (Ecological Transport Information Tool).

EcoTransIT compares environmental impacts of different transport modes for freight traffic. Energy consumption, carbon dioxide emissions and exhaust emissions are considered as impact parameters. The considered transport modes are road and rail transport as well as inland waterway and sea transport. The tool allows the calculation of information on any individual route and defined transport volume.

1. Possibilities for selection

EcoTransIT gives the client the details of more than **1250 different European transport nodes**, of which some 450 can be selected as the starting point or destination of freight transports. The user only has to enter the dispatch and delivery locations. If the loading location is not to be found in the selection offered by EcoTransIT, the user can specify a feeder line to the nearest location on the list.

For the calculation, the client can choose different **transport modes** (road, rail, inland waterway, sea, air). In addition, under "Individually designed route", the user can either combine various modes of transport directly, or express his preferences as to the choice of route. For a combined route, the EcoTransIT transshipment sites can be selected, as well as the transport facilities to be used between the transshipment sites. If the selected mode of transport is not possible for a part of the chosen route, the route will be selected automatically.

For the inclusion of a **feeder**, the client can choose from two types of feeder line access: the route from the place of dispatch to the closest EcoTransIT dispatch location or from the EcoTransIT delivery location to the delivery location. The user can choose from two types of feeder line transport: either

"truck" (truck is taken as feeder line transport for all means of transport selected) or "train" for rail transport, otherwise "truck" (truck is taken as feeder line transport for all means of transport other than rail). For truck, sea-going vessel, airplane and shipment by inland waterway, the truck is the only possible option for feeder line transport.

The client can choose between different kinds of **goods** to be transported:

Bulk goods: the vehicle can be loaded with freight up to the load limit (e.g. coal, steel, ore and liquid freight like oil and chemicals).

Average goods: if classification is difficult, the client should select this category. For calculation purposes, an average level of capacity utilization will be assumed.

Volume goods: maximum load will be reached on the basis of volume, before mass-based limitations come into play (e.g. industrial products like furniture, clothing etc.).

2. Assumptions relating to the means of transport

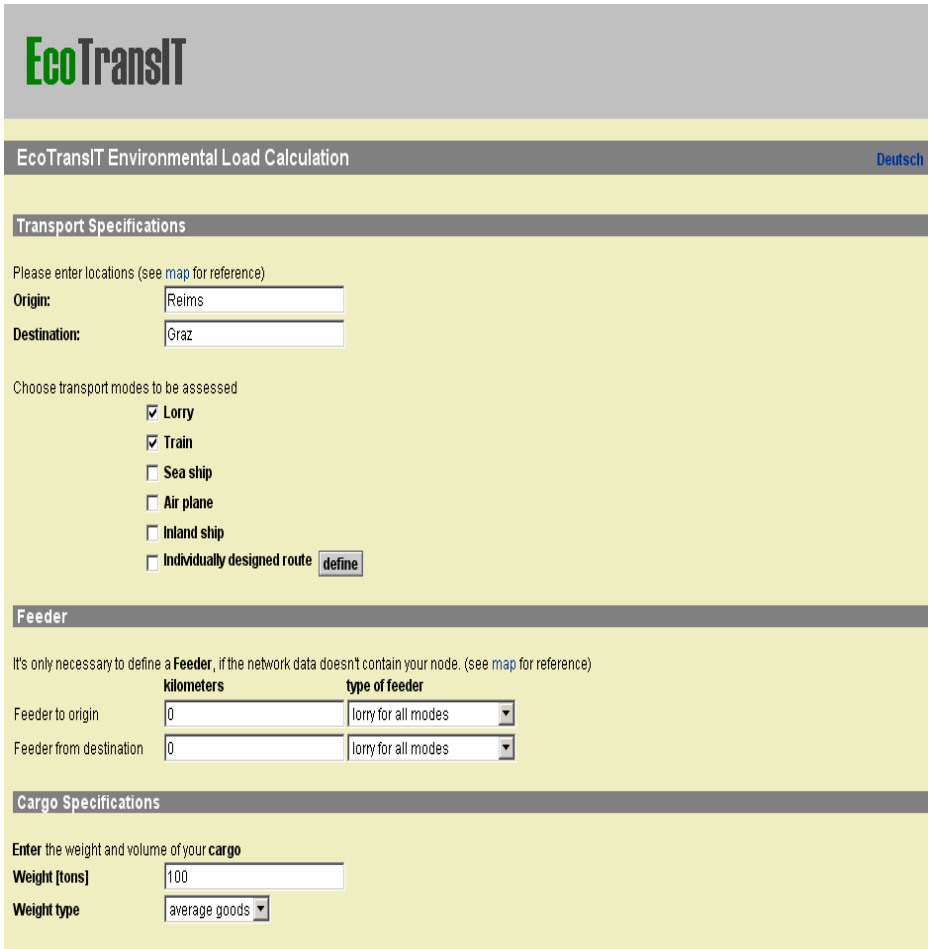
EcoTransIT calculates the impact of a shipment on the environment on the basis of default assumptions with reference to the vehicles typically used in European/ international transport. For a main shipment by truck, it is assumed that a 40 ton truck (emission category EURO 2) will be used. As a truck for feeder line transport will generally be smaller, the system setting in this case is for a size of 7.5 tons (emission category EURO 1). If the train is used as the main means of transport, a train of average length with electrical traction is postulated. When a train is used for feeder line transport, a short train with diesel traction is the default setting. The client can adjust these pre-defined assumptions in keeping with the requirements of his shipment.

For trucks, the vehicle size (permissible maximum weight) and emission category can be changed. For rail transport, the length of train and type of traction can be adjusted. Settings for feeder line transport can be adjusted independently of the main shipment. Typically, small trucks are used for feeder line transport, or short trains in the case of rail transport. It is rarely necessary to alter the system setting in this case.

Truck emission categories refer to the exhaust emission characteristics of the vehicle. The newer a truck is, the higher its EURO category will be.

The exhaust emission properties will be calculated on the basis of the type of traction used, i.e. diesel and electrical in the case of rail transport. With electrical traction, the shipment itself does not give rise to any emissions, but there are the emissions from the power plant that produces the electricity to be taken into considerationEcoTransIT takes into account both, the direct emissions from the vehicle and those that are indirectly caused, at the power plant for instance.

Figure 1: Main input mask of EcoTransIT



3. Results

EcoTransIT calculates the overall consumption of primary energy for the defined shipment, together with the emissions of various pollutants (carbon dioxide, nitrogen oxides, sulphur dioxide, non-methane hydrocarbons, total dust emission, soot particles).

The default setting for the presentation of results shows a diagram for primary energy consumption and carbon dioxide emissions. A direct comparison is possible. Diagrams for other pollutants can be added to the result presentation. Furthermore, all results can also be displayed in a table, together with the transport distances in each case.

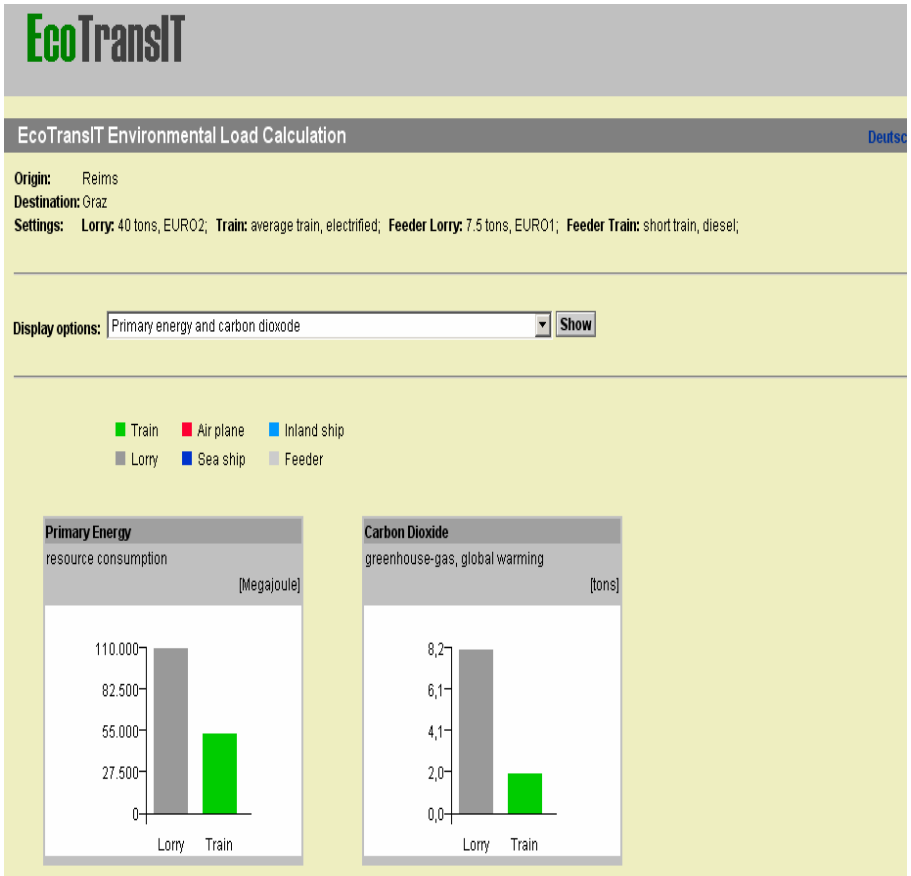
More information about EcoTransIT can be found at www.ecotransit.org .

Environmental Mobility Check

The Environmental Mobility Check enables the client to make his own personal mobility decisions on the basis of ecological criteria. The Environmental Mobility Check compares the environmental impacts caused by public transport with rail & bus to the use of a private car on the selected route from any given starting point to any given destination.

After a railway connection has been compiled, the client can select 'Environmental Mobility Check' which leads to a graphic and tabular presentation of the energy consumption and carbon dioxide emissions. Furthermore, also the results for other emissions (sulphur dioxide, nitrogen oxide, non-methane carbons) can be displayed.

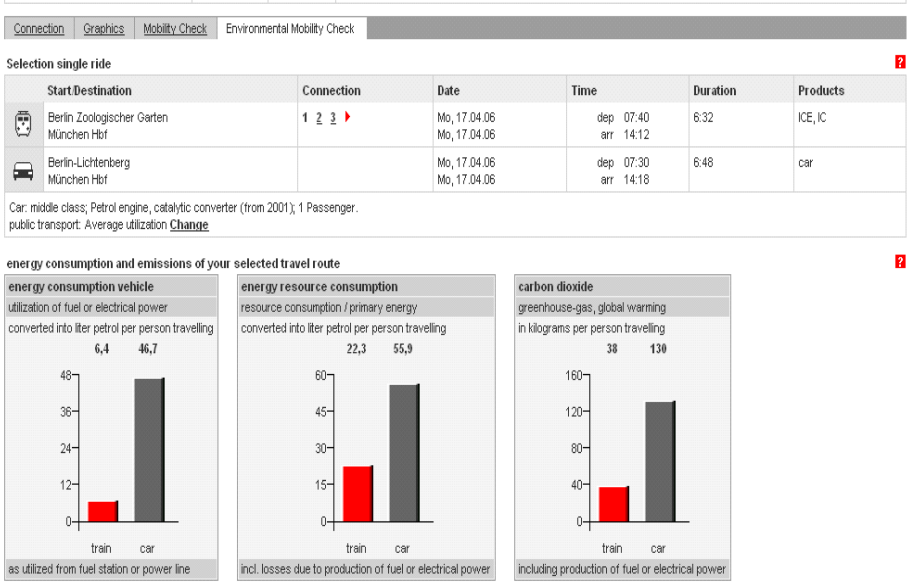
Figure 2: Possible results of EcoTransIT (energy consumption, carbon dioxide emissions)



The results of the Environmental Mobility Check are calculated on the basis of default settings, which are described below the listed travel options and can be adapted if necessary by clicking 'Change'. This enables the client to vary the

car parameters (petrol/diesel engine, pollution class). The public transport potential can be varied by changing the default setting 'average' capacity utilisation to 'full' capacity utilisation, i.e. if all the available seats are occupied. Calculating the capacity utilisation of a car is based on the number of persons which have been stated for the price calculation (this figure can be changed if necessary). Alternatively, the client can also select an 'average' car utilisation factor.

Figure 3: Possible results of the Environmental Mobilty Check (timetable, energy consumption, carbon dioxide emissions)



In addition to the comparison of journey time and costs, the Environmental Mobility Check thus gives the client a further criterion for his decision by supplying information on the most environment friendly route to his destination.

The Environmental Mobility Check considers energy consumption as well as the emission of air pollutants and greenhouse gases as parameters for the environmental impacts of the different means of transport. Energy consumption is presented as the final energy consumption of the vehicle and as the primary energy consumption. To facilitate comparisons, all energy units are converted into litres of petrol equivalents. In addition to the emissions caused directly by the car, the Environmental Mobility Check also includes emission resulting from the provision of energy (e.g. from power stations or refineries).

With the focus on global and regional effects, it considers:

carbon dioxide as the dominant greenhouse gas,

sulphur dioxide which can cause damage such as respiratory diseases, "forest dieback", acidification of soil and water, and acid corrosion of buildings,

nitrogen oxide, an air pollutant with an acidic effect which also contributes to overfertilisation of soil and water, and

non-methane carbons, which are regarded as the precursors of summer smog (ozone near ground level), together with nitrogen oxides.

More information about the Environmental Mobility Check can be found at www.bahn.de/umweltmobilcheck .

Scientific background

For the realisation of the tools, adequate methodologies had to be developed which on the one hand are not too complicated, on the other hand exact enough for a correct quantification of energy consumption and emissions of the different transport modes. Another issue was the use of an up-to-date and commonly accepted database. Therefore, both tools use the current version of the 'Handbook Emission Factors for Road Transport by Keller and de Haan (2004) as the emission factor data base for road transport (passenger car and lorry). For railway transport, special functions for the calculation of energy consumption for different kinds of trains have been developed, based on specific values from the railway companies. The used methodologies and data are described in detail in the scientific reports Knoerr and Reuter (2005) and Knoerr (2006) which can be downloaded from the homepages of UMC and EcoTransIT.

Outlook

Both tools have been updated recently and thus consider the latest data. Further necessary updates of the basic data are ensured for the next years. In addition, some further ideas have already been developed and are partly in the process of implementation, e.g.:

Extension of EcoTransIT into a tool which covers all transports of a company and calculates their environmental impacts.

Inclusion of further European relations and air traffic in the Environmental Mobility Check.

It is thus worthwhile to frequently visit the respective homepages and check for further features and updates.

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TREMOVE 2 : Model application for the assessment of alternative scenarios on future light duty vehicle emission legislation

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Abstract

This paper is a follow-up of the TREMOVE 2 paper presented at the 14th "Transport and Air Pollution" Conference in Graz by Van Herbruggen and Logghe (2005). This paper recapitulates the TREMOVE 2 model structure and provides an overview of its applications so far. The results of two applications in Belgium are presented. More specificly, we discuss an analysis of the possible impact of the current EC proposal on new light duty vehicle emission standards (COM(2005)) as well as the impact of a differentiated car taxation scheme. In a last section the planned further development of the TREMOVE model is discussed.

***Keys-words**: transport model, transport emissions, emission standards, environmental policy, transport policy.*

Résumé

Cet article suit l'article TREMOVE 2 présenté au 14ième coll. "Transport et Pollution de l'air" par Van Herbruggen et Logghe (2005). Cet article récapitule la structure du modèle TREMOVE 2 et donne une vue d'ensemble de ses applications jusqu'ici. Les résultats de deux applications en Belgique sont présentés. Spécifiquement, nous discutons l'analyse de l'impact possible de la proposition COM(2005) concernant les normes d'émissions des nouvelles véhicules légères, aussi que l'impact d'un différenciation des taxes sur les automobiles. Le dernier paragraphe discute les prochains développements du modèle TREMOVE.

***Mots-clefs**: modèle transport, émissions du transport, normes d'émissions.*

TREMOVE 2 Model Structure

TREMOVE is a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector. It is an integrated simulation model developed for the strategic analysis of the costs and effects of a wide range of policy instruments and measures applicable to local, regional and European transport markets. The model is property of the European Commission.

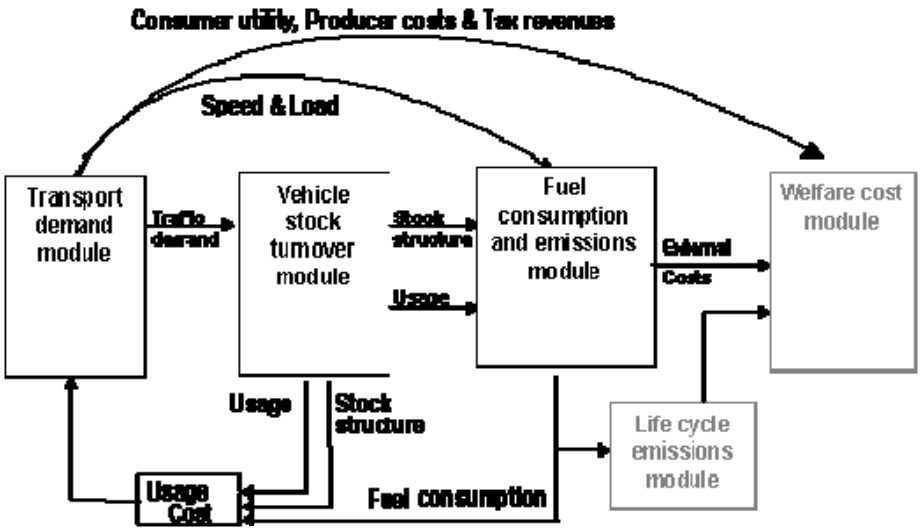
The first versions of the TREMOVE model were developed in 1997-1998 by the Catholic University of Leuven and Standard & Poor's DRI as an analytical underpinning for the European Auto-Oil II Programme (European Commission, Standard & Poors' DRI, K.U.Leuven, 1999). The most recent model version is TREMOVE v2.4 (De Ceuster, Van Herbruggen, Logghe (2006)), which has been developed by the Catholic University of Leuven, Transport & Mobility Leuven and their subcontractors. Recently TML started the TREMOVE 3 (Lot 1) development project in which further development and extension of the model is envisaged.

TREMOVE 2 covers 21 countries and 8 sea regions. All relevant transport modes are modeled, including air and long-distance maritime. The model covers the 1995-2020 period, with yearly intervals.

Figure 1 maps the modular structure of TREMOVE. The model performs a year-by-year loop over its modules. The same modules are used for both the construction of the baseline (business as usual) scenario as for the policy scenarios.

Figure 1 : Modular structure of TREMOVE 2 Model.

Figure 1: Structure modulaire du modèle TREMOVE 2.



TREMOVE consist of 21 parallel country models, and one maritime model (the latter is not discussed in this paper). Each country model consists of three

inter-linked 'core' modules: a transport demand module, a vehicle turnover module and an emission and fuel consumption module, to which we add a welfare cost module and a life cycle emissions module.

The transport demand module describes transport flows and the users' decision making process when it comes to making their modal choice. Starting from the baseline level of demand for passenger and freight transport per mode, period, region etc., the module describes how the implementation of a policy measure will affect the user's and company's choice between these 240 different transport types. The key assumption here is that the transport users will select the volume of transport and their preferred mode, period, region etc. based on the generalized price for each mode: cost, tax or subsidy and time cost per km travelled. The output of the demand module consists of passenger-kilometres (pkm) and ton-kilometres (tkm) that are demanded per transport type for a given policy scenario. The pkm and tkm are then converted into vehicle-kilometres (vkm).

The vehicle stock turnover module describes how changes in demand for transport or changes in vehicle price structure influence the type and age of vehicles in the fleet. The output of the vehicle stock module is twofold: we split both the total fleet and the number of vkm for each year according to vehicle type and age.

The fuel consumption and emissions module is used to calculate fuel consumption and emissions, based on the structure of the vehicle stock, the number of kilometres driven by each vehicle type and the driving conditions. For road transport fuel consumption and emission factors are based on the COPERT 3 methodology (Ntziachristos, Samaras (2000)).

Outputs from the vehicle stock and fuel consumption and emissions modules are fed back into the demand module. As fuel consumption, stock structure and usage influence usage costs, they are important determinants of transport demand and modal split.

In addition to the three core modules, the TREMOVE model includes a lifecycle emissions and a welfare cost module.

The lifecycle emissions module enables to calculate emissions during production of fuels and electricity. The welfare cost module has been developed to compute the cost to society associated with emission reduction scenarios in European urban and non-urban areas. The welfare effect of a policy change is calculated as the discounted sum of changes in utility of households, production costs, external costs of congestion and pollution and benefits of tax recycling. The latter benefits of tax recycling represent the welfare effect of avoiding public funds to be collected from other sectors, when the transport sector generates more revenues.

Applications

So far, the TREMOVE 2 model has been used to evaluate following policy scenarios for the European Commission, Directorate-General Environment :

Reductions of light duty vehicle emissions beyond EURO 4 standard levels;

Fuel efficiency improvements beyond the 2008/2009 voluntary agreement of the car industry;

Heavy duty truck road charge schemes with charges converting external pollution costs;

Fuel excise tax policies;

Shore side electricity, aftertreatment technologies and changes in fuel specifications for maritime vessels.

So far, there is no public report on these simulations performed for the European Commission.

The TREMOVE 2 model has also been applied in the ASSESS project (De Ceuster et al. (2005)) in the context of the mid-term review of the White Paper on European Transport Policy. Furthermore, the model has been applied in the context of the thematic network PREMTECH II on improved road vehicle environmental technology.

In the next section we shortly present two applications of the TREMOVE 2 model which were performed in the context of a Belgian project funded by FEBIAC (Belgian federation of the car and two-wheeler industry) and FPSMT (Federal Government Service Mobility and Transport). Full results of this project are presented in Logghe, Van Herbruggen and Van Zeebroeck (2006).

Impact of new EC proposal and variabilisation of car taxes in Belgium

In the latter project TREMOVE 2 has been used to analyse and forecast emissions of transport in Belgium for the 1990-2030 period. Two business-as-usual scenarios have been developed : one without light duty vehicle emission standards beyond EURO 4 and one including the EC proposal COM(2005). Next to these baseline scenarios, three policy scenarios have been analysed :

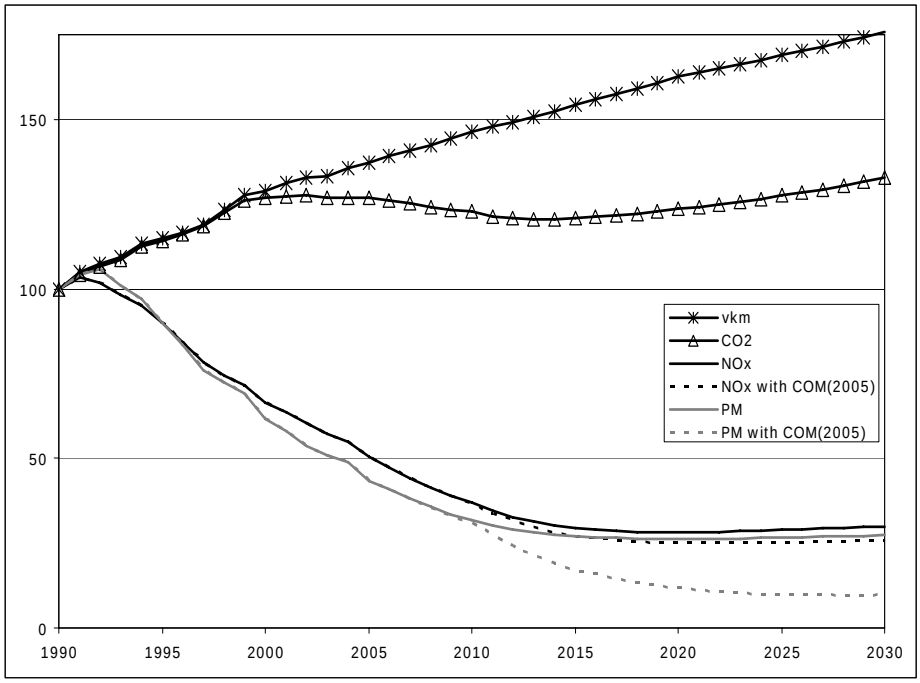
- a homogeneous increase in road transport taxation;
- a sensitivity scenario on the influence of fuel resource costs and fuel taxes including a harmonization of diesel and petrol taxation;
- a variabilisation of the annual taxes on cars as a function of their emission characteristics.

In this section we present a comparison between the two baselines, as well as results from the third policy scenario (variabilisation). The focus is rather on illustrating the functionality of TREMOVE than on giving an exhaustive overview of the model results.

Figure presents the road vkm and exhaust CO_2 emisson trends calculated for the baseline without the new emission standards proposed in COM(2005). For NO_x and particulates results are presented for both the scenarios with and withouh COM(2005). Note that the impact of COM(2005) on CO_2 (and other pollutants as VOC) emissions has been calculated by TREMOVE, but is not presented in Figure .

Figure 2 : Road transport exhaust emissions in Belgium (normalised to 1990)

Figure 2: Emissions d'échappement du transport routier en Belgique



Between 1990 and 2030 belgian transport activity will increase significantly. Nevertheless, a significant reduction in NO_x and particulate emissions is predicted. This reduction is predominantly the result of the tightening EURO standards for all road vehicles. The emission standards proposed in COM(2005) would lead to strong further reductions in particulate emissions, whereas the effect on NO_x is more limited. Note that these latter reductions will not only result from decreases in vehicle emission factors, but also from changes in the vehicle fleet. TREMOVE predicts that the proposed standards would lead to a decrease of the market share for diesel cars (compared to the baseline without COM(2005).

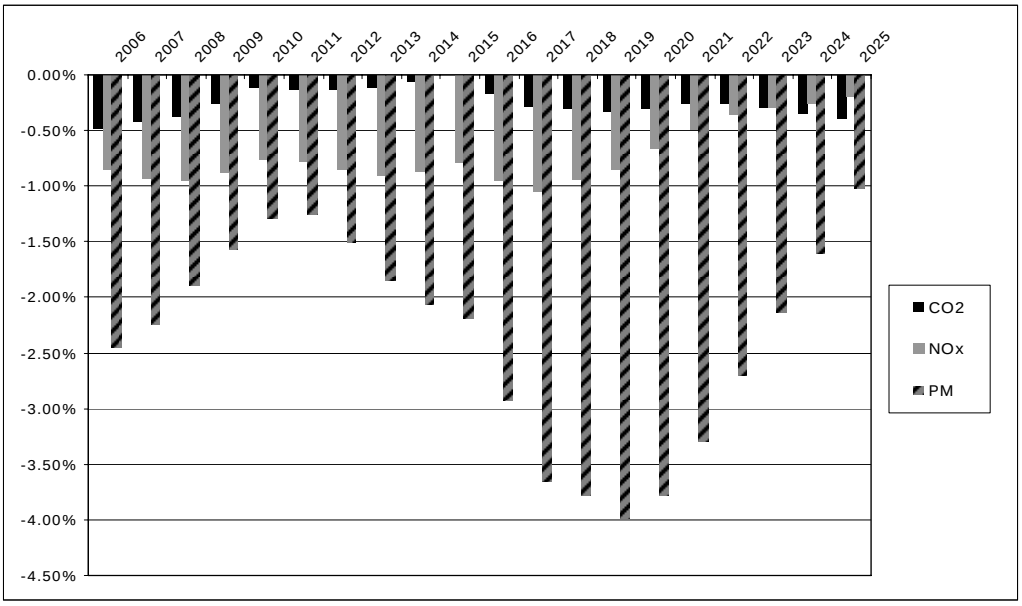
With respect to CO_2, the increase in transport activity will – in the next ten years – be off-set by a.o. the introduction of more fuel-efficient cars following the voluntary agreement of the car industry and the promotion of biofuels and CNG.

Starting from the baseline including COM(2005), the effects of a differentiated car taxation scheme have been simulated. This simulation scenario assumes that new differentiated levels of annual car ownership taxes are introduced, which relate to the emission standards and the CO_2 emissions of the cars. The objective of the policy is to promote the use of young environmental-friendly cars. The tax levels were determined such that the current level of tax revenues for the government is maintained. This means that the average ownership tax level hardly changes. As a result the effect of this policy on overall car transport volumes, as estimated by TREMOVE, is very limited.

Figure presents the effects of the policy on CO_2, NO_x and particulate emissions relative to the baseline.

Figure 3 : Effects of differentiated car ownership taxes on total emissions of road transport

Figure 3: Effets en émissions routier d'une différenciation des taxes annuelles sur automobiles



Emissions of particulates are reduced by 1% to 4% in the 2006-2025 period. Figure shows two peaks in this particulates effect. In 2006, the assumed implementation date of the policy, a significant number of older cars is replaced by new cars complying to the EURO 4 standard. In the later years the number of pre-EURO 4 cars in the baseline fleet decreases and so does the potential for replacement by cleaner EURO 4 cars. From 2011 on however, the new sold cars comply to COM(2005). The effect on particulates of replacing old diesel cars by new ones therefore grows again. As by 2026 almost all cars in the baseline fleet comply to COM(2005) the effect of the differentiated tax policy on particulate emissions fades out.

For NO_x a similar trend is calculated as for particulates albeit that the effects are smaller.

The reduction in CO_2 does not fade out in the later years. The reason is that the tax scheme also gives an advantage to CO_2 efficient technologies, like hybrids.

Further developments

Next to further applications of the model for policy scenario analysis, further development of the model are planned in 2006 and 2007. These developments will include, amongst others :

An update of the road vehicle emission factors to the forthcoming COPERT 4 methodology;

An extension of the model to 31 countries (EU25, Switzerland, Norway, Turkey, Romania, Bulgaria, Croatia);

Addition of air freight transport and improvement/extension of modal shift modeling;

Updating fleet dataset.

Conclusions

With TREMOVE 2 a transport model is available that can be applied for environmental and economic analysis of policies to reduce emissions from all modes of transport in the enlarged European Union.

TREMOVE is an integrated model that estimates transport demands, modal shifts, vehicle fleet renewal, fuel consumption, emissions and welfare levels in baseline and/or policy scenarios.

A wide variety of policy measures can be simulated, including technological measures and fiscal measures. The model has been applied for policy analysis on both EU and national scale.

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Atmospheric pollutant emission factors of light duty vehicles within the Artemis model

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Abstract

The purpose of the work presented is the definition of an emission model for the exhaust pollutants (CO, CO_2, HC, NOx and particulates) and for the fuel consumption of light duty vehicles, to be part of the future European emission model Artemis. Data were collected into different European laboratories and the gaseous emissions of 150 vehicles were obtained with different traffic situations and loads. The vehicles were classified according to the fuel used, the European Standard (pre-Euro 1 to Euro 2) and the European categorization (N1-I, N1-II et N1-III). 24 groups were thus built. For each group and for each pollutant, statistical study using Pearson test was performed in order to compare an average speed emission model with data. If the test is unconfirmed or if the correlation coefficient is low, the influence of vehicle load was investigated. Emission equations were obtained using always average speed and sometimes load as parameters. They were statistically validated by comparison with the experimental data.

***Keys-words**: transport emissions, light duty vehicles, atmospheric pollutants, average speed, load, modelling, Europe.*

Introduction

In the most recent version of the European inventorying tool Copert (Ntziachristos et Samaras, 2000), the Light Duty Vehicle emission factors have been built by extrapolating data obtained from passenger cars to light duty vehicles. Only pre-Euro 1 and Euro 1 vehicles were studied and emission factors expressed according to the average speed. To improve the accuracy of this model, we incorporated the results of a former Inrets project (Joumard *et al*., 2001, 2003) and the tests carried out previously by other European laboratories (Tuev in Germany, TRL in UK, TNO in the Netherlands, Empa in Switzerland and KTI in Hungary). Specific cycles for light duty vehicles were

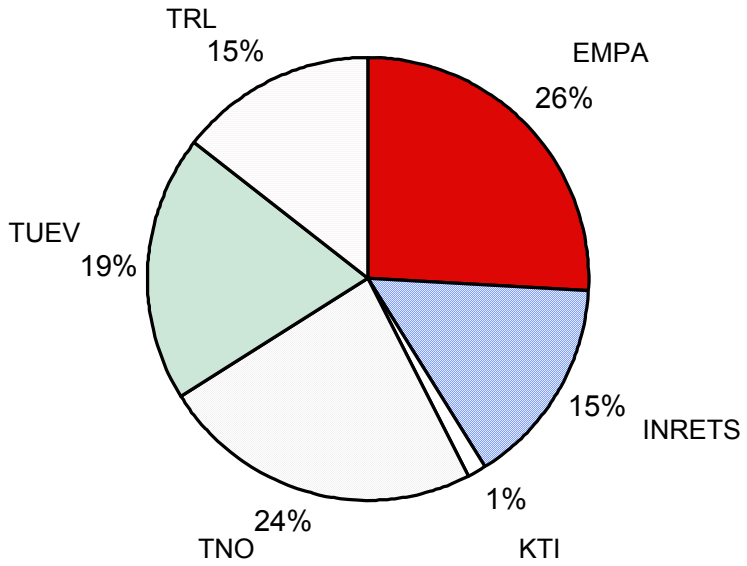
developed for some of these programmes, taking into account the road type and loading rates (André *et al*., 2000).

This study is a part of the Artemis project (Assessment and Reliability of Transport Emission Models and Inventory Systems), whose purpose is to develop a software that calculates emissions of any transport mode, at local, national and international levels.

Data extraction and classification

The first step of the analysis consisted in exhaustively extracting all the light duty vehicles from the Artemis database (Kljun *et al*., 2005 ; Andre, 2005). The LDV database concerns light vans, vans and minivans, i.e. 150 vehicles and 2035 tests (1 test = 1 vehicle and 1 driving cycle). The vehicles were then grouped according to the European categorisation (N1-I to N1-III) based on the vehicle tare weight (cut points: 0, 1 305, 1 760 and 3 859 kg), associated with the European emission standards (Pre-Euro 1 to Euro 3) and the type of fuel used (diesel, petrol). 24 different groups were distinguished, but the different groups were not equal because 19 groups contained less than 4 vehicles while 5 groups contained more than 10 vehicles. In addition, whereas 6 laboratories tested LDVs, no group contained data of more than 4 laboratories and, in a third of cases, only one laboratory was represented per group. This may have had an artificial homogenising effect on the data since the production source of each group was not very diversified. However, as shown in Figure 1, the source of the vehicles was balanced for 5 laboratories out of 6, meaning that the representativeness of 5 out of 6 laboratories was satisfactory.

Figure 1: Source laboratory of LDV data



Emission calculation

To build a model of emission factors, 4 hypotheses were applied:

- The group of vehicles extracted is representative of the global fleet of light duty vehicles and its conditions of use
- All the vehicles of a group are equivalent. The emission measured is independent of vehicle make and analysis laboratory
- All the cycles have the same weight as a function of representativeness
- The number of tests carried out on a vehicle does not influence the weight of the emission

The consequence of these hypotheses is that each data is considered with the same weight of representativeness.

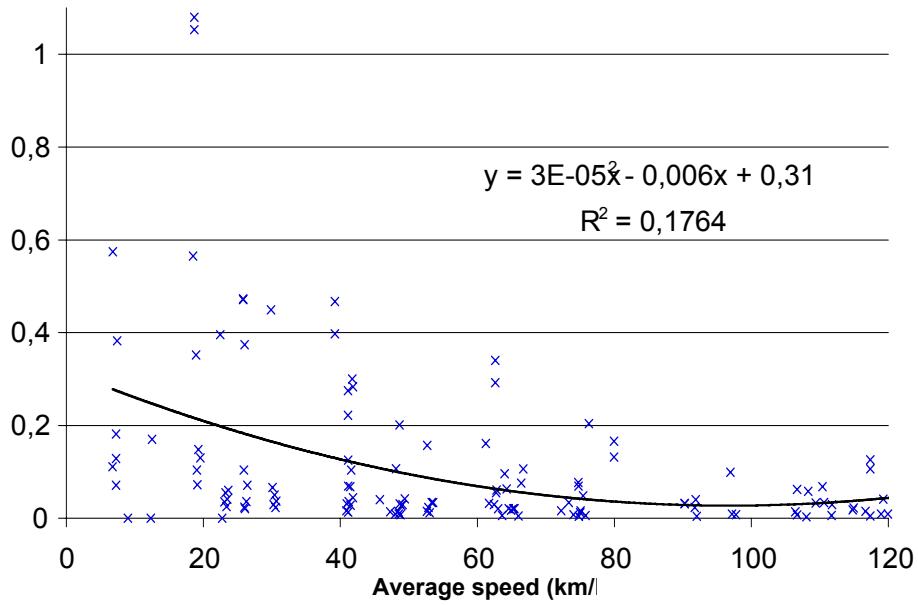
1. Emissions as a function of average speed

For each vehicle, the emission data were analysed according to the average speed of the cycle. The best fit is chosen to minimise the standard deviation between the model and the measurement points. The emissions describe a polynomial curve of order 2 in the great majority of cases and a power curve in a few cases. The coefficients of determination were generally significant (> 0.7). However, for certain vehicles and pollutants, the values obtained were low (< 0.3) showing that other parameters than the average speed (e.g. acceleration) have a significant influence on the emissions.

For each of the 24 groups, the average equation was also calculated by polynomial equation of order 2 or power equation with an average coefficient of determination of 0.41 for diesel and 0.5 for petrol vehicles (see an example Figure 2). The validity of using an average equation was verified by Pearson's test with an error of 0.5 %. The aim of this statistical test was to verify the hypothesis that the two groups were identical, i.e. the data calculated by the average equation and either the raw data or the data obtained from the equations of each vehicle.

The results were then analysed in several steps. The first step consisted in distinguishing the vehicles that satisfied Pearson's test or not. The vehicles that verified Pearson's test were separated into 3 groups as a function of the coefficient of determination obtained. If it was higher than 0.7, the emission was considered as depending only on the average speed. If the coefficient of determination was from 0.5 to 0.7, the equation for this group of vehicles was satisfactory, but other parameters could play a role. If the coefficient of determination was lower than 0.5 and the test validated, the equation was only accepted if the addition of the parameter did not permit any increase of the coefficient of determination. In this case, it was necessary to carry out additional searches.

Figure 2: Average emission for the vehicle group N1-III Diesel Euro 1, as a function of average speed only.



The results are as follows: the petrol vehicles had 18 validated emission factors (confirmation of Pearson's test and a coefficient of correlation higher than 0.7) – i.e. 34 % of the equations – and the diesel vehicles had only 12 – i.e. 12 %. Furthermore, 8 diesel vehicle emission factors and 6 petrol vehicles factors were not validated by Pearson's test. The emission factors were therefore not only dependent on average speed despite the fact that a large number of emissions can be determined by using this single parameter.

2. Correction of emission as a function of vehicle loading rate

The loading rate τ is calculated according to the weight of the vehicle during the test M_{test} and the vehicle tare weight M_{empty} using the following equation:

$$\tau = \frac{M_{test} - M_{empty}}{M_{empty}} \times 100$$

The loading rate, calculated for all the vehicles and all the cycles carried out, varied from 0 to 91 %. However, for 12 % of the tests, it was not possible to calculate the loading rate due to the lack of the vehicle weight during the test: the corresponding emission data won't be used for the calculation of emission factor as a function of loading rate.

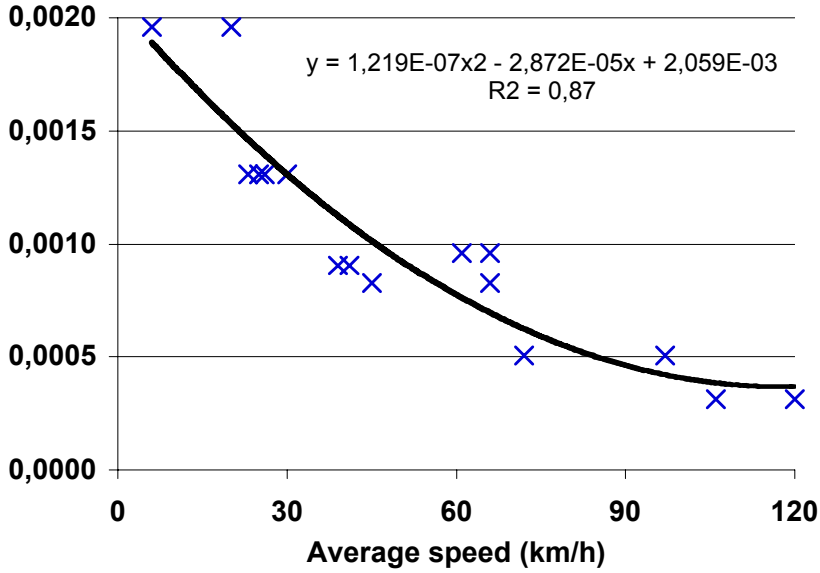
The vehicle load is not the only parameter influencing emission variations since the emission as a function of the average speed of the groups with a low

range of loads has not necessarily a high coefficient of determination nor even validate Pearson's test.

It appears that the entire emission curve is changed by the increase of the vehicle weight: for a given pollutant whose emission curve has as equation $y=av^2+bv+c$ (the most frequent case), the coefficients a, b and c are related to the load. To define the link between these coefficients and the loading rates, we defined speed zones so that the variety of the group in terms of load and vehicles was represented. The equation describing the pollutant emission as a function of load was calculated for each zone. It is a polynomial curve of order 2 at most (order 1 for groups in which fewer than 4 vehicles were studied). The equation in each speed zone was therefore $y=a'\tau^2+b'\tau+c'$. The coefficient of determination between this curve and the emission data was calculated: the coefficients of determination were 0.65 and 0.52 on average for diesel and petrol vehicles respectively. The equations for which the coefficient of determination was less than 0.2 were not used.

Then the coefficients a', b' and c' were expressed according to the average speed of the speed zone (see an example Figure 3). If the coefficient of determination was lower than 0.5, the speed zones were revised until a better coefficient was obtained, otherwise this group of vehicles was withdrawn from the load study. The coefficients obtained were thus 0.75 and 0.76 on average for diesel and petrol vehicles respectively. The equation of each coefficient was then incorporated into the pollutant emission equation, which depends on the average speed and load: $y=a'(v)\tau^2+b'(v)\tau+c'(v)$.

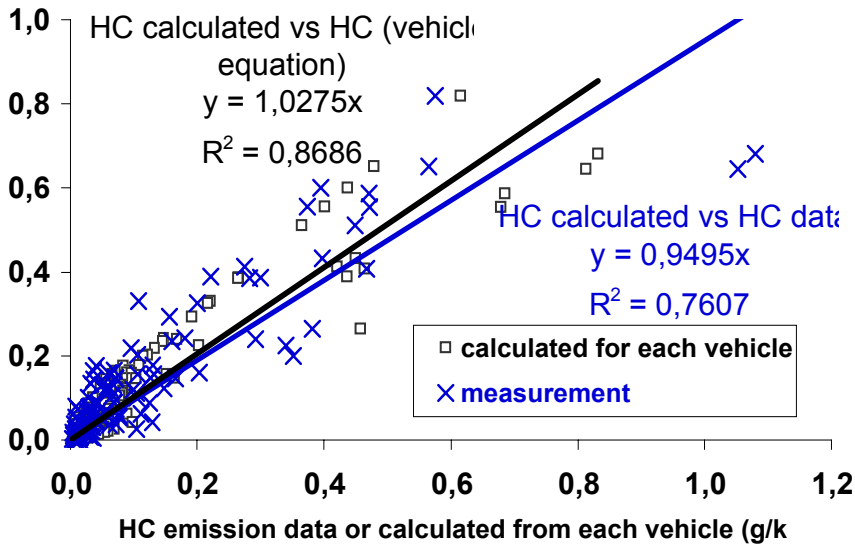
Figure 3: Coefficient a' of the HC emission of group N1-III Diesel Euro 1 as a function of average speed.



Two series of verifications were applied to the equation obtained. The first verification consisted in verifying that the group of measured emission data and that of calculated emissions could be considered identical. To do this,

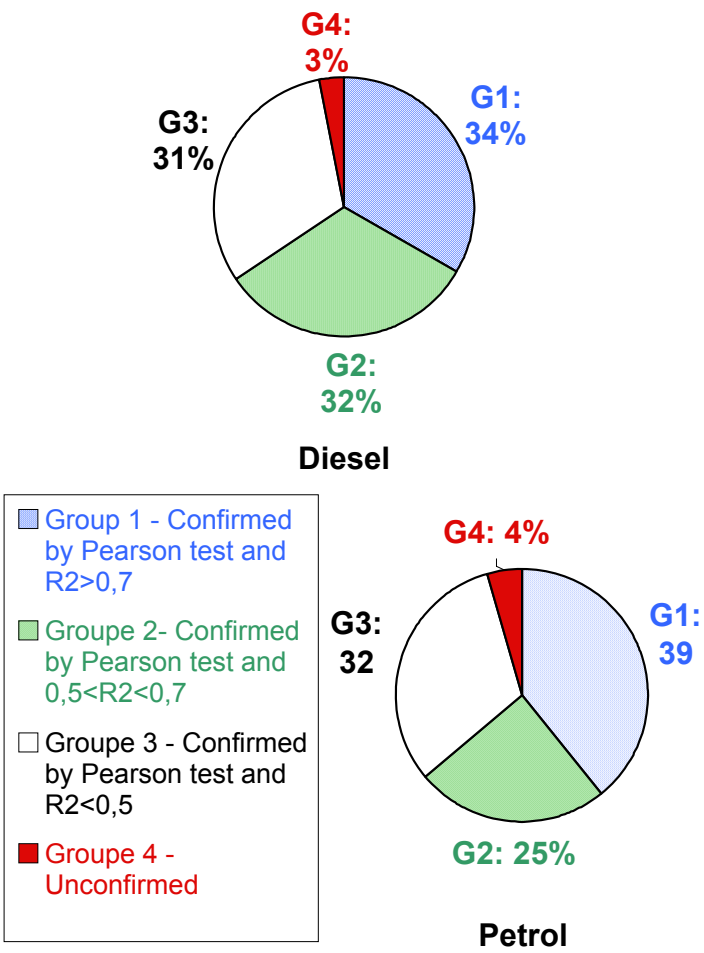
Pearson's test was performed and compared with Student's law with (n-2) degrees of freedom for an error of less than 0.5 %. The second verification consisted in comparing the values calculated by the equation to the values of the emission curves. As before, the two groups were compared using Pearson's test for an error less than 0.5 %. The equations were also classified into 4 groups as a function of the validation of Pearson's test and of the coefficient of determination obtained. Figure 4 shows an example of correspondence between the emissions calculated as a function of speed and loading rate for the group of vehicles and the raw data or the emissions calculated as a function of speed for each vehicle.

Figure 4: Statistical validation of the emission as a function of loading rate and average speed for the HC emission of group N1-III Diesel Euro-1.



The emissions of N1-I Diesel pre-Euro 1 and Euro 2, N1-II Diesel Euro 2, N1-I Petrol Euro-1 and N1-III Petrol Euro 2 and the hydrocarbon emissions of N1-I Petrol Euro 1, N1-II Petrol pre-Euro 1 and Euro 1 are not linked with the vehicle load. For the other groups, an equation defining the emission as a function of average speed and load was established with an average coefficient of determination of 0.56 for diesel vehicles and 0.61 for petrol vehicles. This shows that the load parameter has a significant impact on the precision of the emission factor equation. In addition, load and speed permit defining a satisfactory emission factor (Pearson test validated and coefficient of determination higher than 0.7) for 26 % and 27 % of the groups of diesel and petrol vehicles respectively. A synthesis of the results is presented in Figure 5.

Figure 5: Distribution and validation of the equations obtained



A result is considered as satisfactory when the Pearson test is validated and the coefficient of determinations is higher than 0.7. This is the case for 34 % and 39 % of the emission factors calculated for diesel and petrol vehicles respectively. For these groups it was possible to determine an equation highly representative of the group by using average speed and/or the loading rate as sole parameters. A result is considered as valid but needing further analysis for another impact parameter on the emission, when the result is validated by Pearson's test and the two coefficients of correlation are higher than 0.5 (and do not belong to the previous case). This is the case of 32 % and 25 % of the emission factors calculated for diesel and petrol vehicles respectively. Thus, in 66 % of groups containing diesel vehicles and 64 % of the groups containing petrol vehicles, an equation representing the group is determined and validated with a coefficient of determination higher than 0.5 and therefore higher than the average value of the equations used in Copert. Regarding the remaining vehicles, it was necessary to study another factor even though only 3 % and 4 % of the equations were not validated by the Pearson test. These are HC and

particle emissions for the vehicles of group N1-II Diesel Euro 2 and CO, HC and NOx of N1-III Petrol Euro 2 where few data were obtained with only two vehicles.

For each of the equations obtained and in particular for those including the load factor, it was necessary to model the behaviour of the emission outside the load zone studied. For that, the lower and higher values of the emission at limit load were compared to the values calculated at 0 % and 100 % respectively. When the difference is greater than 30 %, the equation is not used outside the study zone and the value used is equal to that of the nearest bound. In other cases, the calculation is carried out on the basis of the equation.

Conclusion

After extracting the emission data of light duty vehicles from the European Artemis database, it was possible to formulate equations of emission factors for these vehicles as a function of average speed and loading rate. This method was used to statistically validate 97 % and 96 % of the emission factors of diesel and petrol LDV respectively.

Furthermore, a considerable increase in precision of the quality of the equations was observed. In the Copert model, the average coefficient of determination was 0.39 for diesel LDV and 0.49 for petrol LDV. By updating the data in Artemis and calculating the emission factors by using only the average speed as parameter, a slight improvement of the coefficients of determination could be observed since it was resp. 0.41 and 0.5. However, by adding load as a parameter, the average coefficient of determination changed to 0.59 for diesel and 0.56 for petrol vehicles. In addition, whereas Copert only deals with pre-Euro 1 and Euro 1 vehicles, we propose emission factors for Euro 2 vehicles.

Testing of the emission factors obtained must, however, be continued and their equations improved, if necessary, by using additional vehicles added during updates of the Artemis database.

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Gaseous and solid exhaust emissions from diesel cars equipped or not with a particulate filter

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Abstract

Regulated and unregulated emissions, including a dozen metals, were assessed from 5 diesel cars equipped with a particle filter. The current particulate reduction systems use metallic catalysts substrates or the fuel is additivated with metallic compounds coupled in both cases, with a precise management of the fuel injection to facilitate the burning of accumulated soot. The efficiency of three diesel filter types is analysed, regarding the particulate total mass, the particulate size distribution, and metal emissions as well. The second objective is to compare the results on metal emissions with those obtained on a sample of non-filtered diesel cars, tested previously according to the same procedures. The unregulated pollutants such as VOC, aldehydes and cetones are also compared and the effect of cold start is assessed regarding all compounds.

***Keys-words**: Diesel particulate filter, diesel car, emission measurement, regulated pollutants, particulate size distribution, metals, VOC, aldehydes, cetones.*

Context and objectives

Increasingly stringent emission limits for European vehicles and especially, the future Euro 5 standards, force the car manufacturers to gradually equip their diesel models with a particulate filter (DPF), beginning with their most powerful

engines. Many tests have demonstrated the efficiency of particulate traps in terms of particle retention rate, including ultra fine particles, with the use of ceramic monoliths (silicon carbide or cordierite). Most of tests have been initially carried out on buses and heavy-duty vehicles (Mayer, 2003). Few independent studies have addressed a wide range of gaseous and solid emissions from current diesel cars equipped with a particulate filter. (Coroller and Plassat, 2002), (Mohr et ali, 2006).

Different types of particulate reduction system for cars are available now. Continuous oxidation of soot is achieved according various techniques: fuel-borne catalyst (FBC) or catalytic coating in the filter (CSF) are the main strategies adopted by the DPF manufacturers. FBCs use a cerium or iron-based fuel additive and platinum or noble metal formulations were chosen as the most effective substrates for catalytic action and soot reduction. A third filter type (DPNR system from Toyota) combines treatment of NOx and particles. An oxidation catalyst placed upstream from the filter converts NO to NO2, which is used to oxidize continuously the soot in the filter as it accumulates. This system could not run until recently in France, as it requires a low-sulphur fuel (< 50 ppm). Precise combustion control or fuel post-injections are needed by interval in any of the three systems to achieve complete soot burning and filter clean up (every 300 to 800 km as reported, depending on the system and the engine operating conditions). The three filter types mentioned above were tested in the study. They are all fully managed by an internal calculator, which prevents from any regeneration control. In the case of the Toyota DPNR, a specific tester could be used to lock the regeneration on most driving cycles and obtain it on a dedicated cycle (specific highway + Reg.). For the other vehicles, the only way to avoid uncontrolled regenerations when testing the vehicles is to induce previously filter regeneration by means of the necessary mileage.

The main objective of the study is to extend knowledge regarding regulated emissions as well as metal emissions and gaseous emissions such as VOC from a small selection of recent diesel cars. PAH emissions were also investigated and are presented in a distinct paper (Paturel et ali, 2006). The five selected vehicles are equipped with a particulate filter and fulfil the Euro 4 limits or are Euro-4 equivalent. Ten diesel vehicles from ECE1504 to Euro 3 technologies served as references for the metal and VOC emissions.

Procedures

The regulated emissions were measured according to the legislated CVS method, from vehicles following selected driving cycles on the Inrets chassis test bench. Samplings were made simultaneously from the dilution tunnel to dedicated cartridges and analysed subsequently for the VOC (among which aldehydes and cetones) in different labs (ref. to the authors' labs). The same driving cycles (standard and real, cold or hot start) and same analysis methods for the VOC and aldehydes-cetones as in a previous study on older diesel cars were used to enable comparisons (Joumard et ali, 2004). Metals were extracted from the CVS filters after the standard weighing for determining PM emissions (in g/km). A specific method for dosing metal was set up and is described

hereafter. In addition, a special sampling line located close to the tailpipe directed a small and constant fraction of the exhaust to the size distribution analyser (ELPI). This specific measurement setup dedicated to the analysis of the size specific particle concentration is derived from the protocol adopted in the EU Particulates project (Samaras et ali, 2003).

1. Vehicle specifications

The 5 DPF-equipped diesel cars tested in the study are supposed to comply with Euro 4 legislation, even if they could not all be certificated under these limits at the time of their registration. The oldest was registered in September 2004, the most recent in January 2006 (see Tab. 1). The wide range of engine power that was investigated, from 80 to 150 kW, gives an interesting view of the emission specifications from current diesel vehicles equipped with DPF.

Table 1: Specifications of the Euro-4 vehicles tested in the study (the figures ⓪ refer to the vehicles on the graphs).

Tableau 1 : Caractéristiques des véhicules Euro 4 testés dans l'étude (les chiffres ⓪ renvoient aux véhicules dans les graphes)

Manufacturer	Peugeot ❶	Peugeot ❷	Toyota ❸	VW ❹	Renault ❺
Model	407 1.6 HDI	607 2.7 V6 Aut. gearbox	Avensis 2.2 D-cat	Passat 2.0 TDI	Laguna 1.9 DCI
Engine displa.	1560 cm3	2720 cm3	2231 cm3	1968 cm3	1870 cm3
Power	80 kW	150 kW	130 kW	103 kW	92 kW
After treatment system	oxidation catalyst, fuel borne catalyst (cerium based)	oxidation catalyst, fuel borne catalyst (cerium based)	combined NOx adsorber and DPF (DPNR)	oxidation catalyst, fuel borne catalyst (iron based)	oxidation catalyst, catalyzed DPF (CSF)
Mileage	6100 km	4000 km	4600 km	2000 km	2400 km

The vehicles ran with a common commercial diesel fuel with a 50-ppm sulphur content. The vehicles tested in the former study and used as a basis for comparison on regulated, metal and VOC emissions comprise 3 Euro-1 vehicles, 10 Euro-2 vehicles and 2 Euro-3 vehicles. The particles deposited on the CVS filters were analyzed for metal determination only for 10 of them.

2. Driving cycles

The standard NEDC cycle was used to get results on a certification reference. The so-called Artemis cycles were chosen as real-world cycles and widespread references as well. They were set up by Inrets for the Artemis project. The analyses of unregulated pollutants –metals, VOC and PAH– were performed on 4 specific driving cycles (André, 2004):

- the *Inrets urbain fluide court* (short urban cold) repeated 15 times after cold starting;
- the same *Inrets urbain fluide court* (short urban) repeated 15 times after hot starting;
- the *VP faible/forte motorisation urbain* (specific urban cycle according to the power/weight ratio of the vehicle: low/high) after hot starting, at an average speed of 18.3 km/h (resp.19.3 km/h);
- the *VP faible/forte motorisation autoroute* (specific highway) cycle after hot starting, at an average speed of 119.0 km/h (resp.121.8 km/h).

3. Metal dosing, VOC, aldehydes and cetones analyses

Concentrations of metallic elements in the total of solid particles obtained from the CVS filters were determined by the PIXE method (particle induced X-ray emission). The dosing of metal elements from the usual CVS filters in the 1st campaign (10 diesel vehicles w/o DPF) required to set up a new experimental protocol: X-ray emission tended to count the metallic elements of the support it-self (Pallflex filter) so that the particles had to be first extracted and re-deposed on a different filter (polycarbonate filter). The polycarbonate filter used for the 5 DPF vehicles creates a low background on the PIXE spectrum, and contains few trace elements. Extracting yields were determined by weighing of the filters before and after operations. Twelve metallic elements were analysed initially (Ti, Cr, Mn, Fe, Ni, Cu, Zn, Br, Sr, Ba, Pb, Ce), only five were measured significantly, despite the high sensitivity of the method (5 to 10 ng per filter for most elements).

Analysis of the samples taken was done by gaseous phase chromatography equipped with a thermal desorption system. The hydrocarbons of lower molecular weight (C2 to C6) were detected by flame ionisation, whereas the heavier hydrocarbons were identified by mass spectrometry (comparison with databases of reference products). By comparison with the previous study (Caplain, 2006 and Joumard, 2004) the sampling flow rate of exhaust gas was increased twice, due to low emission level of VOCs observed with the newer technologies (Euro-4 DPF system).

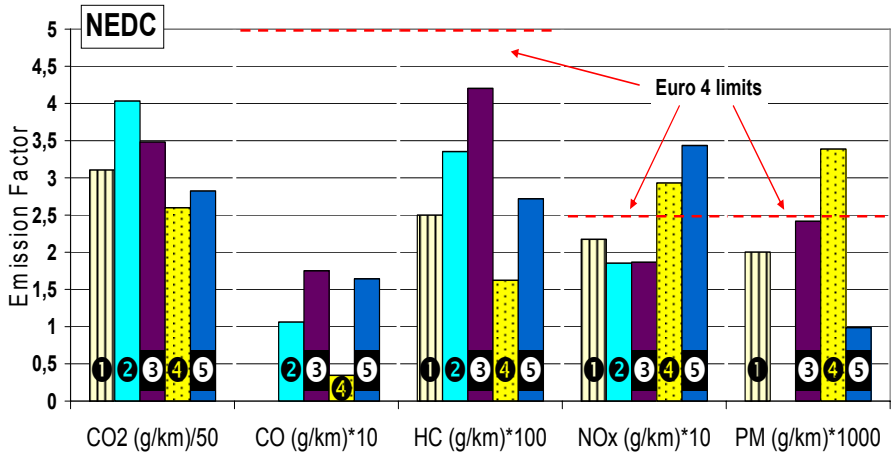
Results and discussion

1. Regulated pollutants and CO_2

The 5 diesel vehicles tested on the NEDC cycle do not all comply with the Euro-4 limits regarding NOx and particulates although they should do so (fig. 1). However, no conclusion can be drawn from data given by one vehicle and one test. The PM emission levels are consistent in this vehicle class and significantly lower than the ones of the previous samples of vehicles: the mean PM emission is here 2.2 mg/km whereas the one of the Euro-3 vehicles was 11.8 mg/km and the one of the Euro-2 vehicles was 25.8 g/km. This PM retention efficiency is also demonstrated along real-world driving cycles (fig. 2b): the average specific emission for all the 5 vehicles without apparent regeneration is no more than 1.9 mg/km (std dev. = 1.1 mg/km). When regeneration is forced or identified (higher CO2 emissions), PM specific emissions average 8.5 mg/km for the DPNR vehicle, which is still under the rate of Euro-3 vehicles. The Artemis urban cycle gives a consistent level of PM emission with data coming from 4 vehicles: 3.6 mg/km (std dev. = 0.4 mg/km).

Figure 1: CO2, CO, HC, NOx and PM emission factors measured over the NEDC driving cycle for the 5 DPF-equipped vehicles (Euro-4 or Euro-4 equivalent)

Figure 1 : Emissions de CO2, CO, HC, NOx et particules en g/km sur le cycle d'homologation NEDC pour les 5 véhicules diesel FAP (Euro-4 ou Euro-4 équivalents).

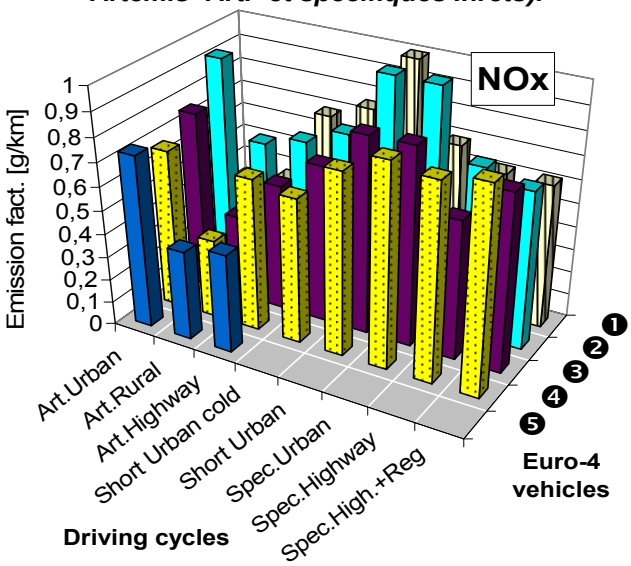


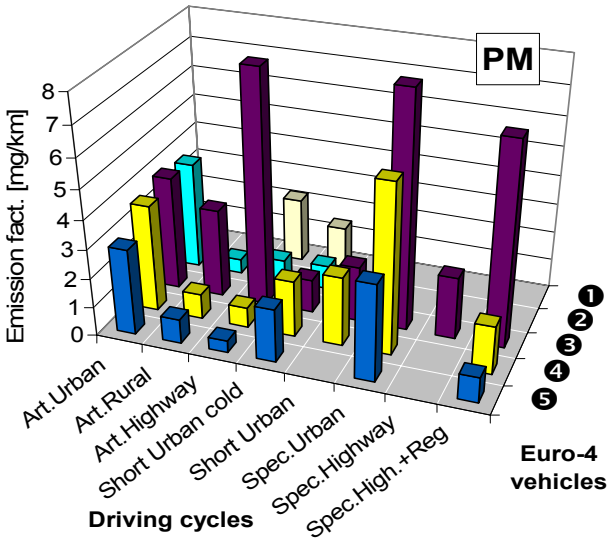
The average NOx reduction from Euro-3 to Euro-4 tested vehicles on the NEDC cycle follows exactly the NOx evolution required by EC limits, i.e. a 50 % abatement: the mean NOx emission factor goes from 0.56 g/km for the Euro-3 vehicles previously tested to 0.28 g/km for these Euro-4 DPF-equipped vehicles. The NOx emissions with the DPNR system (veh. n°3) are not the lowest of all the 5 vehicles, as it could be expected, but close to the best one,

all the same. The DPNR system is especially efficient during highway running, i.e. with steady state and high speed operating of the engine: figure 2a gives NOx emissions close to 0.57 g/km on the "Artemis highway" and the "specific highway" cycles. However, regeneration could impact on NOx emission as a value of 0.75 g/km is observed for the same "specific highway" cycle with forced regeneration.

Figures 2a & 2b:NOx and PM emission factors for the 5 DPF-equipped vehicles (Euro 4 eq.) tested over several real-world driving cycles (Artemis -Art.- and specific Inrets cycles).

Figures 2a & 2b:Emissions de NOx et particules en g/km pour les 5 véhicules diesel FAP (Euro4 eq.) testés sur plusieurs cycles réels (cycles Artemis -Art.- et spécifiques Inrets).





A general comment can be made relatively to the NEDC limit of 0.25 g/km: no vehicle can reach this limit over the real-world cycles and the overall average emission of NOx is 0.70 g/km for all the 8 cycles selected and the 5 Euro-4 vehicles. Globally, PM emissions are of the same level when measured on NEDC cycle and on real-world cycles, whereas this is not true for the NOx emissions. Nevertheless, the general NOx reduction from Euro-3 to Euro-4 vehicles is also observed when considering the real-world cycles: Euro-2 and Euro-3 NOx averages are respectively 1.13 and 1.21 g/km to compare with the Euro-4 average of 0.70 g/km. The reduction is the largest on highway and rural cycles with a mean abatement of 50 %, consistently with the result from the NEDC cycle.

CO2 emissions from vehicles 4 and 5 are noticeably low with 130 and 141 g/km respectively versus the high power output of the engines. Despite the 202 g/km from the 2.7cc V6 engine, the overall Euro-4 CO2 emission is 160 g/km (Fig.1), which is still lower than the Euro-2 and Euro-3 averages, 189 and 176 g/km respectively, with lower average power: 67 and 70 kW resp. compared to the mean 111 kW of the Euro-4 vehicles. This CO2 savings of 9 % on the NEDC cycle is confirmed by an average reduction of 8 % observed on the set of 8 real-word cycles already mentioned. Actually, variations range from -27 % in highway running to +16% in specific urban traffic. This overall CO2 reduction obtained with more powerful vehicles makes it clear that car manufacturers managed to lower concurrently all the 4 regulated pollutants and the fuel consumption. Cold starting has little influence on diesel vehicle emissions: it is of course positive regarding NOx emission and without significant impact on PM emission with the retention efficiency of the trap.

2. Particle size distribution

Size particle distributions were analyzed on the 5 specific Inrets driving cycles. The number of particulates is given for each stage of the impactor (ELPI), or 9 mean particle diameters, between 7 to 1021 nm (10^{-9} m). The particle number emissions measured in this study, are in good agreement with measurements reported in Mohr et ali (2006) performed with a CPC (condensation particle counter). The numbers of ultra-fine particles (< 100 nm) emitted per km have a relatively flat distribution between 10^{10} and 10^{12}, the upper limit being given by the less efficient system, the DPNR one. The cycle type, urban or highway does not influence significantly the distribution shape or the absolute numbers. The regeneration has a clear effect on the particle concentration which stands then close to 10^{14} per km, either with the DPNR system or the catalyst coated filter (VW).

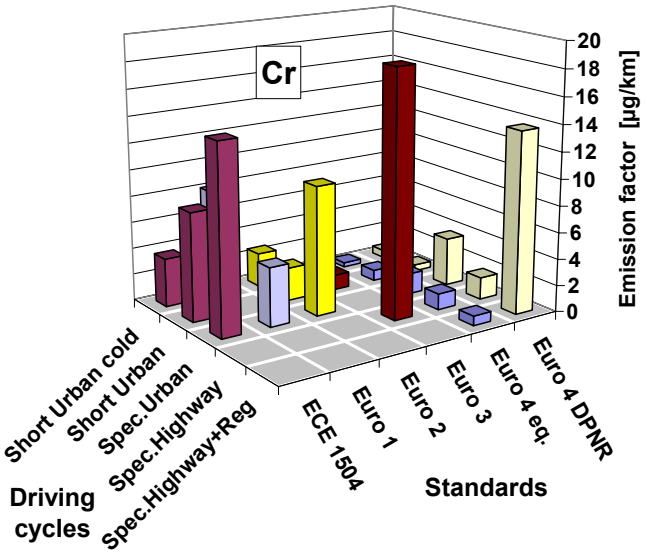
3. Metal emissions

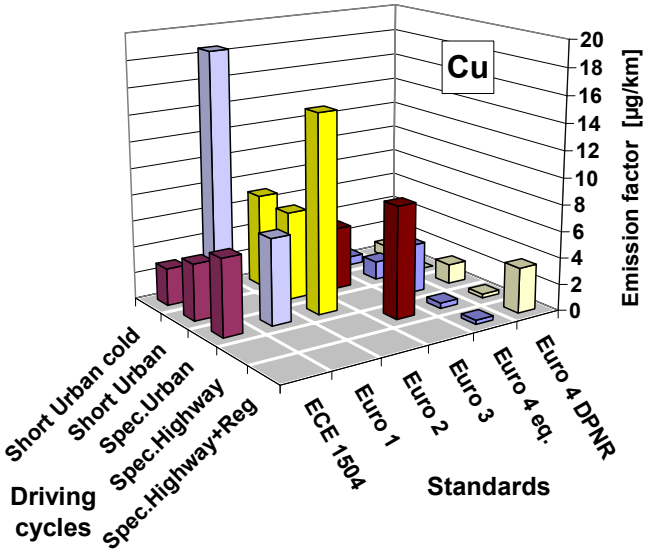
Cr, Ni and Fe are composites of stainless steel and are founded inevitably in the exhaust gas due to the internal engine wear. Cu and Zn are present in lube oils and fuels. The efficiency of particulate filters is again demonstrated with significant retention of all metals as shown on figures 3a and 3b. The problem is to know if all these metallic particles which can not be eliminated but trapped in

the filter, are completely re-emitted during regeneration. Figure 3a might indicate that a large amount of Cr is emitted during regeneration, compared to the normal service, but not especially greater to that of vehicles without filter. However, Ni and Fe emissions are much bigger during regeneration than the mean levels obtained on Euro-3 vehicles.

Figures 3a & 3b: Mean values of Cr & Cu emission factors (in µg/km) according to the emission class of cars (Euro 4 eq. are DPF-equipped) tested over several real-world cycles.

Figures 3a & 3b: Emissions moyennes de Cr et Cu en µg/km selon la technologie pour les véhicules diesel (les Euro4 eq. sont avec FAP) testés sur des cycles réels (cycles Inrets).





4. VOC emissions

Globally, the profile of VOC emissions versus emission class of cars when moving from ECE 1504 to Euro-4 technologies is quite similar for each driving cycle. The emission factors obtained after averaging the results with all cars of each category show lower VOC emissions for diesel vehicles with DPF systems than older cars. To compare with older technologies, DPF technologies involve fewer quantities of VOC. The cold start with Euro-4 DPF-equipped vehicles has no negative effect on VOC emissions comparing with hot start (short urban cold & hot cycles). Whereas the previous study had shown that the amount of aromatic compounds (54 - 75% emitted compounds) are on average 2,2 times greater with a cold start, for former diesel vehicles (Euro-1 to 3). As regards the effect of the driving cycle, the VOC specific emissions are greater for the urban cycle than for the highway cycle, with a factor of 8 for Euro-4 DPF and 2 for Euro-4 DPNR cars.

Overview

Euro-4 diesel cars showed significant reductions of NOx and particle emissions, in all operation conditions, compared to the vehicles of former emission certifications. Particle traps have a high retention efficiency but with nuances, depending on the system type. The numbers of non-volatile particles varied up to 3 orders of magnitudes between vehicles, whereas differences in the mass emissions are bigger between driving cycles, than between vehicles, except during regeneration. The DPNR system could be controlled in order to analyse regeneration impact: mass specific emissions were then multiplied by a factor of 3 to 5, but with levels still under the ones of the Euro-3 vehicles. The same statement is valid for some metal emissions, but not for all: Ni and Fe emissions are much bigger during regeneration than the mean levels obtained on Euro-3 vehicles. VOC emissions are reduced as well with the particulate filters and the negative “cold start effect” is no more observed. Again, VOC emissions are more cycle-dependent than vehicle-dependent for this small sample of Euro-4 diesel vehicles tested. Data are still being analysed and will be the subject of a further publication.

Acknowledgments

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Chemical composition of $PM_{2.5}$ emitted from transport

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Abstract

Particulate matters are represented by solid and liquid particles suspended for some time in the atmosphere. These particles are very hazardous due to their negative effects because many organic and inorganic pollutants (PAHs, toxic metals), mostly with carcinogenic and mutagenic effects, are adsorbed on the particle surface. These particles originate during the combustions processes in vehicle engines (exhaust emissions) or during mechanical abrasion of vehicle tyres and brakes and pavement (non-exhaust emissions). Particles smaller than 2,5 μm penetrate into the lungs and smaller deeper into the pulmonary alveoli and can be deposited here. This paper presents results of large data volume of $PM_{2.5}$ concentrations from localities with different traffic intensity.

Keywords: *particulate matter, $PM_{2.5}$, chemical composition, transport*

Introduction

Within the context of increasing number of gases and solid pollutants emitted to the atmosphere become particulate matter (PM) an important part of air quality monitoring because their concentrations in the ambient air continually increase. Mainly road transport is important source of these particles especially of fine fraction of PM with diameter smaller than 2,5 µm. These particles are hazardous not only for their physical parameters but first at all for the content of many risk organic and inorganic compounds that demonstrably have adverse effects on human health and environment. Sources together with other factors such as mechanisms of formation, meteorological conditions and distance from the source determine their specific physical parameters (such as shape, diameter, electric charge, solubility, surface of the particles) and chemical composition. The qualitative and quantitative contents of organic compounds and metals and biological availability are the most often discussed chemical properties. PM emitted from transport contain many substances such as elementary carbon (soot), organic compounds such as hydrocarbons, polyaromatic hydrocarbons (PAHs) and their derivates, aldehydes, PCBs,

PCDDs/Fs, inorganic metals such as Pb, Pt, Cd, As, Cu, Zn and others, nitrates, ammonia ions, sulphates etc. Particulate matter can be also divided into primary particles that are emitted directly from source and secondary particles that originate in the atmosphere during the chemical reaction among oxygen, water vapour and other reactants such as ozone, hydroxyl radicals, nitrates radicals, SO_2, NO_x.

Methods

PM with diameter smaller than 2 µm have weightiest adverse effects on human health. That is why concentrations of $PM_{2.5}$ were measured and pollutants adsorbed on their surface were identified. Two urban localities with different transport intensity and surrounding landscape were chosen for air quality monitoring within the solution of the problem of transport share on burden of environment (see tab. 1). Middle volume samplers LECKEL MVS6 (Sven Leckel Ingenierbüro, Germany) were used for taking ambient air samples, two on each locality - one equipped with nitrocellulose filter for $PM_{2.5}$ concentrations determination and identification of metal contents, second with quartz filter for analyses of PAHs adsorbed on the surface of this PM fraction. 84 samples from both localities were taken and analysed during seven days campaigns in 24 hours intervals. $PM_{2.5}$ concentrations were determined by using gravimetric surveying of each exposed filter. Continual measurements of $PM_{1.0}$, $PM_{2.5}$ a PM_{10} fraction with EnvironCheck 107 (Grimm Aerosol Technik GmbH, Germany) were performed on the locality Kotlářská in summer season between 27.6. – 4. 7. and in autumn between 28. 11. – 5. 12. to determine the weight share of each fraction. Measurement principle in this instrument is the dispersion of the X-ray beam due to particles coming through measuring cell.

Results and discusion

Content of particulate matter (especially PM_{10}) in the ambient air is currently monitored on 188 localities in the Czech Republic. These sites represent various areas in term of landscape, building density, industry occurrence etc. Transport is considered as the main source of PM in the 38 localities of noted above. PM contents are regularly monitored in the Czech Republic since 2002 in terms of the law on air quality conservation (no. 86/2002 Collection of Law, Directive 350/2002). Content of PM_{10} in the ambient air must not exceed according to Council Directive 1999/30/EC daily limit 50 $\mu g.m^{-3}$ more than 35times per year whereas proceeds year average limit 40 $\mu g.m^{-3}$. Daily limit was exceeded on the 63 % of transport localities from the whole number of sampling sites mentioned above. Identified concentrations of PAHs and metals adsorbed on particles surface are summarised in tab. 1. and diagrammatized in fig. 1. $PM_{2.5}$ concentrations development trend is also shown for comparison in fig. 1. Time progress of PAHs concentrations is similar to that one for $PM_{2.5}$ concentrations. This trend was not observed for metal contents (see fig. 2). Obtained results show the correlation between $PM_{2.5}$ concentrations and temperature with statistically significant correlation coefficient –0,57. The

highest $PM_{2.5}$ concentrations were determined in autumn (turn of November and December) whereas the lowest in summer (turn of June and July).

Table. 1: Summary of measuring campaigns, characteristics of the sampling sites and conditions during measurements.

Locality	Characteristics	Geographic coordinates	Date	Average temperature (^{o}C)	Average relative himidity (%)
Brno	Campus Faculty of Science MU **Kotlářská** street, urban house-building forthcoming to street canyon, distance from road: 3 m, intensity: 36 000 vehicles/24 hours	N49°12,300‘ E16°34,830‘ altitude 230 m.	4. – 11.4.2005	-	-
			23. – 30.5.2005	-	-
			27.6. – 4.7.2005	22,30	62,50
			22. – 29.8.2005	-	-
			10. – 17.10.2005	-	-
			28. 11. – 5.12.2005	1,70	78,10
	Arboretum MZLU, soft downhill reverse from road with green vegetation, distance from road: 25 m, intensity: 34 500 vehicles/24 hours	N49°12,792‘ E16°36,978‘ altitude 256 m.	4. – 11. 4. 2005	12,19	62,68
			23. – 30.5.2005	18,81	63,07
			27.6. – 4.7.2005	20,72	73,84
			22. – 29.8.2005	18,86	83,81
			10. – 17.10.2005	11,36	79,72
			28.11. – 5.12.2005	0,63	95,20

Legend: - not measured
MU – Masaryk university Brno
MZLU – Mendel university of agriculture and forestry Brno

Fig. 1: Development trend of concentrations of PAHs adsorbed on PM2.5

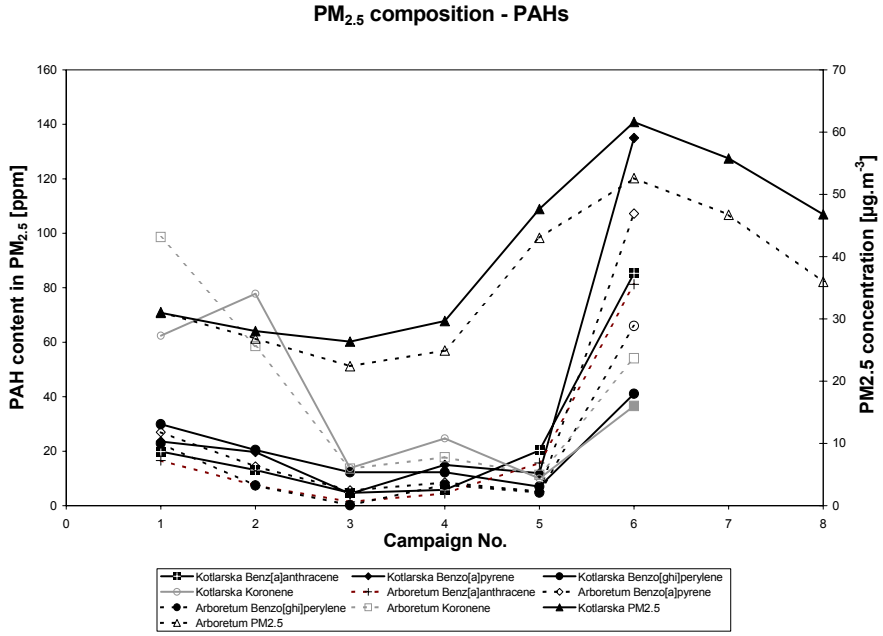


Fig. 2: Development trend of concentrations of metals adsorbed on PM2.5

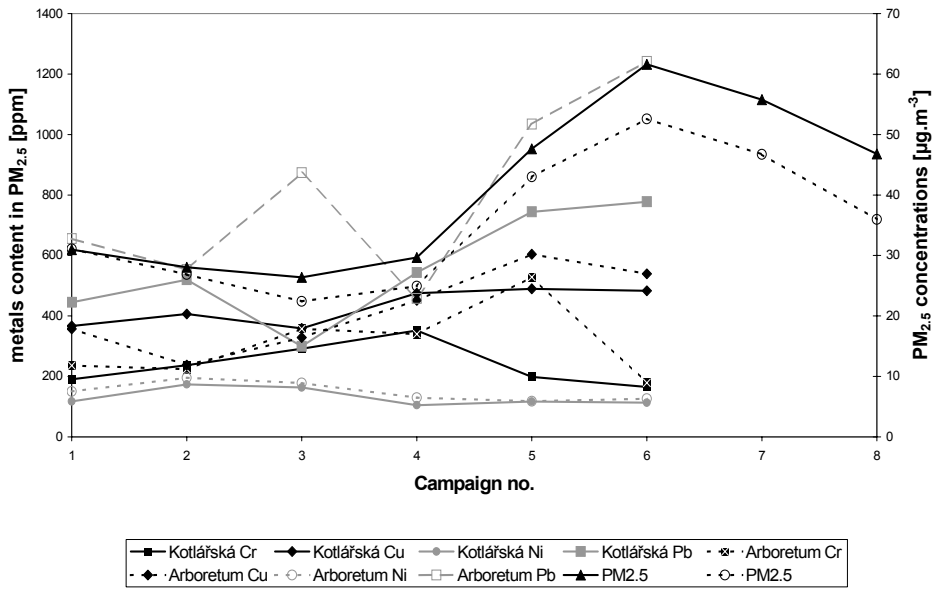


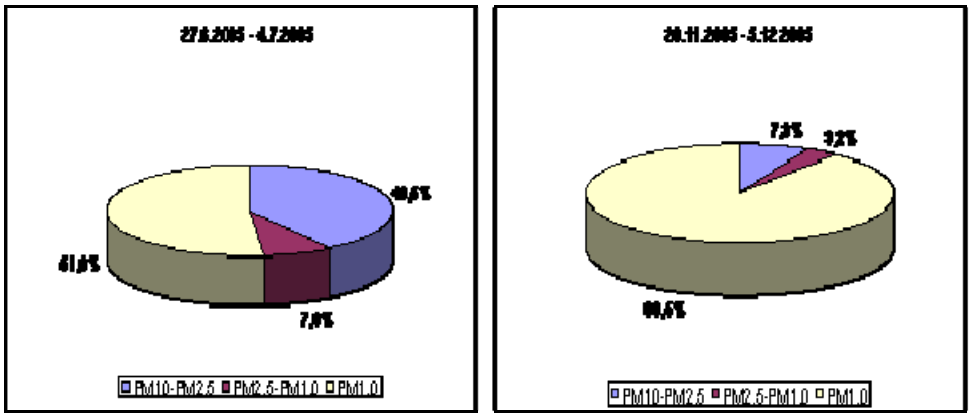
Table. 2: Average concentrations of $PM_{2.5}$, metals and PAHs adsorbed on the surface of these particles.

Pollutant	Unit	Average concentration	
		Kotlářská	Arboretum
Naphtalene	ppm	70,07	64,73
Acenaphtylene	ppm	3,18	2,08
Acenaphtene	ppm	2,70	2,76
Fluorene	ppm	10,60	9,43
Phenanthrene	ppm	146,88	126,68
Anthracene	ppm	10,72	6,93
Fluoranthene	ppm	69,25	61,63
Pyrene	ppm	98,82	88,82
Benz[a]anthracene	ppm	24,85	21,15
Chrysene	ppm	36,25	33,12
Benzo[j]fluoranthene	ppm	18,42	20,62
Benzo[k]fluoranthene	ppm	26,93	26,82
Benzo[a]pyrene	ppm	34,93	27,98
Indeno[1,2,3-cd]pyrene	ppm	33,32	23,63
Dibenz[a,h]anthracene	ppm	8,70	7,66
Benzo[ghi]perylene	ppm	20,52	18,15
Coronene	ppm	37,55	42,33
PAHs sum (from EPA)	ppm	614,70	540,48
As	ppm	34,06	40,71
Cr	ppm	238,91	310,75
Cd	ppm	20,73	26,17
Cu	ppm	429,91	419,65
Mn	ppm	329,02	888,83
Ni	ppm	131,58	149,44
Pb	ppm	554,93	802,81
Sb	ppm	81,51	69,29
Zn	ppm	1695,87	3006,31
$PM_{2.5}$	$\mu g.m^{-3}$	40,9	35,5

The same development trend was assessed also for PAHs concentrations (see fig. 1). This effect could be either due to loss of volatile PM compounds (such as ammonium salt) in warmer period or it could have connection to vertical stability of the atmosphere. Better ventilation in warmer season (convection) amuses pollutants further from the sources whereas in colder season ventilation is limited and PM cumulate in the baser parts of the atmosphere near the source. Local furnace that heat surrounding houses could

be another important source of these particles in colder period. $PM_{1.0}$ share outweigh in PM_{10} fraction, 69,5 % of particles were those with diameter smaller than 2,5 µm in the summer period whereas the share of these particles was 92,7 % in autumn period (see fig. 3.). g.

Fig. 3: Comparison of share of separate fractions



Conclusions

Obtained results indicate long-term progress of $PM_{2.5}$ concentrations and adsorbed PAHs. As arise out of results, $PM_{2.5}$ concentrations are affected except the transport intensity by other factors. Meteorological conditions, especially temperature and presence of green vegetation that can cut transport of the PM seem to be very important limiting factors.

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Estimation of NO_2/NOx relations of traffic emissions in Baden-Württemberg from 1995 to 2005

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Abstract

Carslaw and Beevers have developed a method to derive traffic related NO_2/NOx ratios by using measurements from urban and traffic stations. This method has been applied to four cities in Baden-Württemberg using hourly air quality data for the years 1995 to 2005. Results for NO_2/NOx ratios of traffic emissions start at 5 % (1995) and show a continuous increase since approximately 1999/2000 to values of over 20% (2005)

***Keywords**: : NO2/NOx ratio of traffic emissions, NO_2 estimation at traffic sites*

Introduction

The development of NOx-concentrations at air quality monitoring stations from 1995 onwards shows a significant decline, reflecting the reductions of traffic emissions. However, measurements of NO_2 concentrations at traffic-related stations in Baden-Württemberg, Germany, reveal a slower decline or even a slight increase over the last 11 years (Rabl and Scholz, 2005). Forecasts of NO_2 data for 2010 indicate that it will be difficult to meet future NO_2 concentration limits at stations close to heavily trafficked roads.

Reasons for the divergent behaviour of NO and NO_2 concentrations discussed so far are centred on an increased background ozone contribution and/or a shift in the relation of NO_2/NOx of traffic emissions. Drive cycle measurements of emitted NO/ NO_2 are scarce but display a large variation, far from the ratio of 5% (NO_2/NOx) considered for traffic emissions in the past.

Carslaw and Beevers (2005) have developed a method to derive traffic related NO_2/NOx ratios by using measurements from urban and traffic stations. This method has been applied to four cities in Baden-Württemberg (Freiburg/214 thousand inhabitants, Karlsruhe/284, Mannheim/325, and the

capital Stuttgart/592) using hourly air quality data for the years 1995 to 2005. Baden-Württemberg (11 million inhabitants) is one of sixteen states (Bundesland) in Germany.

Methodology

In short, NO_2-concentrations are computed with results from measurements of NO_2, NO and ozone at urban background station and results from measurements of NO_2 and NO at traffic stations in the same city. The computation assumes, that a relationship exists between background and traffic station. Air masses from an urban background station are mixed with traffic emissions as well as with the air at the traffic station (mixing is parameterised by a mixing time τ) and undergo chemical transformations. The source strength of traffic and other emissions does not enter the computations as their effect is contained in the measurements of the traffic station.

With a mixing time and the assumed NO_2/NOx-ratio of traffic emissions hourly NO_2-concentrations are computed for the traffic station and compared to the concentration measured at that station. The set of mixing time and NO_2/NOx-ratio giving the best approximation for all hourly values reflects the most probable NO_2/NOx-ratio of traffic emissions.

The method incorporates two chemical equations, where NO and NO_2 are converted with consumption/production of ozone:

$NO + O_3$	→	$NO_2 + O_2$	(reaction rate k)
NO_2 + hv (+O2)	→	$NO + O_3$	(photolysis rate J)

The differential equation system which incorporates mixing and chemistry (Berkowicz,2000; Palmgren et al. 1996) is:

$$\frac{d[NO_2]}{dt} = k \cdot [NO] \cdot [O3] - J\,[NO2] + \frac{[NO_2]_{VV}}{\tau} + \frac{[NO_2]_B - [NO_2]}{\tau}$$

(1)

$$\frac{d[NO]}{dt} = -k \cdot [NO] \cdot [O3] + J\,[NO2] + \frac{[NO]_{VV}}{\tau} + \frac{[NO]_B - [NO]}{\tau}$$

(2)

$$\frac{d[O_3]}{dt} = -k \cdot [NO] \cdot [O3] + J\,[NO2] + \frac{[O_3]_B - [O_3]}{\tau}$$

(3)

The first two terms on the right hand side describe chemical transformation, the third term describes the effect of emissions with index VV (no emissions of ozone) and the last term denotes the effect of mixing of background air (index B) and air at the traffic station. The mixing time is denoted by τ.

The contribution of NO_2 traffic emissions is parameterised with the difference between concentrations of NOx at traffic and background station and the ratio of NO_2/NOx (p, to be varied):

$$[NO_2]_{VV} = p([NO_x]_V - [NO_x]_B)$$

Assuming that equilibrium is reached in a short time, the differential terms d/dt are zero and the analytical solution is:

$$[NO_2] = 0.5\left(B - \sqrt{B^2 - 4([NO_x][NO_2]_O + [NO_2]_n / k\tau)}\right)$$

$$[NO_2]_n = [NO_2]_{VV} + [NO_2]_B$$

$$[NO_2]_O = [NO_2]_n + [O_3]_B$$

$$B = [NO_x]_V + [NO_2]_O + \frac{1}{k}\left(J + \frac{1}{\tau}\right)$$

To derive ratios of NO_2/NOx on an annual level. we computed with the paired sites all possible analytical NO_2 values for one year, i.e. where all valid hour values were present for both stations. With one set of parameters p and τ an NO_2-concentration was computed and the difference to the concentration measured at the traffic station was computed as mean value for all hours. The set of τ and p with the lowest difference gives the best fit and describes the NO_2/NOx-ratio of that year.

Estimated NO_2/NOx-ratio at roadside

An overview of the stations in Table 7 gives the characteristics of the stations, either urban background or traffic, i.e. close to a heavily trafficked road. For Mannheim and Stuttgart more than one urban background station is present, so that results with different background and one traffic stations can be compared.

Table 7: Long name and code for air quality stations in Baden-Württemberg. Height above sea level is given and characteristic ub for urban background and t for traffic

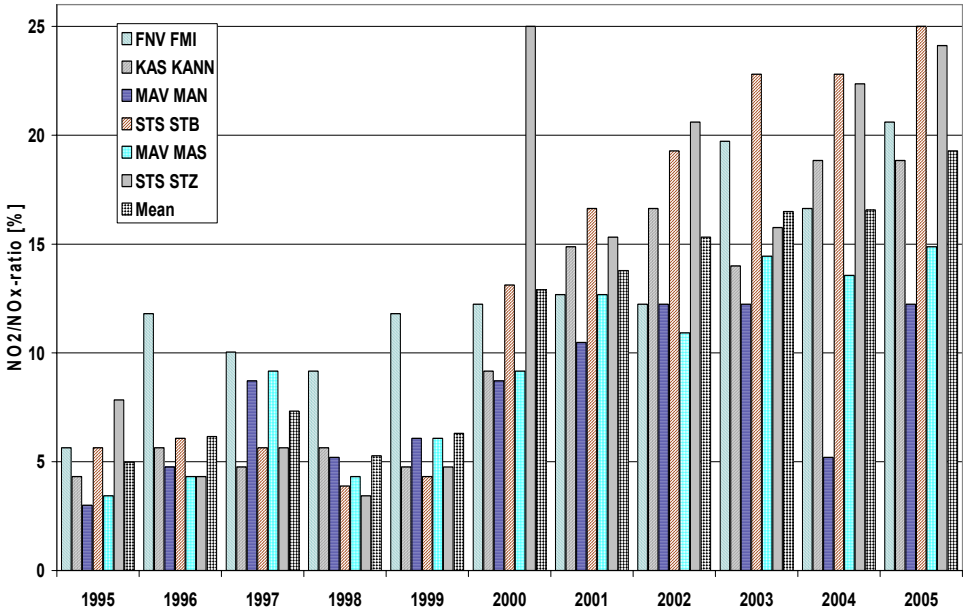
station name	code	H asl (m)	type
Mannheim Nord	MAN	95	ub
Mannheim Süd	MAS	95	ub
Mannheim Straßenstation	MAV	95	t
Stuttgart Bad Cannstatt	STB	235	ub
Stuttgart Zuffenhausen	STZ	260	ub
Stuttgart Straßenstation	STS	245	t
Karlsruhe Nordwest	KAN	113	ub
Karlsruhe Straßenstation	KAS	115	t
Freiburg Mitte	FMI	240	ub
Freiburg Straßenstation	FNV	260	t

1. Results Monday through Friday

The results in Figure 4 show a clear distinction between the years 1995 to 1999 and from 2000 to 2005. Whereas the ratio in the first period is close to the long assumed NO_2/NOx-ratio of 5% a sharp increase appears in the second period. The mean ratio in the second period suggests an increase for the years following 2005.

Another distinct fact is the large diversity in the computed NO_2/NOx-ratio for one year across the station pairs. This is believed to be the influence of meteorology which might affect the coupling between pairs, i.e. luv/lee-effects but also the influence of composition of traffic at a particular site or a large construction site nearby. High values are e.g. found at Freiburg (FNI FMI) the southernmost site and also the smallest city. However, photolysis rate are of lower importance and cannot explain the offshoots.

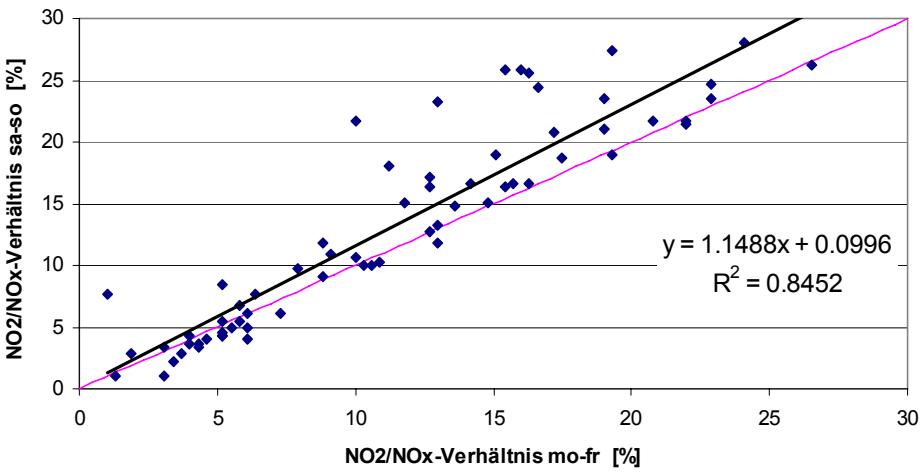
Figure 4: Computed NO_2/NOx-ratio from traffic emissions for weekday (mo through fri) for six station pairs and mean value for all stations in one year.



2. Results Saturday through Sunday

Traffic composition (e.g. the amount of passenger cars with Diesel engines and oxidation catalyst) is changing strongly between working days (Monday through Friday) and weekends. On Saturday and Sunday the amount of heavy duty traffic is lower, enhancing the relative influence of passenger cars. Figure 5 shows a scatter with computed NO_2/NOx-ratio for both types of traffic. The difference is most apparent at higher NO_2/NOx-ratios.

Figure 5: Scatterplot for computed traffic NO_2/NOx-ratio on working days for same stations and years but different week type: ratio on mo through fri vs. ratio on Saturday through Sunday, linear regression and 1:1 line



3. Sensitivity

A sensitivity study was performed to determine a ranking of the influence of input parameters. A set of hourly values for all working day mondays in 2004 was calculated where parameters were varied by 50%. This subset was chosen as it greatly reduced computing time while still retaining the characteristic of the mean value computation. A study of mean values, rather than discussing the analytical solution, is required since the method is concerned with a search for a minimum along a two dimensional parameter variation.

Table 8: Sensitivity of computed NO_2/NOx-ratio (p) and mixing time (τ) to input parameters. E.g decreasing the background concentration of NO_2 by 50% results in a decrease of the NO_2/NOx-ratio, p, of 42.6% and a decrease in mixing time of 32.0%. J and T are photolysis rate and temperature.

	NO2b-50%	NO2b+50%	NOb-50%	NOb+50%	NO2v-50%	NO2v+50%	NOv-50%	NOv+50%	O3b-50%
p	42.6%	-39.3%	-6.8%	6.8%	-95.1%	83.6%	74.7%	-33.9%	11.5%
τ	-32.0%	42.7%	18.8%	-18.8%	-45.8%	-5.7%	75.2%	-18.8%	192.1%

	O3b+50%	NOxb-50%	NOxb+50%	NOxv-50%	NOxv+50%	J-50%	J+50%	T-15°C	T+15°C
p	3.3%	33.9%	-33.9%	-61.1%	20.4%	1.4%	1.4%	1.4%	0.9%
τ	-53.4%	-18.8%	37.6%	0.0%	37.6%	-10.8%	0.0%	21.7%	-21.7%

A change in NO_2- and NO-concentrations at the traffic station influences computed NO_2/NOX-ratio strongly (Table 8) as it is changing the goal of the computation (i.e. the computed NO_2-concentration is compared to NO_2 at the traffic station). It also creates a misbalance between NO_2 and NO. Changing

the sum, NOx at the traffic station, has a smaller effect. The ozone level shows a rather small effect on computed NO_2/NOx-ratio and the effect of photolysis and temperature is almost negligible.

Conclusions

A rather straightforward algorithm (Carslaw and Beevers, 2005) to compute the ratio of NO_2/NOx in the emissions of vehicle traffic has been applied to find changes in NOx-composition in six cities in the german Bundesland Baden-Württemberg from the year 1995 to 2005. Necessary inputs parameters are concentration measurements at pairs of background and traffic related air quality stations. The results show a strong increase from 2000 onwards. The value of 5% seems to be too low for actual air quality calculations in view of the upper range of 25% found in this study for the year 2005. The increase, possibly, accompanies the increasing ratio of modern Diesel passenger cars with oxidation catalyst. NO_2, as an oxidative agent, helps to burn soot residues in Diesel particulate filters and thus prevents clogging.

The large variation of NO_2/NOx-ratio across station pairs in a same year, however, is difficult to explain with variations in traffic composition alone. Other parameters exist which are not yet sufficiently understood. A sensitivity study showed that the computed ratio is very sensitive to both NO_2 and NO concentrations at the traffic site. Ozone sensitivity was much smaller. If this finding is corroborated by other studies, it could help in the discussion of the blame for (future) NO_2-increases.

Helpful to get insight into the reliability of the method should be a characterisation of the station pairs in place and in time. I.e. not only traffic densities and composition adjacent to the station but also major construction work nearby or changes in public facilities (e.g. repositioning of public bus stops close to the station) which might change the real NO_2/NOx-ratio of traffic emissions close to the air quality station.

Results of this study are necessary for a gain in precision of e.g. air quality simulations relying on improved traffic NO_2/NOx-ratios. They are also useful in the tedious discussion on where to put the blame and on the reasons for future non-attainment of EU-air quality limits.

Acknowledgement

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A model for the estimate of urban traffic emissions in signalized intersection

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Abstract

The levels of congestion frequently reached on the road infrastructure produce increasingly harmful effects on environmental quality; the correct management of the road transport system appears, therefore, the only solution to an ever more deeply felt problem.

The research presented by the authors falls into this context, as it aims to analyze the relationship between vehicular flows and the polluting emissions produced by them around a traffic light junction at variation of the duration of the traffic light cycle.

The paper is divided into two parts: the first part describes the reference scenarios for the evaluation of polluting emissions, illustrates the methodology utilized to obtain the comparison values for the calibration of the estimate model and analyzes the results produced by the simulation of the previously-described scenarios; the second part describes the regression model adopted by the authors to obtain the predictions of levels of polluting emissions by the vehicular traffic, with the purpose of providing indications on the correct planning of traffic light installations.

Keys-words*: polluting emissions, prediction model, road traffic, air quality, urban signalized intersection.*

Resumé

Les niveaux d'engorgement du trafic, fréquentement rejoints sur les infrastructures routières, produisent des effets toujours plus nuisibles sur la qualité de l'air; la correcte gestion du système de transport routier apparaît, donc, l'unique solution à un problème très senti.

Dans ce contexte s'insère l'étude présentée par les auteurs, qui analyse la relation existante entre les flux des véhicules et les émissions en polluants par elles produites autour d'une intersection sémaphorique pour cycles sémaphoriques variables.

La communication s'articule en deux parts. Dans la première partie on décrit les scénarios de référence pour l'évalution des émissions, on illustre la

méthodologie utilisée pour obtenir les valeurs de comparaison pour le calibrage du modèle d'évaluation et on analyse les résultats produits par la simulation des scénarios précédemment décrits. Dans la deuxième partie on décrit le modèle de régression adopté par les auteurs pour obtenir les prévisions des niveaux des émissions du trafic automobile, dans le but de fournir des indications pour la correcte planification des installations sémaphoriques.

***Mots-clés**: émissions, modèle de prévision, trafic routier, qualité de l'air, intersection sémaphorique urbaine.*

Introduction

As everybody knows, the vehicular flow in urban areas usually takes place in a situation of interrupted flow, with constant acceleration and deceleration phases and frequent stop and goes. In this situation, polluting emissions produced by traffic are extremely high and the average flow speed is very low. Measures taken or believed to be necessary for the regulation of traffic aim to reduce polluting emissions and to a fluidisation of vehicular flow. The above-mentioned aim could be reached through the creation of long routes, which allow constant speed. Signalized intersections inevitably lead to breakdowns of the flow and, consequently, to acceleration phases. Therefore, to be able to reduce emissions, the existent traffic-lights system must be as consistent as possible with the flow values.

The present study analyses the correlation between flows at signalized intersections and the production of polluting emissions in the area, in order to individuate a model which can provide the relationship between the levels of polluting emissions and the traffic flows. This analysis is a continuation and a closer examination of a previous study, d'Elia and Guido (2005), concerning an intersection regulated by give-way signs, where we analysed the correlations between the entity of emissions and the variables of traffic flows.

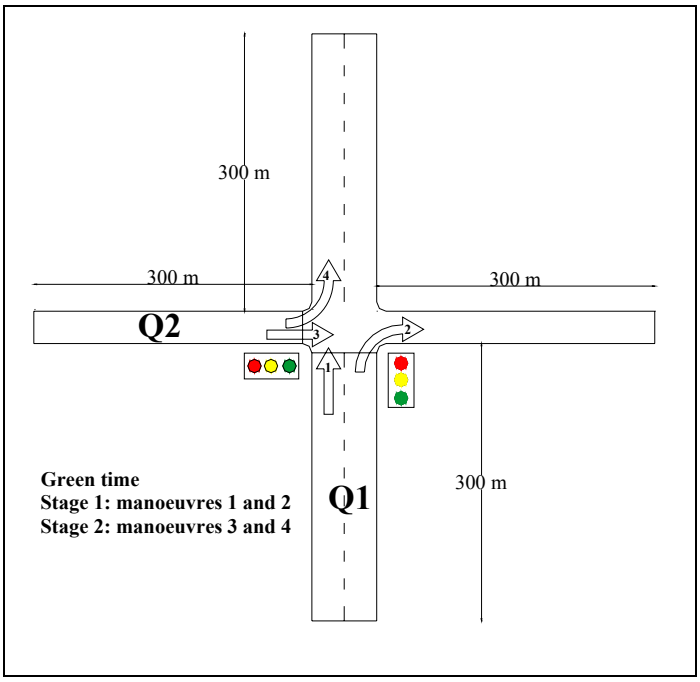
Waiting times and length of queues at the intersection have an important role in the estimation of polluting emissions; through a regression model, we want to make a prediction of polluting levels, thanks to calibrations carried out in a sample area. The experimentation has been carried out through a microsimulation traffic model (Integration). The evaluation of emissions has been carried out on a hypothetic reference scenario. However, the evaluation above supplies us with universally valid conclusions concerning the definition and the management of strategies which are necessary for the safeguard of the environment.

Various studies have been carried out on the evaluation of polluting emissions produced by vehicular traffic, both in an urban context (Ma, 1999; Gadner et al., 1999; Bell et al., 2000; d'Elia et al., 2002) and in an extra-urban context, Ahn et al. (1999), sometimes with an approach mainly directed at the study of the phenomenon at junctions (Mustafa et al., 1993; Latini et al., 2005) or at the relationship between the phenomenon itself and user behaviour, Niittymäki et al. (1999). The authors, with this paper, aim to provide support to the studies developed in the sector by identifying what are the best

combinations among the quantities in play (vehicular flows, traffic light cycle) to guarantee an lesser impact of the traffic on air quality.

Figure 1: Intersection schema

Figure 1: Schéma de l'intersection



Data collection methodology

The analysis was carried out on a reference scenario, simulated by means of a traffic micro-simulation model (Integration), represented by a crossroad regulated by a two-phase traffic light installation (figure 1). The crossroad considered is made up of one-way roads: the main road is composed of two 3.5-metre wide lanes, the secondary road of one lane of equal width. It is supposed that the percentage of turning manoeuvres, both from the main and from the secondary road, are 25%.

Previously to assignment on the network, the main parameters were determined for the calculation of the minimum duration of the traffic light cycle (degree of saturation per manoeuvre, time loss, saturation flows, etc.). The estimate of the minimum duration cycle is based on the methodology supplied by HCM 2000. According to the indications suggested by HCM, the distribution of the green light was carried out by assigning to phase 1 a number of seconds such that the saturation ratio is equal to one for the critical manoeuvre.

Once fixed the geometry of the crossroad, 528 dynamic assignments were carried out, combining variable values of vehicular flows between 300 and 800 veh./h on the main road, variable values of vehicular flows between 100 e 800 veh./h on the secondary road and a duration of the traffic light cycle variable

from 20 to 120 seconds. To guarantee the reliability of the output of the simulations, three assignments were carried out for each of the combinations of the above-mentioned quantities and the relative results were averaged out.

It should be specified that the vehicular flows assigned to the network through Integration is made up of the vehicular park endogenously defined in the same package conceived by Van Aerde (1995). Therefore, the values of the emissions observed are strongly affected by this assumption. To calibrate the estimation model of the emissions, the values of the flow parameters and of the emissions of CO, NOx and HC offered in output by the above-mentioned model were considered as reference values.

Integration computes the fuel consumption for each vehicle on a second-by-second basis as a function of speed and acceleration. It then estimates vehicle emissions on a second-by-second basis as a function of the fuel consumption, ambient air temperature, and the extent to which a particular vehicle's catalytic converter has already been warmed up during an earlier portion of the trip.

From an analysis of the output data supplied by the micro-simulation model, HC emission values can be seen to be variable between 11.00 and 48.72 grams; the two values were obtained, respectively, for a 120-second duration of the traffic light cycle, a value of Q1 equal to 300 veh./h and a value of Q2 equal to 100 veh./h, and for a 20-second duration of the traffic light cycle and values of Q1 and Q2 equal to 800 veh./h. Analogously, for emissions of CO and NOx, in the same reference scenarios just cited, oscillations were recorded, respectively, between 152.92 and 545.70 grams and between 14.36 and 59.74 grams. It should be specified that the said values regard a mean development of the route per user equal to about 600 metres and for a valuation interval equal to 900 seconds.

The regression model

The data analysis, elaborated on the basis of the 1584 simulations effected, provided the availability of a numerous sample of observations and allowed the construction of a mathematical model to predict the levels of polluting emissions.

The quantities considered as a basis for the construction of the model are represented by the sum of the vehicular flows transiting at the crossroad, by the ratio of the "secondary" vehicular flow to the "main" vehicular flow and by the duration of the traffic light cycle.

The choice of the said quantities derives from a considered analysis of the data discussed in the previous section; in fact, the conjoint effect of the variability of the values of vehicular flows on the two traffic directors was taken into account.

Therefore, the mathematical formulation of the model that best interpolates the emission data, for a generic polluting agent (i), can be expressed in the following form:

$$E_{(i)}=a\cdot x1+b\cdot x2+c\cdot x3+d \qquad (1)$$

with

a, b, c, d = coefficients to be valued;

x1 = cycle length (sec);

x2=Q1+Q2 (veh./h);

x3=Q2/Q1 (veh./h).

The regression analysis supplies us with the following expressions:

$E_{(HC)}=-0,117 \cdot x1+0,026 \cdot x2+1,272 \cdot x3+9,344$ (2)

$E_{(CO)}=-1,135 \cdot x1+0,285 \cdot x2+8,401 \cdot x3+150,044$ (3)

$E_{(NOx)}=-0,039 \cdot x1+0,036 \cdot x2+1,774 \cdot x3+3,175$ (4)

The statistics (table 1) attest to the efficiency of the above-mentioned models. The signs of the coefficients prove to be correctly estimated, the values of the t-Student appear to be greater than critical at a level of 0.01 and, therefore, the estimates prove highly significant.

Overall, the correlation coefficients indicate a strong relationship between the independent and dependent variables.

Table 1: Coefficients and statistics of the regression model

Tableau 1: Coefficients et statistiques du modèle de régression

DOF 524	*A*	*B*	*C*	*D*	*T(A)*	*T(B)*	*T(C)*	*T(D)*	^{2}	*F*
E_{HC}	-0,117	0,026	1,272	9,344	-35,61	66,80	6,83	21,07	0,927	2210,47
E_{CO}	-1,135	0,285	8,401	150,044	-41,11	88,24	5,35	41,73	0,954	3585,46
E_{NOX}	-0,039	0,036	1,774	3,175	-13,22	106,29	10,65	8,00	0,963	4576,78

For completeness, the graphs are shown (figures 2, 3 and 4) relative to the dispersion of the observed values and of the values obtained by the model.

Figure 2: Comparison between observed emissions of HC (in grams) and model results

Figure 2: Comparaison entre les émissions de HC (en grammes) observées et les résultats du modèle

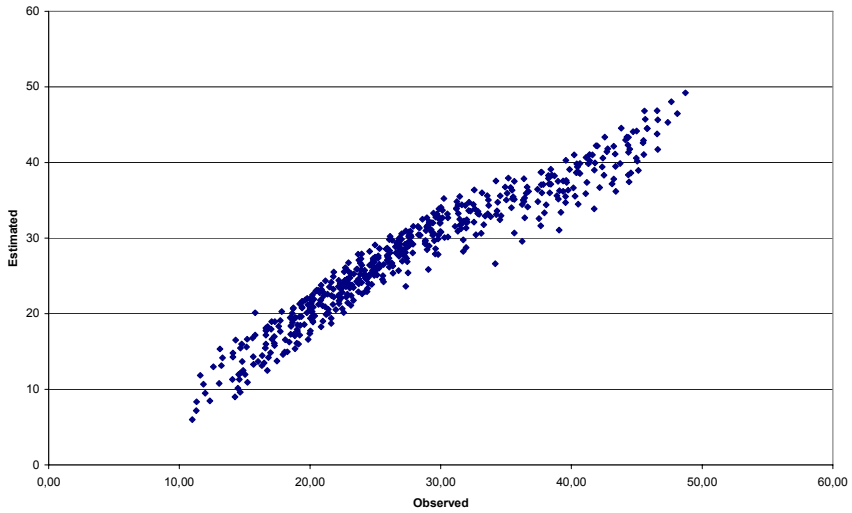


Figure 3: Comparison between observed emissions of CO (in grams) and model results

Figure 3: Comparaison entre les émissions de CO (en grammes) observées et les résultats du modèle

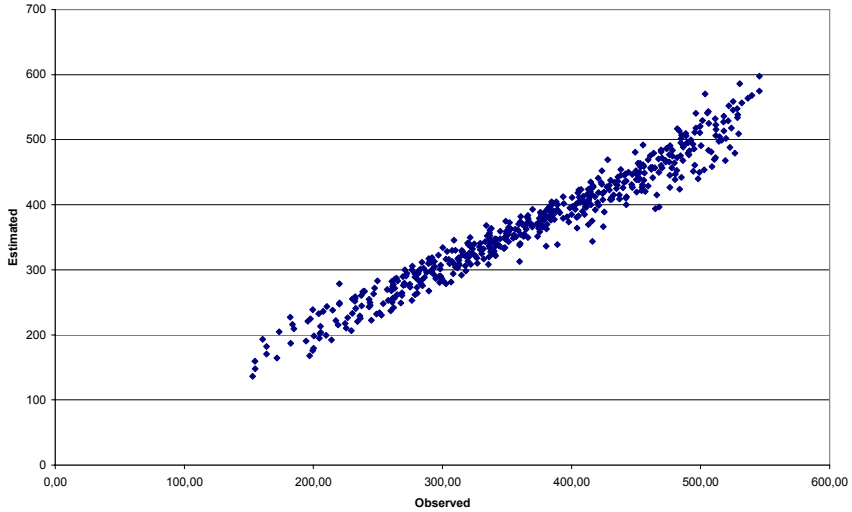
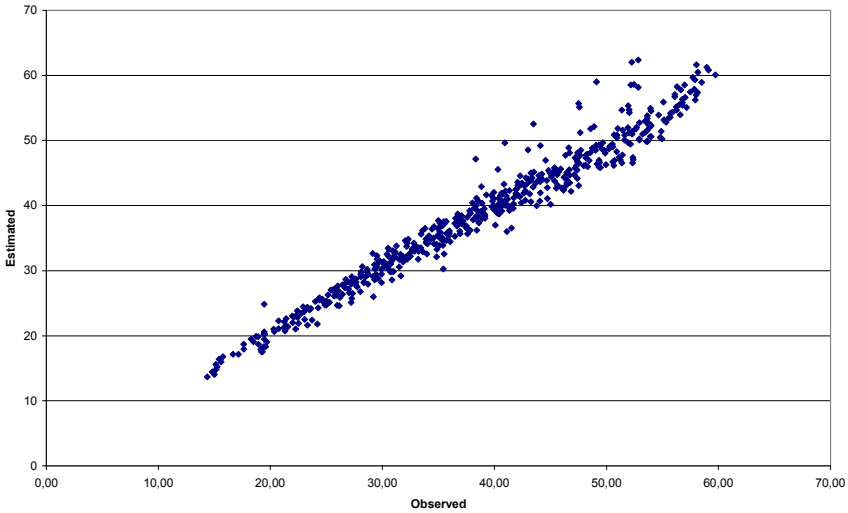


Figure 4: Comparison between observed emissions of NOx (in grams) and model results

Figure 4: Comparaison entre les émissions de NOx (en grammes) observées et les résultats du modèle



Conclusions

The specific context analyzed in the paper is typical of urban environments, where the crossroad is regulated by traffic light installations. Anyway, by researching more deeply, the authors wish to confer a character of generality to the prediction model described for different boundary conditions than those supposed. The specific geometric configuration considered, the prediction on the percentage of turning manoeuvre and the number of phases of the traffic light cycle led to the results previously discussed.

Currently research is under way on the understanding of the phenomenon analyzed in this paper at variation of the above-mentioned characteristics. The analysis conducted and the model presented allow an estimate with satisfactory approximation of the level of polluting emissions produced by vehicular traffic at variation of the flows involved at a crossroad with traffic lights having analogous characteristics to the one examined and of the same duration of the traffic light cycle.

Based on the assumption of the optimization of the phasing of the traffic light cycle in favour of the main traffic flow, a linear growth of emissions was found at an increase in flows, but decreasing values of the same emissions at an increase in the duration of the traffic light cycle.

For critical (minimum) values of the duration of the traffic light cycle, estimated by the individuation of the greater load index, very high levels of polluting emissions were observed. The indication that emerges is that it is necessary to define the programming of traffic light installations by trying to

achieve a compromise between the performances of the network and the level of service and of the containment of levels of polluting emissions.

The foregoing translates into the need to guarantee not only the optimization of the indexes relative to the saturation ratios for the various manoeuvres allowed, but also to reduce the effects produced on the air quality by the phasing of the said installations.

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The Electronic Toll and Car Drivers' Behaviour in Relation to Environment and Road Safety

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Abstract

Nowadays the electronic toll becomes the important part of transport systems and it is possible to use it as the promoting element in a road transport sustainable development. The paper describes the toll system proposal that instead of to a usual way of vehicles' per kilometre charging takes into account harmful environmental impacts and road safety as well. The purpose of proposal is the charging according to every specific vehicle's harmful environmental impacts and road safety per particular road section. The results of a theoretical analysis are presented in the paper that includes the experimental engine's evaluation and telematic part.

***Key words**: electronic toll, ecology, emissions, engine vehicles, telematics.*

Introduction

The modern systems of electronic toll can significantly increase to solve problems of the sustainable development of motorway, road and urban traffic. Up to now usually applied electronic toll is designed in different modifications but with the same basic aim to charge vehicle's drive per concrete road section. The only contemporary electronic toll systems' aim was used by authors in their

more complex proposal as one part so called economy toll part. Beside this part another two parts are proposed i.e. ecological and safety ones. The principle of presented electronic toll proposal is based on individual and technically validated payment for the harmful vehicle's environmental and safety impacts. The proposal's purpose is to promote driver's behaviour to maintain his vehicle in correct technical conditions and to drive safely. The paper contains only a part of the mentioned task i.e. engine's problems linked with the ecological part of electronic toll. It is technical reasons of individually aimed charge of harmful emission mass production in different sections of a transport infrastructure. To achieve this aim it is necessary to monitor an every vehicle involved into the system from the viewpoint of the instantaneous production of single harmful emission fractions. It requires some specific smaller changes as in a way of the homologation measurement as in some more principle changes in the content of regular emission inspections. The relatively simple indirect measurement within the whole vehicle's operation is linked with these changes.

Problems of the driven vehicle's emission measurement

Principle of proposed way of indirect emission measurement of driven vehicle: The production quantification of single emission fraction of an every single vehicle during the whole operational period on specified road sections is possible to solve technically. But it would be extremely expensive to equip a vehicle by small physical and chemical laboratory installed e.g. in the engine's exhaust design section. This equipment is usual on markets but their initial price could exceed the luxury car's price. In case these equipments' price would not be decreased in future by way of some radical invention it is possible to say that their utilisation remain in a applicable research area or in vehicles' homologation measuring system only.

In virtue of above mentioned statements authors concentrated on the indirect operational measurement of engine vehicles in their proposal i.e.:

The "standard" emission characteristics will be determined by precise methods during homologation measurement of every specific type of vehicle's engine. These characteristics describes the instantaneous value of mass production of single harmful emission fractions and it is in dependence on the set of specific engine's operational modes that is possible to take into account.

The operational modes of vehicles' engines use to be defined by two independent quantities i.e. revolutions n [1.min.$^{-1}$] and the useful torque of crankshaft M [Nm]. The emission characteristics are described by 3D – dependences under usual conditions where every instantaneous mass production Q_i of every *i-th* emission fraction is quantity depending on n_i and M_i. It concluded that at modern engines, (compressor and electronically operated combustion), it is necessary to define their operational modes by more independent quantities on purpose.

With the regard to the gradual engines' wear-out the above mentioned "standard" characteristics are updated during vehicles' periodical inspections.

These updated characteristics are derived from "inherited" basic shapes of "standard" characteristics where the modification is carried out on important areas by updating measurement only. The proposed quasi-static measuring method likes to be suitable for the periodical measurement with low investments and operational costs and it provides the adequate preciseness.

During the whole vehicle's drive and under any changing operational conditions the sequence of operational engine's modes is only monitored and saved into a memory. Consequently the sequence of mass production of instantaneous emission values is assigned to operational modes by updated emission characteristics. The integration in time determines total production values of single harmful emission fractions at any chosen road section.

The proposed methods of telematics enable to monitor every single vehicle involved into the system. This way of electronic toll is rightful and significantly promoting the ecological behaviour. The appreciation of vehicle measured harmful impact per unit stays as the only problem here. In financially hierarchal localities the *economy's* toll per kilometre is possible to determine and its ecological toll's fraction (done by the vehicle's unfavourable impact on the environment) as well.

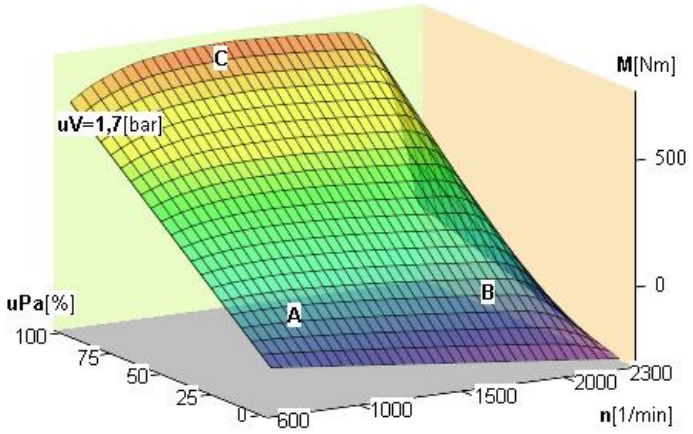
Form choice of dynamic and emission characteristics: The instantaneous and total production of single emission fractions is possible to determine in virtue of measured engine modes' sequence with the support of power and emission stated engine's characteristics. The engine's torque becomes derived (calculated) quantity i.e. indirectly measured output quantity of engine's power characteristics and this torque is dependent directly on measured input quantities under the proposed system of operational measurement. Directly measured input quantities of the computation are in principle chosen the same as for the torque as for the instantaneous production values of every single emission fraction.

In proceeded proposal the unified form of power and emission characteristics was chosen. The "4D" dependence of every single output quantity on three input quantities i.e. revolutions *n*, indicator of the fuel supply *uPa* and indicator of the air supply *uV* . Fig. 1 shows useful torque as the chosen output quantity but it is the only one possibility from the other quantities' set (chosen mainly in a form of single emission fractions). Experiments were carried out with a four-stroke diesel compressor engine ŠKODA LIAZ ML 635.

Directly measured input quantities of computation i.e. *n*, *uPa* and *uV* is generally possible to measure in relatively easy way. This measurement is possible carried out continually during the whole vehicle's drive. For example the attitude of injection pump's ratchet within the bounds 0 – 100% was chosen as the fuel supply indicator *uPa* and input air pressure into the engine (behind a turbo-blower) within the bounds 1.3 – 1.7 bar was chosen as the air supply indicator *uV*.

Fig. 1 shows the example of general relation in a shape of the skew surface *M*(*n, uPa, uV*), presented for the only one chosen value of input quantity *uV* = 1.7 bar.

Figure 1: Example: 4D characteristics of diesel compressor engine. The indirectly measured useful torque *M* is charted in dependence on revolutions *n* and the fuel supply indicator *uPa* and the air supply indicator *uV*. The only one surface is shown uV=1,7 bar (from the measure range 1,3 - 1,7 bar).



Similarly **z** – axis can be used for another quantities in different characteristics e.g. engine's operation characterized by fuel supply *dPa*[mg/s], emissions *CO*[mg/s], CO_2[mg/s], *NOx*[mg/s], *HC*[mg/s], solid particles *PM*[mg/s]etc.

The advantage of further analysis is done by mathematical expression and its charting. The researched particular dependencies are charted by the same way and it is possible to carry out computable or graphical comparisons e.g. by the overlapping of two researched quantities on **z**-axis when axis **x** and **y** are constant.

Ways of characteristics' periodical actualization: The shown characteristics' form (see Fig. 1) will be determined in its "standard view" on the needed graduate levels *uV* at homologation measurements. These characteristics could be valid for the first three years of new vehicle's operation. After it, during the first and next regular technical and emission inspections the applied characteristics' update could be carried out. The measurement could be carried out at three points (see Fig. 1) marked as **A, B** and **C**.

The principle of expectation is that characteristics' updated surfaces of gradually wearing engine keep the basic features of "standard" characteristics. Every single standard characteristics obtained at the homologation is possible only to "shift and rotate" onto the position done by points **A, B** and **C**. This method is evaluated and obtained preliminary results perspective. In case of need it would be possible to enlarge number of measured points and the single characteristics preciseness' update would increase. The characteristics' surface could be changed into anomaly skew one that could express the results of engine's gradual wear-out precisely. The update could be carried out by simpler and cheaper way e.g. quasi-static method that is described in another paper. The schema of proceed is following:

The vehicle's driven wheels are placed on freely rotating cylinders. The suitable gear is shifted (usually low) and the engine is operated with adjusted revolutions on value adequate to measured points e.g. point **A**. The later repeated measurement should do the same but with points **B** and **C**.

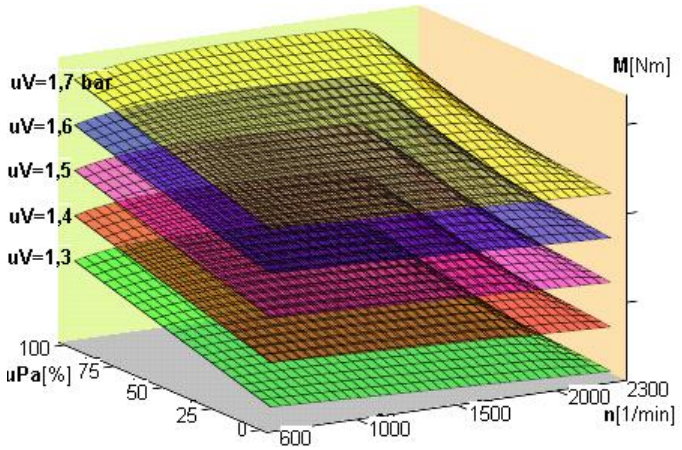
The engine is loaded by unmeasured brake' torque for short time e.g. by vehicle's brake or by electric or hydraulic retarder. The value of load torque must be app. adequate to point **A**.

During app. two minutes of constant and in this moment not measured load all required output parameters are measured in form of single emission fraction production

Then it is necessary to clutch down smartly and at this moment the engine gets into full free acceleration and during several initial milliseconds [ms] the useful torque is measured by angle acceleration. In this way measured value is highly precise and it is adequate to stabile torque (by what the engine was loaded during former two minutes).

At points **A**, **B** and **C** is possible to keep the pre-adjusted revolutions nevertheless the load torque is not possible to adjust precisely. It influences the real points **A, B** and **C** attitude form the general required slightly differ.

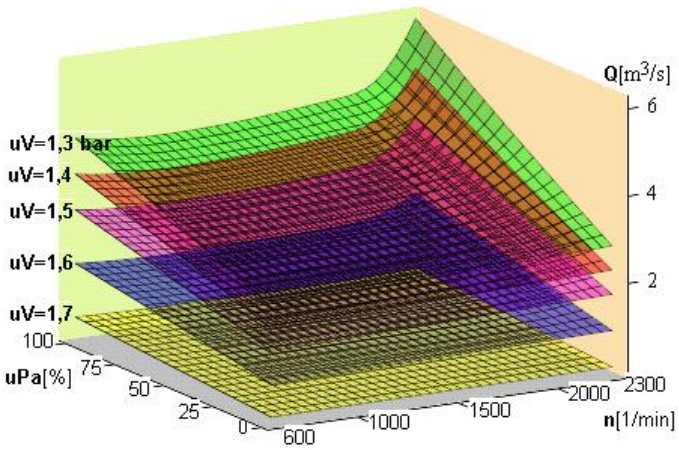
Figure 2: Example of power characteristics of diesel engine. *M* is engine's useful torque in dependence on regulations *n*, fuel supply indicator *uPa* and air supply indicator *uV* within the bounds *uV*=1,3 - 1,7 bar.



Example of the measurement and vehicle engine power characteristics' computation The updated 4D – characteristics are possible to obtain in the form of continuous functions immediately usable to computation. Clearly it possible to imagine this function as the set of quantities' surfaces that is shown in Fig. 2. The example shown in Fig.1 was developed hereby: shown surfaces gradually stepped by one tenth of 1 bar *uV* and they are gradually shifted on the vertical axis but it was only done for clear presentation. The scales of presented shifts are not drawn in Fig. 2 for a greater clarity. If the

specific vehicle engine's characteristics exist in practice, where on the vertical axis **z** is torque and on the others are single emission fractions, then is possible to observe vehicle's power and emission operation without nay problems during the whole drive.

Figure 3: Example of diesel engine's emission characteristics. *Q*[m^3/s] is quantified opacity (air volume in m^3.s^{-1}, disqualified on hygienic limit 5% of opacity), in dependence on revolutions *n,* fel supply indicator *uPa* and air supply indicator *uV* within the bounds 1.3 -1,7 bar.



Example of the measurement and vehicle engine's emission characteristic computation As an example of the quantitative expression of diesel engines' exhaust gas solid particles the quantity called "quantified opacity" (working name) is applied here; using a symbol *Q*[m^3/s] and representing air volume disqualified by the engine (in m^3 per second) on the proposed hygienic limit e.g. 5% opacity.

The presented hygienic limit was selected as the preliminary one to clearly show the way of computation and it will be necessary to detachedly determine it in collaboration with a health research.

The possibility of characteristics' utilisation to optimise engine's working modes and vehicle Signals of directly measured quantities i.e. n_i [1/min], uPa_i [%], uV_i [bar] and the instantaneous vehicle's speed v_i [km/h] are saved into the board computer at every i-th moment of its drive (at time intervals e.g. Δt = 0,01 [s]). In virtue of this saved data and the above mentioned actualised characteristics the value of useful torque M_i [Nm] is computed in real time at every *i* –th moment (as the basic data to analyse vehicle's instantaneous dynamic properties):

$$M_i\left(n_i, uPa_i, uV_i\right) (1)$$

and other data of every inspected emission fraction e.g. the above defined quantified opacity Q_i [m^3/s]:

$$Q_i\left(n_i, uPa_i, uV_i\right) (2)$$

Then it is easy to compute different emission quantities in real time with chosen sample frequency that are possibly usable to optimise vehicle's drive economy and ecology. For example it can be instantaneous specific opacity Qm_i [m^3/kWh] that determines disqualified air volume [m^3] above the hygienic opacity limit as a result of engine's useful work 1 kWh:

$$Qm_i = \frac{1{,}08 \cdot 10^8}{\pi} \cdot \frac{Q_i}{M_i \cdot n_i} \quad (3)$$

Likewise every other instantaneous value of the inspected emission quantity production is possible to continually determine. The possibility of continual evaluation from the point of view of economy and ecology is evident. The aim of the continual evaluation is to instantaneously operate the engine's modes and the way of vehicle's drive. The optimization criterion of this operating is the complex technical and economy.

The possibility of characteristics' utilisation in the fair ecological taxation The vehicle, included into the proposed electronic toll system, is driven in time sequence Δt [s] on geodetically defined road sections ΔS_i [m]. Indirectly measured values of single harmful emission fractions of instantaneous production are linked with these sections e.g. by quantified opacity Q_i [m^3/s]. Example: the vehicle was driven at the moment *i=a* into the especially observed urban area and at moment *i=b* left the area.

At every single *i*-th road section the optimisation criterion of vehicle's driving mode is defined by a support of measured data. This can be stated e.g. as the instantaneous production Qv_i [m^3/m]of the inspected emission fraction related to 1 meter of road:

$$Qv_i = \Delta t \cdot \frac{Q_i}{\Delta S_i} \quad (4)$$

Then the criterion of ecological tax is obtained by the data summarisation within the bounds of *i=a* and *i=b*. This can be described by e.g. total production *Qs* of the specified emission fraction during the vehicle's operation on the inspected road section:

$$Qs = \sum_{i=a}^{b} Qv_i \cdot \Delta t_i \quad (5)$$

Presented quantities *Qvi* and *Qs*, multiplied by charging rate that expresses a measure of environmental degradation, compose the proposal of ecology and economy criterion for continual technical operating optimal vehicles' drive mode with regard to its load, time and geodetically defined crossed locality.

The proposal principles of telematics' part

The original conception of on-board unit (OBU) is proposed to solve the above specified problems. The OBU's functionality includes not only known

telematics' applications e.g. electronic toll, digital speed recorder, GPS etc. but it is enlarged by vehicle's information module. Information are processed and verified there and the computation of driving properties and emission parameters is carried out to determine the toll. Except of the presented elementary application the utilisation of obtained information in further telematic applications will be derived.

The final analysis stems from European project MISTER (Minimum Interoperability Specification for Tolling on European Roads) and from prepared standard CEN 17 575 that solved a OBU's technical specification in future electronic toll systems. The further used source was national project's results (MD ČR 802/210/108 ITS) - ITS's architecture under conditions of a transport and a telecommunication in the Czech Republic.

Conclusion

The presented proposal of modern electronic toll conception stems from the principle of road transport sustainable development. The form of aimed influence at vehicle's user was proposed to promote user's activities in way of the vehicle's correct technical maintenance (minimizing harmful emissions) and the keeping of regardful and safe drive.

The telematics' view is linked with principals of current electronic toll systems that fulfil economy part only up to now. Two other parts of toll are proposed in the paper i.e. ecological and safety toll. The engines's system viewpoint is that continually quantifies harmful impacts of every individual vehicle during the whole operation and on the specified "tolled" roads (sections) was proposed.

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GIS modelling of accessibility indices to analyse induced effects on the environment due to transport infrastructure plans development

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Abstract

Transport improvements usually facilitate access between two given points on the territory. As a consequence, there is a likely pressure increase, in terms of potential land use change, in those areas where a great improvement in their accessibility occurs, mainly through high speed motorways. This is a type of indirect effect, that rarely forms part of the Environmental Assessment current practise. Madrid Region and its area of influence has been chosen in the present analysis, computing travel time from all potential origins to potential employment destinations for the years 1990 and 2000. An analysis of the land use changes that have taken place between these years could then be carried out by comparing the European Corine Land Cover map for 1990 and 2000 using Geographic Information Systems (GIS) and statistical analysis of different variables. Its results give an idea of the relationship between accessibility improvements and land use change development of the area, and a good amount of data for discussion.

Keywords*: Induced effects, Strategic Environmental Assessment, Accessibility, Land Use, Geographic Information Systems, Transport network improvements.*

Introduction

As the cities and metropolitan areas growth in spatial and economic influence, there is an increase concern on understanding and assessing the impacts that its pattern of development may cause on a number of issues, including environmental quality, social inclusion or economic efficiency. Metropolitan areas and regions have experienced, especially over the last two

decades, an important decline in a number of aspects, such as air quality, noise or lack of open spaces, and, at the same time, an increase in development patterns excessively favourable to the use of private car, leading to congestion and environmental quality deterioration.

The process seems to be that pursuing rapid access to a larger number of locations creates a need for more roads and better access to them, leading to lower land use densities, thus bringing destinations even farther apart, which, in turn, increases demand for more roads. The foregoing is an approximation of the land –use transport feedback cycle included in Wegener, M. and Fürst, F. (1999). The underlying principle of all this process is the spatial separation of human activities, which creates the need for travel. This process is of course enhanced by a number of variables, namely housing prices in the core urban area in comparison with suburban spaces, the search for naturalness or the peacefulness of being out of the city while maintaining its opportunities, among others.

An understanding of the interactions between land use and transport has been pursued since the 1950s, as described in Wegener, M. and Fürst, F. (1999). Thus, Hansen (1956) was able to prove that locations enjoying higher accessibility within Washington DC had higher chances of developing, and to a higher density, than remoter locations. Over time, a number of more complex theories and models have been developed in an attempt to provide a better explanation on this issue, including socio-economic and market aspects along with those related to the actual operation of the transport systems.

As Wegener (2003) states, there is some vague understanding that the evolution from the dense urban fabric of medieval cities, where almost all daily mobility was on foot, to the vast expansion of modern metropolitan areas with their massive volumes of intraregional traffic would not have been possible without the development of first the railway and later the private automobile. However, exactly how the development of the transport system influences the location decisions of landlords, investors, firms and households is not clearly understood even by many urban planners.

In general, whenever a new transport infrastructure is contemplated, the environmental impact assessment takes into account a number of (mostly direct) possible effects. However, there are many other relationships that have not as yet been studied to the extent they deserve, or which are usually not included in environmental impact studies, probably on account of the difficulties involved in their measurement and appraisal.

Indirect effects could be defined as those that are not a direct result of the project, plan or program. They come as a consequence of the likely evolution of an effect or impact of a transport plan program or project, and occur at a distance from the original action and/or as a result of a complex pathway of cause-effect chain. An indirect impact can be short or long term, and could also act thereafter with other effects. The extension of the assessment procedure has in fact more to do with uncertainty than the likely link with other effects. As an indirect impact is never as straightforward to assess as a direct one, there are difficulties in having enough evidence to go much further and assure that a given indirect impact could also accumulate with another one, thus probability

will be the word for most of those impacts. Secondary or induce effects would then be a type of indirect effect, those related with induced development and resulting effects.

Accessibility is an inverse function of the physical separation between places, improved by the capacity of links connecting places, and the attractiveness of each place as a trip origin or destination. Transportation improvements that increase the accessibility of land and economic activities tend to have system wide impacts rather than isolated impacts proximate to specific improvements. (T. W. Sanchez and K. J. Dueker; 1998). The inclusion of the indirect effects will unquestionably improve the decision-making processes, as many environmental problems faced today result from the accumulation of multiple small, often indirect effects rather than a few large obvious ones, as stressed by a number of authors (The Louis Berger Group, Inc. 2002; James, E. 2003 and Therivel, R. 2004; among others).

The challenge is to accommodate local and regional travel demand with existing infrastructure and some occasional projects, at the same time not encouraging dispersed development. This requires an understanding of the dynamic relationship between transport and land use where accessibility increases, i.e. the easy of movement between places, plays an important role. The aim of the present study is to advance on the knowledge of this process, i.e., to analyse the extent to which a geographical probability of land use changes can be made from the improvement or construction of road transport infrastructures in a given area.

Methodology

Corine Land Cover datasets, developed for the years 1990 and 2000 from Landsat images, provide information about land use changes that have taken place in the study area during this period of time. These maps have a comprehensive legend where 44 different categories are described, although they have been clustered in order to work with five main land use categories for each year. The comparison of these two datasets makes possible the identification of changes that have taken place from forest and agriculture areas to artificial land uses. Statistically, this dependent variable can be modelled as a Bernouilli process, taking on two possible values:1 - land use change occur; 0 - land use does not change.

The independent variables that have been used to explain these changes are:

- the existing accessibility values in 1990
- accessibility variations between 1990 and 2000
- distance to existing artificial land use (mainly urban) in 1990

The accessibility indicator that has been used is based on the location index developed by TRANSyT, UCLM, UCM, US (2004), and measures travel time that would be spent by a user in order to satisfy transport demand. The mathematical expression is the following:

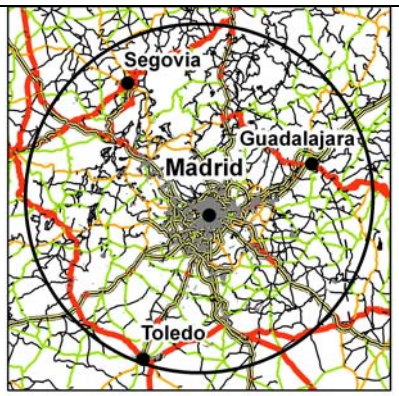
$$E_i = \sum_{j=1}^{n} \frac{I_{ij} \cdot w_{ij}}{\sum_{j=1}^{n} w_{ij}}$$

Where I_{ij} is the impedance between points i and j: real trip time along the shortest route (minutes), according to the real road typology and the maximum speed legally allowed on each category. w_{ij} is a gravitational factor, calculated as a quotient between the destination population and real trip time between i and j. Therefore, it reflects the relative importance of better connections to the nearest and more populated destinations.

The analysis starts with the network available on the Official Road Map issued by the Ministry of Public Works. The network has been treated in order to reflect the situation on both years 1990 and 2000, using a Geographic Information System (GIS), which also provides tools for network analysis in order to obtain shortest path and, finally, the accessibility indicator for both years.

In order to obtain high precision accessibility maps, all network nodes have been treated as potential origin points. In the case of destinations, population data has been gathered from the National Statistic Institute (INE) for all municipalities and their position is assigned to the most important city or village within each municipality. Although the area under study has been set up as a circle of 150 km. diameter from the city of Madrid (see Figure 1), all Spanish municipalities have been taken into account regardless its location, avoiding border effects in the accessibility calculation. The accessibility values along the network have been obtained by applying a linear interpolation of the nodes values, previously calculated, using GIS.

Figure 1: Map of the study area and the road network present in 2000



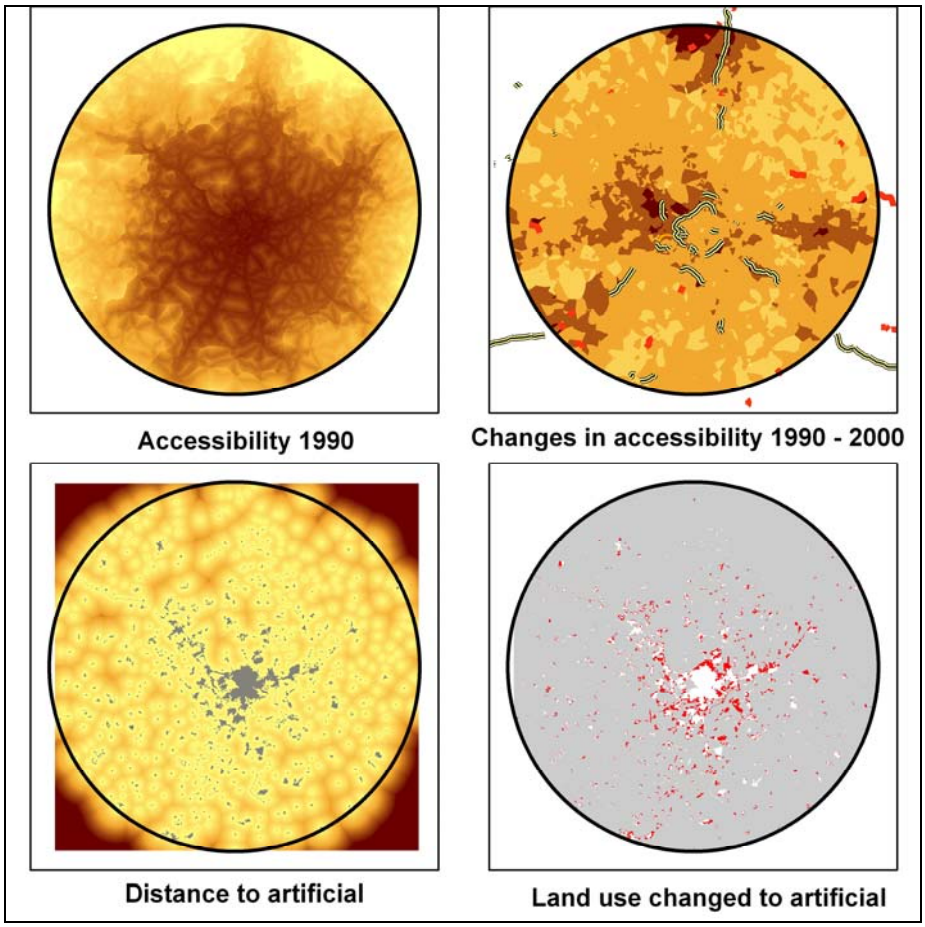
Road network 2000

The accessibility for the rest of the territory that have no direct access to the road network is calculated by using and impedance of 30 km/h to the nearest road. This method is based on the hypothesis that forest or agricultural land use

change to artificial areas would have attached the construction of local roads to access the network.

Accessibility values obtained for the year 1990 are used as a first independent variable. The second variable, changes in accessibility between 1990 and 2000 is calculated by comparing these two maps. The third independent variable, distance to existing artificial land use in 1990, can be easily taken from the 1990 Corine Land Cover map by identifying artificial areas and calculating the euclidean distance from all locations to these artificial areas. Figure 2 shows the geographical representation of all studied variables.

Figure 2: Maps corresponding to the four variables involved in this analysis.



Statistically, the relationship between variables could be analysed using two methodologies:

- Analysis of calculated values for the independent variables according to the two possible land use changes, i.e., with and without transformation to artificial.

- Analysis of land use changes according to the values of the rest of variables.

The second method was chosen in the present study as it allows the use of more powerful statistical tools. This method entails the classification of the territory according to the values obtained for the three independent variables, as well as obtaining a land use change value for each of the statistical classes generated. In other words, land use change probability is analysed within each independent class, which allows the use of ANOVA analysis (Analysis of Variance) in order to determine how much each variable could explain. It also allows the use of linear and non linear continuous quantitative methods in order to explain this probability according to the values of independent variables.

The hypothesis of independence between independent variables that is imposed by the ANOVA analysis was verified by using correlation processes between each pair of variables. Likewise, as the goodness of a explicative mathematical model such as linear and no linear multivariable regressions applied in this study is related to the lack of autocorrelation of residual values not explained, these values were also analysed. A statistical software package was used in order to perform all these calculations.

Results

The first adjusted model to the studied area was linear:

$$a + b \times distance\ to\ artificial + c \times accessibility\ 1990 + d \times accessibility\ changes$$

The quality of the adjustment measured through R^2 coefficient was 0.3124. By analysing the relationship between each independent variable and the dependent, one of the parameters of the model, the variable “changes in accessibility” was not statistically significant (p=0,6862). The latter means that this variable is not explaining the variability of land use change probability. The other two parameters are significant, although, in this model, present some negative correlation (-0,4018). Each variable in isolation explains 22% of the variance, and 32% if taken together. The graphic that compares observed and predicted values presents a clear potential or exponential shape, and therefore it was decided to adjust a multivariable model, as the following:

$$a \times distance\ to\ artificial^{b} \times accessibility\ 1990^{c} \times accessibility\ changes^{d}$$

In a first instance, the linearization of this equation was analysed using logarithms. The value of R^2 adjusted coefficient was appreciably higher 0.7239 and, again, the variable “changes in accessibility” was not statistically significant (p=0,8662). The other two parameters are still presenting some correlation (-0,2560). In isolation, “distance to artificial” explains 61% and “1990 accessibility” 27% of the variability, while 72% if taken together.

Finally, the model was adjusted with non linear expression (using Marquardt algorithm for performing non linear regressions) and taking out the parameter

corresponding to “changes in accessibility”. The value of R^2 adjusted coefficient rose to 0.9252 and the resulting model was the following:

$$y = \frac{15264{,}2}{accessibility^{3{,}62497} \times distance\ to\ artificial^{1{,}05417}}$$

By analysing residual errors it can be verified that the real predictive capacity of this model is moderate: the average probability of land use changes to artificial in the studied area has been 0.03, and the error range varies between -0.15 and 0.07, being the root mean square (RMS) error 0.02 and the absolute mean error 0.01. That is, probabilities around 0.03 have been observed, and the errors in its prediction are around 0.01.

According to the latter equation, a forest or agriculture land use area with an accessibility of 25 minutes in 1990 and located at a distance of 2 km to the nearest artificial site would have a probability of changing to artificial land use of 0.06 or 6% in the next 10 years. The confidence interval would be of ± 0.02 or ± 2% at a confidence level of 67% (RMS).

Conclusions

Obviously, the nearest a given point of the territory to an existing artificial area, the more probability of changing its land use to artificial, being distance a key factor for transformation. The present study demonstrates that the accessibility of the territory is also an important factor. The adjusted multivariable models show that accessibility explains a notorious part of the probability of land use change, independently of the effect of the other factor.

The lack of prediction capacity showed by the variable “changes of accessibility” could be associated to the low amount of change that have occurred in the study area during the time period analysed. Another possible reason is that the effects of accessibility are often noticed or apparent after some years. A continuous monitoring of the land use in Europe, instead of having just two snapshots, would help to solve this question.

The adjusted model can predict, although with limited precision, the probability of a given point of the territory to change its land use to artificial. This has a major application for planners and environmental analysts as they can predict at some extent the percentage of the territory that could potentially change its land use to artificial due to the rise in accessibility after an improvement or construction of transport infrastructures. Once this tool is mature enough, it is the decision of planners, politicians and society to decide which measures should be applied in order to protect this territory from the transformation process, as induced impact derived from transport projects, or whether to permit its progressive suburbanization.

The next step in the analysis is to perform this research on a wider area, probably the whole Spain, in order to avoid the influence of the city of Madrid. This influence can explain the spatial correlations detected, as the amount of independent information is limited. Likewise, the number of variables in the

analysis is to be extended, in order to incorporate some key factors such as GDP, growth in GDP, employment areas, degree of “centrality”, etc. Taking these variables on board will certainly improve the results of the present analysis.

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Évaluation de l'impact du plan de déplacements urbains de Lille-Métropole sur le trafic, les concentrations de polluants atmosphériques et la mortalité

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Résumé

Ce travail évalue l'impact sur les concentrations de polluants atmosphériques et sur la mortalité des orientations du plan de déplacements urbains de Lille-Métropole Communauté Urbaine, en comparant les résultats attendus de ces orientations en 2015 à la situation observée en 1998 et à un scénario tendanciel 2015. Ceci a été réalisé à l'aide d'une chaîne de modélisation complexe associant un modèle de trafic décomposant les trafics sur les 24 heures de la journée moyenne ouvrable annuelle, un modèle d'émission, dérivé de COPERT III, un modèle complet de chimie-transport et une modélisation de l'impact sur la mortalité. L'impact sur les scénarios 2015 du PDU est significatif sur le trafic et les émissions ; par contre, l'impact spécifique sur les concentrations de NO_2, d'ozone et de particules est très faible, de même que l'impact estimé à court terme sur la mortalité.

Mots-clefs : *Modélisation, impact, pollution de l'air, santé, PDU.*

Abstract

This work aims at evaluating the impact of the Lille-Métropole Urban Community urban mobility plan on traffic, atmospheric pollutant concentrations and mortality, by comparing the results expected from the orientations decided by 2015 (UMP scenario) with those observed in 1998 and a trend scenario. This was achieved by the implementation of a complex modelling chain linking a traffic model, EMME2, whose results are traffic assignments on over more than 7000 strands representing over 2,500 kilometres of roads, breaking down HT, LUV, HGV, Bus&Car and 2 wheeled vehicles over 24 hours of an annual average day, by taking into account cold-start trips; an emission model, derived from COPERT III, that calculates the emissions of this traffic for the whole year, to which were added the emissions of other SNAP sources in the conurbation of Lille, a dispersion model known as Polair3D, a complete chemical-transport model and model of the impact on mortality, based on the recommendations of WHO Europe and using in particular the risk-exposure relations produced in the framework of the PSAS9 programme of the Health Monitoring Institute. The whole chain was successfully validated against the concentrations data provided by the local air pollution measurement network The impact of the UMP on the scenarios of 2015, whose objectives and resources are very ambitious, is significant on traffic and its emissions. On the contrary, the specific impact of the UMP on NO_2, ozone and particulate matter concentrations is very low. Therefore, the health impact of the UMP on these three is almost nil.

Keys-words*: Modelling, impact, air pollution, health, Urban Mobility Plan.*

Introduction

Votée en décembre 1996, la loi sur l'air reconnaît à chacun 'le droit de respirer un air qui ne nuise pas à sa santé'. Elle oblige les agglomérations françaises de plus de 100 000 habitants à se doter d'un plan de déplacements urbains (PDU). Lille Métropole, conurbation de presque 1.100.000 habitants, a adopté son PDU en juin 2000, il vise le doublement de l'usage des transports collectifs et du vélo d'ici 2015, une stabilisation du trafic automobile des habitants de Lille Métropole et un maintien de la marche à pied. L'objectif de ce travail est d'évaluer le PDU à terme relativement proche (15 ans) pour la thématique des impacts sur la santé humaine de la qualité de l'air –ce qui n'est bien sûr qu'une facette des bénéfices attendus de sa mise en place.

Méthode

Cette estimation des impacts santé liés à la pollution de l'air ne peut être effectuée qu'en ayant recours aux outils de modélisation, soit successivement une modélisation des trafics, des émissions liées à ces trafics, des concentrations des polluants atmosphériques ainsi engendrés et enfin des impacts sur la santé humaine desdits polluants. Cet enchaînement de modèle a fait l'objet d'une attention toute particulière afin d'exploiter au mieux les possibilités de chaque modèle et de renforcer les cohérences des données ainsi transformées d'un modèle 'générateur' au modèle 'consommateur' (au

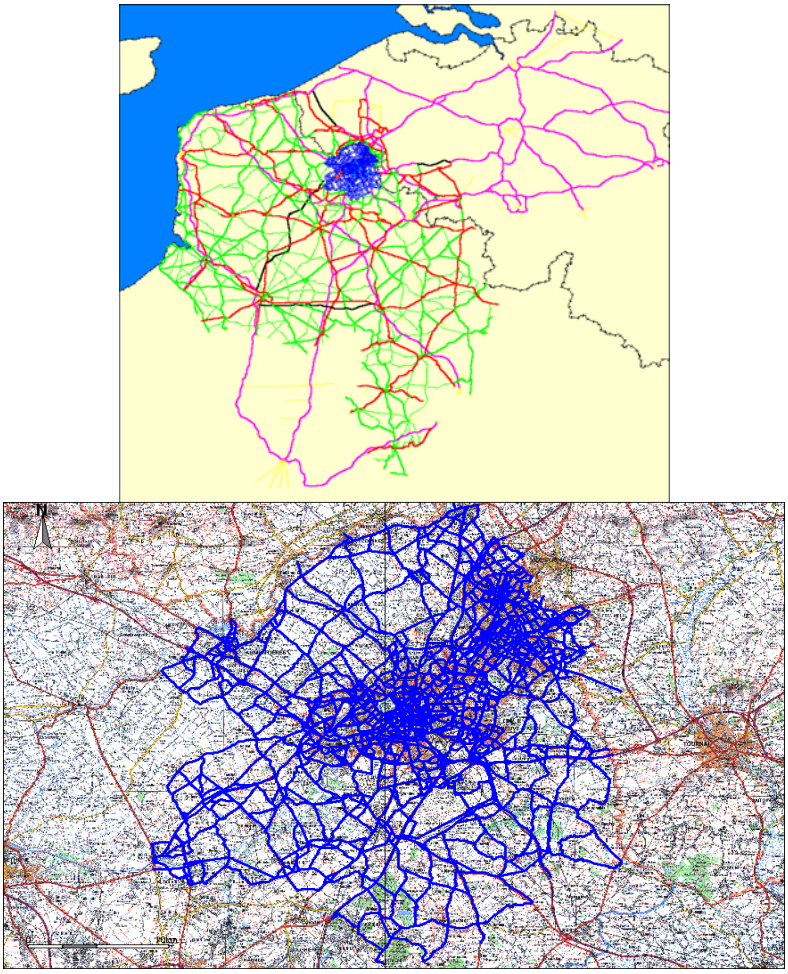
sens de leur place dans la chaîne de modélisation), ainsi que la cohérence globale quant aux objectifs de l'étude : une comparaison de variante d'aménagement et de politique de déplacements urbains.

1. Modélisation des trafics

Les trafics ont été modélisés à l'aide du logiciel EMME/2 (INRO 2005), mettant en œuvre une démarche de modélisation classique en quatre étapes : génération de la demande de déplacement, distribution de cette demande, choix modal et enfin affectation sur le réseau de transport.

Figure 1 : réseau du modèle 'externe' du trafic VL&PL (à gauche), réseau du modèle 'métropole de Lille' (à droite)

Figure 1: HDV&LV network for the external model (left), the Lille metropolis network (right).



Le trafic dit 'externe' (poids lourds et véhicules légers) a été modélisé sur une zone d'étude allant de la Belgique à Paris et de Dunkerque à Reims, et

incorporé pour sa partie totalement à l'extérieur de l'arrondissement de Lille, comme une contrainte préexistante en terme d'occupation de la voirie. Le trafic 'externe' intercepté par l'arrondissement de Lille a été modélisé et intégré au modèle détaillé sur l'arrondissement de Lille. Ce modèle détaillé sur la grande métropole Lilloise comprend 324 zones internes sur lesquelles sont identifiées les informations Origine/Destination et 7603 tronçons représentant 2500 kilomètres de voiries, soit 30% du total des infrastructures, mais la grande majorité des trafics totaux.

Une attention toute particulière a été apportée à trois paramètres généralement peu investigués lors des modélisations 'trafic' habituelles : la vitesse des véhicules, le taux de véhicules ayant un moteur 'froid' –et donc générateur d'une surémission de polluants- et la répartition horaire sur l'ensemble de la journée du trafic.

Le trafic par transports en commun a été modélisé à partir des données de l'exploitant, le trafic deux roues est estimé à partir de ratio du trafic total sur chaque tronçon, ratio issu de l'exploitation des données enquêtes ménages.

Enfin, les hypothèses de traduction des objectifs généraux du PDU ont été clairement explicités, tant pour les nouvelles infrastructures (véhicules automobiles, transports en commun) que pour les variables connexes de la modélisation (taux d'occupation des véhicules, part modale des modes doux…).

2. Modélisation des émissions

Les résultats des modélisations des scénarii de trafic sont les données d'entrée de la méthodologie COPERT III (Ntziachristos 2000), le logiciel utilisé étant COPCETE, développement du Ministère français de l'Equipement. L'utilisation de COPERT dans ce contexte – données de trafic extrêmement détaillées et spatialisées- doit être considérée comme à la limite de validité d'emploi du modèle. Il n'existe cependant pas de meilleure solution scientifique répondant au besoin simultané d'une connaissance du trafic automobile détaillée spatialement et d'une possibilité de projection à long terme de politiques de transport contrastées.

Le parc roulant utilisé est le parc dynamique de l'Institut National de REcherche sur les Transports et leur Sécurité issu des travaux de (Bourdeau 1997), les travaux d'actualisation de (Hugrel 2004) n'étant pas encore disponibles à la date de réalisation de l'étude.

Les besoins des modélisations d'immissions sont bien plus étendus que la simple modélisation des 24 heures de la journée moyenne modélisée lors de la phase d'estimation des trafics puisque l'année entière doit être décrite au pas de temps de l'heure. Ce raffinement temporel n'étant pas accessible par la modélisation du trafic, il a été décidé de traiter cette exigence au niveau de la modélisation des émissions en appliquant un coefficient temporel homogène sur toute l'aire d'étude. Ce coefficient est issu de l'analyse statistique des trafics comptabilisés par l'ensemble des 71 dispositifs permanents de comptages sur l'aire d'étude et permet donc de calculer l'émission liée au trafic pour les 8760 heures de l'année d'étude.

Les émissions ponctuelles des principaux gros émetteurs appartenant aux secteurs d'activité du chauffage urbain, de l'industrie et de l'incinération de déchets sont inventoriées et leurs hauteurs de rejet sont disponibles. Ces données proviennent de la DRIRE Nord - Pas-de-Calais (Direction Régionale de l'Industrie, de la Recherche et de l'Environnement).

Enfin, les émissions non décrites par ces méthodes ont été calculées en distribuant les émissions EMEP (EMEP 2004) sur les mailles du domaine lillois en utilisant les caractéristiques d'occupation des sols issues des données Global Land Cover Facility (Hansen 1998) et en utilisant une matrice de distribution verticale dépendant de la SNAP (Selected Nomenclature for Air Pollution). La répartition horaire se fait en appliquant un coefficient mensuel, hebdomadaire et horaire de GENEMIS (Generation and Evaluation of Emission Data, sous-projet EUROTRAC-2).

En ce qui concerne les simulations pour les scenarii occurant en 2015, il est prévu que les émissions baissent fortement d'ici cette échéance, ce qui va entraîner une modification de la composition des masses d'air en Europe et en particulier celles qui vont être advectées jusqu'au domaine lillois. Une première étape consiste à simuler la qualité de l'air à l'échelle européenne par le biais d'une projection d'un inventaire d'émissions à horizon 2015. L'exercice de modélisation européenne CITY-DELTA a mis en oeuvre des scénarios d'émissions pour l'année 2010 à l'échelle européenne. Pour établir l'inventaire de 2015, un coefficient de réduction, interpolation des réductions prévues entre 2010 et 2020, a été appliqué pour le trafic routier à partir du rapport Ntziachristos (2002), soit 0:8 pour les NOx et 0:85 pour les composés organo-volatiles. Les autres composés sont déduits d'une interpolation des projections 2010 et 2020 d'EMEP. Pour la simulation locale de 2015, les émissions sont modifiées à partir des projections d'inventaires du trafic routier avec et sans plan de déplacement urbain. Les grandes sources ponctuelles sont conservées à l'identique.

3. Modélisation des concentrations

Une chaîne complète de modélisation (Polyphemus, www.enpc.fr/cerea/polyphemus) a été développée par le CEREA pour simuler la qualité de l'air aux échelles régionales (Quélo 2005) et continentales (Mallet 2005), notamment pour la photochimie et les aérosols. La chaîne de modélisation inclut d'une part la transformation des données d'émissions, de météorologie, de type de sol, et d'autre part un modèle de chimie-transport (POLAIR3D, Boutahar 2004) pour la simulation des niveaux de concentrations de polluants. POLAIR3D résout l'équation de conservation des espèces chimiques qui décrit la transformation chimique, le transport, le dépôt et les émissions de polluants. Le modèle adopte une approche tri-dimensionnelle eulérienne. Le mécanisme chimique utilisé est RACM (Reactive Atmospheric Chemistry Mechanisms). Il décrit les réactions chimiques de 83 espèces gazeuses par l'intermédiaire de 213 réactions chimiques.

L'agglomération lilloise fait partie d'une zone urbaine dense. Même si les pics de pollution sont observés à proximité des fortes sources d'émissions, une

part importante de polluants est apportée de régions éloignées. Le site pouvant se trouver dans le panache de gros centres d'émissions (Ruhr, Londres, Paris, etc). Ceci justifie d'avoir de bonnes conditions aux limites pour cette étude régionale. Ainsi, une première étape a consisté à faire une simulation sur un domaine large afin de fournir les concentrations aux limites pour la simulation sur le domaine lillois. Les conditions aux limites de la simulation européenne sont fournies par les modèles à l'échelle globale MOZART et GOCART. Elles correspondent à des valeurs journalières typiques pour certaines espèces chimiques. Les champs météorologiques proviennent des réanalyses du CEPMMT (Centre Européen de Prévision à Moyen Terme [ECMWF]). Ces données ont une résolution temporelle de trois heures. Le modèle du CEPMMT possède une résolution spectrale T511 qui correspond à une résolution horizontale d'environ 1.125 degrés (de l'ordre de 150 kilomètres) et 60 niveaux verticaux dont environ 16 pour la couche limite atmosphérique (en-dessous de 3000 mètres).

Pour une utilisation simple de ces conditions aux limites, le domaine européen a été choisi de sorte qu'une maille corresponde exactement au domaine lillois. L'étude a donc été réalisée par modélisation imbriquée. La modélisation d'une année de scénario est résolue en 5 jours CPU sur une station de travail récente. Pour la modélisation des particules, seuls les résultats sur le domaine européen ont été analysés, la qualité de la modélisation étant alors jugée suffisante.

4. Modélisation des effets sur la santé

Le territoire visé par notre exercice d'évaluation de l'impact sanitaire est celui qui avait été analysé dans le cadre du programme PSAS-9 (Cassadou 2002), soit la communauté urbaine de Lille (LMCU). Pour chacun des polluants considérés, un indicateur d'exposition moyenne de la population de LMCU a été construit à partir de la moyenne arithmétique des valeurs journalières mesurées par les stations sélectionnées (INVS 2003). Nous avons ensuite utilisé la moyenne arithmétique des valeurs journalières modélisées aux mailles correspondant aux stations sélectionnées pour examiner l'impact des différents scénarios sur l'exposition moyenne de la population.

Pour suivre les recommandations du guide méthodologique de l'Institut de Veille Sanitaire, nous avons utilisé les résultats de la phase II du programme PSAS-9 pour l'impact à court-terme sur la mortalité totale hors morts violentes et accidentelles de l'ozone et du NO_2. Quand l'hétérogénéité des estimations entre villes n'est pas significative, il est raisonnable de penser que l'estimation combinée des 9 villes est la meilleure estimation du risque relatif local de Lille car, en l'absence d'hétérogénéité, l'estimation locale est plus instable et les variations locales sont purement aléatoires. Par contre, en présence d'une hétérogénéité significative, on peut être tenté d'utiliser l'estimation locale mais celle-ci reflète à la fois la réelle hétérogénéité du risque relatif, qui peut être due au contexte local (caractéristiques de la population et modalités d'exposition, caractéristiques du mélange de polluants), et des variations aléatoires. Il est donc souhaitable d'utiliser des estimations locales lissées qui prennent en compte l'ensemble des estimations locales disponibles, à l'aide d'une approche

bayésienne empirique (Post 2001 et Le Tertre 2005). L'hétérogénéité entre villes est faible pour le NO_2. Nous avons donc utilisé l'estimation combinée du risque relatif pour les 9 villes (modèle à effets fixes). Par contre, l'hétérogénéité entre villes est plus importante pour l'ozone. Nous avons donc utilisé l'estimation bayésienne empirique du risque relatif local. L'impact à court et long terme sur la mortalité des particules en suspension (PM_{10}) a été estimé avec la relation exposition-risque utilisée par Künzli (2000) et construite à partir des résultats des études de cohortes américaines.

Le calcul de l'impact sanitaire à court-terme sur la mortalité, exprimé en nombre annuel cumulé de décès anticipés repose sur le principe exposé suivant : soit N le nombre journalier moyen d'événements, p_j le niveau journalier d'exposition pour le jour j et RR le risque relatif évoqué,.pour chaque jour, on peut calculer F_j, la fraction étiologique associée à l'exposition p_j par rapport au niveau de référence r_j ; le cumul sur l'année des cas anticipés attribuables à l'exposition le jour j est donc :

$$A = \sum_j \left(n_j \times \frac{\left(RR_{p_j - r_j} - 1 \right)}{RR_{p_j - r\,j}} \right)$$

En ce qui concerne l'impact à long terme sur la mortalité, le même type de calcul a été appliqué aux niveaux annuels moyens d'exposition.

Les résultats de l'estimation de l'impact sur la mortalité doivent être interprétés dans le contexte de l'exercice de modélisation, c'est à dire des sources fixes, une météorologie et des conditions socio-démographiques comparables dans les trois scénarios et fixés aux conditions de 1998.

Résultats

Tableau 1 : Synthèses des résultats de trafics aux 3 horizons d'étude : occupation de la voirie (eq-véhicules.kilomètres par jour) et vitesse moyenne des déplacements (km/h) ; scénario 1998, 2015 avec PDU (With UMP) et 2015 sans PDU (Without UMP).

Table 1: Summaries of the results of traffics simulations at the 3 horizons of study : occupation of the roadway system (equivalent-véhicules.kilomètres per day) and mean velocity of displacements (kilometres per hour); scenarii : 1998, 2015 with and without UMP.

	1998	2015		Evolution 2015/1998		Differences 2015
Uvpxkm/j (*10e^6)		without UMP	with UMP	without UMP	with UMP	without UMP vs with UMP
Hot LV	13.698	17.834	15.819	1.30	1.16	**1.13**
Cold LV	3.739	3.922	3.274	1.05	0.88	1.20

HGV	2.325	**2.992**	3.031	1.29	1.30	**0.99**
Total	19.762	24.748	22.124	1.25	1.12	1.12
Mean velocity	42.2	37.7	51.3	0.89	1.22	1.36

1. Modélisation trafic

Pour juger de la pertinence et de la validité des données reconstituées par le modèle en situation actuelle (année 1998), nous avons pu nous appuyer sur des comptages routiers, sur des vitesses observées par des stations SIREDO sur les axes autoroutiers aux entrées de Lille et sur quelques mesures de temps de parcours. La comparaison de ces différentes données observées avec les résultats issus du modèle montre que les trafics sont relativement bien reconstitués par le modèle - les écarts dépassent rarement les 10% sur les grands axes, et 20% sur les axes à faible trafic- et les vitesses modélisées présentent des écarts de l'ordre de ±10% (soit environ 10 à 20km/h) aux périodes creuses et 20% aux heures de pointe.

Sur l'ensemble de l'aire d'étude, l'évolution du trafic modélisé suit bien les inflexions impulsées par le PDU alors que l'évolution des vitesses moyennes de déplacement rend compte de la fluidification due à la mise en place de ces mesures:

2. Modélisation des émissions

Les différences d'émissions totales entre le scénario 1998 et le scénario 2015 sans PDU varient entre 63% (NOx) et 76% (particules), ce qui traduit bien les gains technologiques espérés à cet horizon. Les gains en émissions dus, en 2015, à la mise en place du PDU varient quant à eux de 5% (NOx) à 13% (Benzène).

La modélisation des émissions permet, au-delà des valeurs brutes utilisées pour la phase suivante de modélisation des concentrations de polluants, de mieux connaître les enjeux relatifs aux différents modes de transports : en 1998, les émissions dues aux véhicules légers, véhicules utilitaires légers et poids lourds représentent entre 95.1% (pour les particules) et 98.2% (pour le CO_2) des émissions totales. Hormis pour les composés organiques volatils, ce constat prévaut à nouveau en 2015, quelque soit le scénario étudié.

De plus, de nombreuses études d'incertitudes liées à cette phase de modélisation ont été effectuées, le tableau ci-dessous reprenant les résultats des modélisations – exprimés en pourcentage du calcul de référence- pour les différents scenarii lorsque :

- la vitesse est augmentée de 10 km/h sur l'ensemble des voiries,
- le taux de poids lourds est augmenté de 2 points sur l'ensemble des tronçons modélisés,
- les surémissions liées aux parcours à froid sont calculées avec les données de parcours à froid modélisées dans la phase trafic plutôt que par la méthodologie COPERT standard (β constant),

Tableau 2 : analyse de sensibilité des émissions des sources mobiles. Ratio scénario alternatif – scénario de base

Table 2 : sensitivity analysis of the emissions of the mobile sources. Ratio alternative scenario vs base scenario

Sensitivity	Scenario	CO2	NOx	COV	Benzene	PM
Speed	1998	97	103	92	91	97
	2015 With UMP	97	103	106	110	102
HGVs	1998	108	112	102	100	110
	2015 With UMP	108	112	104	100	103
Cold start	1998	94	92	71	72	84
	2015 With UMP	94	85	47	35	78

Si les incertitudes liées à la vitesse de parcours et celles liées au pourcentage de poids lourds sont significatives (de l'ordre de grandeur, pour certains polluants, des gains attendus avec la mise en place du PDU), les incertitudes liées aux surémissions dues au parcours dit 'à froid' sont quant à elles extrêmement importantes.

Enfin, les résultats ne varient quasiment pas (99-103%) lorsque les calculs sont fait suivant une agrégation horaire de 4 périodes de modélisation trafic plutôt que 24 heures modélisées de façon différentiées.

3. Modélisation des concentrations

Les modélisations du scénario 1998 sont comparées aux données des stations de mesures de l'association locale de surveillance de la qualité de l'air a fin de validation de la chaîne de modélisation. Les résultats sont satisfaisants, tant pour les polluants que pour les polluants particulaires :

Tableau 3 : Statistiques des comparaisons entre les concentrations simulées à l'échelle locale et les mesures. Elles sont calculées sur des valeurs horaires, station par station pour le NO_2 (seules les valeurs extrêmes sont ici représentées) et sur des valeurs journalières sur la moyenne des cinq stations de fond pour les PM_{10}.

Table 3 : Statistics of the comparisons between the concentrations simulated on a local scale and measurements. These statistics are calculated on hourly values, station by station for the NO_2 (only the extreme values are represented here) and on day values on the average of the five urban background stations for the PM_{10}.

Station	Number of measurements	Measurement mean for $\mu g.m^3$	Simulated concentrations µg.m3	Bias µg.m3	RMS	Correlation %
Dense urban – NO2 (6 stations)						
Armentières	6870 - 8731	27.2 – 37-9	22.9 – 36.2	-5.0 – 3.1	13.5 –	54 - 67

Station	Number of measurements	Measurement mean for $\mu g.m^3$	Simulated concentrations µg.m3	Bias µg.m3	RMS	Correlation %
					19.6	
Peri-urban – NO2 (3 stations)						
	8562 - 8696	23.1 – 25.9	21.5 – 26.3	-3.1 – 3.1	11.9 – 15.6	57 - 65
***Dense urban** – PM10 (station mean over 5 stations)*						
Halluin	363	25.7	23.4	-0.1	10.0	71%

Les modélisations des deux scénarios 2015 –avec et sans réalisation du PDU- engendrent très peu de différences quant aux différentes concentrations de polluants, au plus 5% sur les moyennes annuelles par maille sont relevés.

4. Modélisation des effets sur la santé

La diminution des moyennes journalières de NO_2 et de PM_{10} dans le scénario 2015 avec PDU –par rapport au scénario 1998- conduit à une réduction du nombre de décès anticipés cumulés sur l'année (environ 135 décès par an en considérant l'impact de la réduction des niveaux de NO_2 et 73 décès en considérant les niveaux de PM_{10}), alors que l'augmentation des maxima 8-horaires journaliers d'ozone conduit à une augmentation du nombre de décès anticipés (environ 15 décès). Pour les trois polluants, l'impact du scénario 2015 avec PDU, par rapport au scénario 2015 sans PDU, est quasiment nul.

En ce qui concerne l'impact sur la mortalité à long terme de la réduction des niveaux de PM_{10}, la différence scénario 1998 - scénario 2015 avec ou sans PDU est tout à fait significatif (environ 500 décès par an) et l'impact du PDU par rapport au scénario 'fil de l'eau' en 2015 est à nouveau négligeable.

Conclusion

L'impact sur les scénarios 2015 du PDU, très ambitieux dans ses objectifs et les moyens déployés, est significatif sur le trafic et les émissions avec des réductions de 5 à 13% selon le polluant considéré.

L'évaluation des concentrations journalières modélisées en 1998 par rapport aux valeurs mesurées en 1998 montre que les résultats obtenus sont satisfaisants : le biais moyen est inférieur à 2 µg/m3. Les concentrations en NO_2 sont réduites en moyenne de 50 % dans le scénario sans PDU (vs 1998) alors que les concentrations en ozone augmentent en moyenne de 16 %. Par contre, l'impact spécifique du PDU (par comparaison des deux scenarii 2015) sur les concentrations de PM, NO_2 et d'ozone est très faible. Il en est de même pour les effets sur la santé des polluants atmosphériques étudiés. Ces résultats sanitaires sont axés sur la thématique de la pollution de l'air, ils ne présagent

bien sûr en rien des gains dus au PDU pour d'autres thématiques (sécurité routière, bruit…).

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Understanding CO_2 reduction and efficiency in road freight transport and logistics. German surveys and case studies 2002-2005

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Abstract

Since 2002, numerous case studies have investigated the sustainability effects of efficiency measures in German road haulage companies. Particular focus was set on the impacts of the company measures "scheduling systems" and "introduction of on-board telematics" and on the sector analysis for the efficiency improvements in Courier, Express and Parcel (CEP) services. The purpose has been to arrive at further insights into the energy efficiency issues in those fields of business which have until now remained largely unexplored. One objective is to gain understanding of the mechanisms of various processes, which influence efficiency and create new framework conditions; qualitative investigations were carried out to this end. To tackle the lack of data, it is necessary to quantify the current efficiency values at the company level, so that company decision making can be based on them. The aim is to discover whether the decoupling of freight traffic from energy consumption is taking place at the business level and to investigate the potential for further steps in order to be able to make policy and company related recommendations.
Keywords: *CO_2 reduction, energy efficiency, freight transport, decoupling, surveys, case studies*

Résumé

Une enquête sur les transports routiers a permis de collecter des données dans plus de 200 entreprises allemandes et de relier la consommation d'énergie aux paramètres de performance du transport. L'efficacité énergétique a été analysée pour les mesures « systèmes de gestion et planification des tournées » et « télématique embarquée », ainsi que pour le secteur des messageries. Les résultats montrent un potentiel d'amélioration à cause du niveau assez bas du taux d'utilisation des véhicules, du faible nombre de camions à carrosserie légères, et d'un taux élevé de transports à vide. Le découplage entre la performance économique (PIB national), les distances parcourues et les émissions de gaz carbonique par camion, a été montré dans

plusieurs études de cas. Des recommandations pour la prise de décision sont dérivées des analyses et des résultats des enquêtes.
Mots clés: *Réduction des émissions de CO_2, efficacité énergétique, transport de marchandises, découplage, enquêtes, études de cas*

Trends in decoupling and the example of Company C

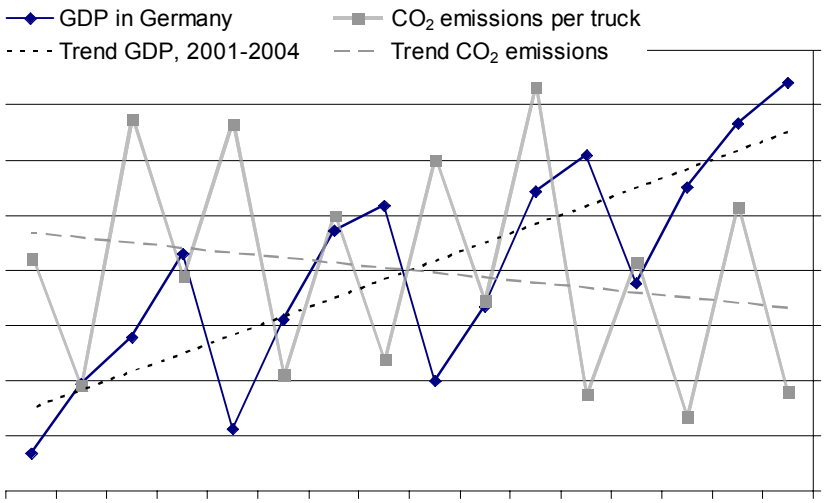
Road freight transport growth is, in terms of turnover, coupled with GDP growth in Germany. In terms of tonnes (volume) or tonne-kilometres (performance), the growth is only partially coupled with GDP. Since fuel use is slowly declining in road freight, a weak decoupling of climatic impacts from freight growth has been observed since 2001. The drivers of road freight growth in recent years in Germany have been demand growth due to globalisation and the opening of Eastern European markets, growth absorption only in the road and not in the rail sector (due to the low competitiveness of German rail freight), reduced parcel size, an increasing demand for cabotage, etc. The drivers of reduced fuel use (and a slight reduction in CO_2 emissions) have been the new tax and higher fuel prices, improved engines and goods vehicle design, slightly improved load factor, and more generalised use of traffic telematics.

Transport performance data and fuel consumption data were recorded by onboard systems on 60 trucks in one general cargo company, chosen for its business practice “normality” for one case study survey in 2005. A net CO_2 reduction per vehicle has been demonstrated for the years 2001 to 2004 (figure 1). Calculated were standardised mean quarter values, allowing a comparison with GDP data from the national statistics. In this period, mileage per vehicle is continuing to show a slight increase, but less than GDP growth. These results on decoupling are not contradictory, but complementary to the results from Finland (Tapio, 2005), Denmark (Fosgerau and Kveiborg, 2004) and UK (McKinnon, 2003).

The empirical survey of CO_2 efficiency in freight: the aim of the general survey (January to May 2003) was to investigate the state of the art in CO_2 efficiency and the available potential for optimisation in the German road haulage sector. The results of the data collection in a randomly chosen German sample is a set of 153 coupled data, representing 2-4 days complete and exact tkm and fuel use records, and a total performance of more than 1.6 million tkm. These data are showing that the CO_2 efficiency of the transports fluctuates from 0.8 to 26 tkm per kg CO_2. A close correlation exists between efficiency of vehicle use (tkm/total mass-km) and CO_2 efficiency (figure 2). Further influencing factors for efficiency are load capacity utilisation rate, vehicle size, and payload/dead weight ratio. Empty mileage, size and sector of the business are less strongly correlated to CO_2 efficiency.

Figure 1: GDP in Germany and CO_2 emissions per heavy duty truck in Company C, 2001 to 2004 **Quarter means from telematics data recorded by 60 trucks; from: Stat. Bundesamt 2005, survey NESTOR**

Figure 1: PIB en Allemagne et émissions de CO_2 par véhicule poids lourd dans l'entreprise C, de 2001 à 2004; Stat. Bundesamt 2005, enquête NESTOR



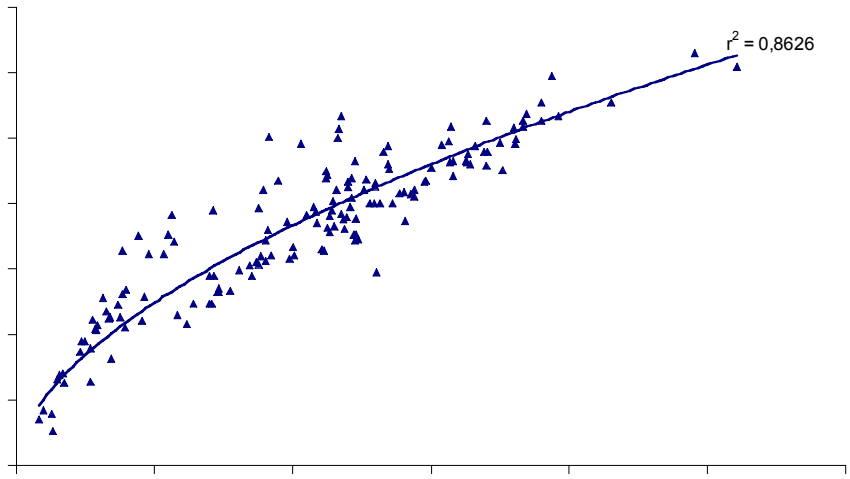
The market share of CO_2 efficiency measures was determined for 52 German companies. According to these figures (Leonardi and Baumgartner, 2004), only a few successful technological and other measures like driver training have been introduced across Germany in logistics and transport companies. The potential for further improvements in efficiency is high, and the possible short term CO_2 reduction has been estimated at 20% of the total current emissions generated by road haulage.

Efficiency in the CEP sector and for a company case: the market for CEP services is growing in Germany, and the potential for efficiency improvements lies with the vehicles themselves and the company organisation. The use of gas-powered vehicles, IT-supported scheduling optimisation, driver training, and many other measures have a potential. Application barriers have been identified in the form of the limited financial resources available for new decisions on the side of self-employed drivers and in the low level of interest shown by company central offices in making sure, through organisational means, that the fleet is used in the most energy efficient way. The reason for this is that the extremely demanding time conditions for parcel delivery in the CEP sector implicates that all the attention focus on time efficiency in the daily business. Efficient vehicle use is not a priority. The use of one car for delivering a single parcel with an average weight of 5 kg is a common figure. In the case of the German company GO! (3000 vehicles), 48 distribution trips, 24 collection

trips, 53 direct transport trips and 14 night line deliveries were surveyed in March and April 2005. Questionnaires gives values on parcel number, mileage, vehicle characteristics and fuel consumption of each trip. Each trip dataset obtained allow the calculation of the key variables for energy efficiency. The mean vehicle consumption is around 8 l/100km. The best car used 4,5l/100km and the least efficient one about 14 l/100km. City trips vary from 45 up to 530 km per day. Hub transports are about 6 to 700 km per night. The lowest average efficiency value is around 0.57l per parcel for a nationwide shipment. This is a low value, which shows that a high level of efficiency can be achieved for parcel shipments in CEP logistics. However, the detailed analysis of trips efficiency, differentiated by the business sub-sectors of the company, allows the identification of areas with a high potential for further improvements. Especially high efficiency potential exist for "direct courier" delivery for the case, where a single parcel has to be directly sent by car from the customer to a far distance destination. For such cases, occurring often in the day-to-day business, a factor 60 between the most efficient and least efficient day average is a clear indication that solutions for efficiency improvements are worth to be tested and implemented.

Figure 2: Average values for the surveyed 2-4 days: trips performance, efficiency of vehicle use and CO_2 efficiency; from: survey NESTOR

Figure 2: Valeurs moyennes pour les trajets de 2 à 4 jours: performance, efficacité de l'utilisation des véhicules et efficacité énergétique; enquête NESTOR



Scheduling software and telematics: it was demonstrated that, when the load volume remains constant, the CO_2 efficiency of a road haulage company improves by about 10% upon introduction of an IT-supported scheduling system (Leonardi et al. 2004).

Technologies and markets are very complex and therefore not transparent in terms of cost-benefits analysis or environmental cost-effectiveness. One assumes that the companies should have a financial interest for investments in new technologies allowing a better efficiency performance. This argument is only partly validated by the interviews with 20 decision makers in transport companies and software producer. Due to the lack of cost benefit examples, decision maker in companies are reluctant to invest in systems with complicated handling and relative high prices (2000-5000 euro/truck). The identified efficiency potential is depending on the low German average of 49% load factor in 2003-04. Our case study with onboard telematics indicates an even lower mean value of 44% load capacity utilisation.

The main question for further developments is, to what extent IT scheduling and telematics systems could be improved ? Users frequently mentioned as desirable such points as a greater degree of integration between the various IT supported scheduling and telematics systems for data communication and location, as well as improvements in the stability of the on-board telematics components. Further improvements could be achieved through filling the technological “missing link” between data communication devices and on-board-monitoring (CAN-bus) systems. This could be done by creating interfaces between IT scheduling and on-board monitoring systems, the automatic measurement of volume capacity utilisation, and an improved or more widely used semi-automated route and run optimisation system.

A small case study on the implementation of the Logiplan software in a company shows a reduction of 16% in distance covered with the same load after the introduction of the new scheduling and tour planning system. Therefore, a high level of market potential for IT scheduling and telematics is given. The need for simplified technology and transparent market information is also high.

Policy analysis: Instruments, solutions and measures proposed for decoupling

One of the main points of the dialogue with various German decision makers interviewed in the years 2002 to 2005 was the policy dimension and the future improvement of the efficiency potential in freight transport. Many instruments were identified, having a high potential for lowering total fuel consumption in road freight. The principal solutions improving the market diffusion of efficiency measures in companies or at the level of entire supply chains are:

Information campaigns and diffusion programmes for all technologies and organisational measures such as telematics systems and technologies, aiming at enhancing the goods vehicle load factor and lowering the emissions per tonne kilometre or per unit (parcel or pallet), (e.g. in the context of a freight energy efficiency campaign).

Cost-revenue examples show that, in some cases, a return on investment in efficient technologies and organisational measures is possible within a few

weeks for a trucking company. To spread such cost-revenue examples, a kind of free accessible European best practice catalogue should be started. To ensure independency and impartiality in cost-revenue analyses for efficiency measures, the aid of independent public agencies is needed. Only then, efficiency analysis could become part of the strategic thinking of company decision makers. Transport agencies, energy agencies, environmental agencies or city authorities could be actively linked. This would help to overcome one main market barrier: the lack of product and service transparency due to a very large amount of suppliers and concepts on the market.

Further independent technology tests and evaluations of performance under real road traffic conditions are required, aiming at measuring energy efficiency gains for each type of technology and each sub-sector of activity. The test results should be available to the companies. Objectives here are

- the improving of the information base for decision-making,
- the lowering of the risk of investments and
- the improving of the application rate of efficiency technologies in Europe.

Further needed is the effective harmonisation of driver regulations and goods vehicle control practices with, for example, the introduction of a digital tachograph.

Driver training programmes and promotion of eco-efficient driving techniques. As it is a fact that driving courses are generally not well attended because of the loss of at least one business day, some incentives are required here. The main barrier to implementation is the high time pressure in the sector. Cost-free training courses offered by vehicle manufacturers - for example, at the point of purchase of a new truck - should include energy efficient driving techniques and become a further generalised practice.

Research and Development on goods vehicle technologies such as fuel switch (biodiesel, CNG etc.), on-board telematics, light vehicle design, improved engine performance (for all vehicle types, not only heavy duty trucks) etc.

Market studies on following topics (among other):

- diffusion of innovative technologies,
- restrictions on, and possibilities for, the different logistics concepts aiming at efficiency improvements,
- solutions for overcoming the market barriers.

Modal change: Improve the competitiveness, reliability and speed of rail freight transport system and rail-road intermodal structures. The objective is a substantial increase in the demand for long-haul rail freight.

Effects of instruments and measures proposed

Positive market development and environmental effects are expected from a further implementation of existing measures, such as road pricing, and also

from future efficiency measures (technologies and organisation) such as on-board systems, IT-disposition and telematics, fuel switch, new co-operative agreements etc.

There are no potentially negative effects of the proposed measures on the road haulage and logistics sectors in terms of business turnover growth. For the side of the shipper from industry and trade, the logistics service quality can only improve and therefore growth conditions can only be positively affected.

Most of the proposed measures require very low cost for the state and the authorities. A significant decrease in total fossil fuel demand will affect the oil industry, only if its decision-makers are not actively developing alternative fuels and not improving the market diffusion of renewable energy sources on their own initiative.

However, the other drivers for logistics market development like globalisation and rapid growth in NMS could induce some possibly negative effects, and counteract the effects of the measures, for example through a strong increase in total vehicle fleets and an unexpected growth in international (European) demand for road freight in terms of mileage.

Policy recommendations

- Implement the measures and technologies proposed above
- Strengthen the decision making process and develop the information base for energy efficiency in road freight transport, with the help of public relation campaigns, thus giving impetus for new company policy directions. It is also necessary to change some regulatory frameworks.
- Help internalise at least partially the external costs from the road freight transport sector and improve the ecological effectiveness of fuel tax and other fiscal instruments. Reinvest at least a part of the fuel tax revenues (and the revenues from other fiscal instruments such as road user charges) into measures and technologies proposed and into accident prevention and safety measures.
- Promote collaborative socio-economic research on energy efficiency in the freight transport sector in OECD countries (improve research co-operation between European, North American and East Asian research institutions in this field).

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Muffler design using finite element modelling and performance simulation

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Abstract

Computer simulation offers the possibilities to achieve better values for all factors that will minimize the production efforts and costs of a muffler design and fabrication process. The most important factors involving in muffler design are noise level attenuation, backpressure, size and weight. In order to obtain the optimal solution for a specifically muffler design, many prototypes involving material, time spend and expensive costs are necessary, including acoustic tests and measurements. Precise computer modelling and simulation using FE programs can replace all this operations resulting considerable improvement in shorting the design time and cost production.

Keys-words: *muffler, silencer, acoustic, finite element, modelling, simulation*

Introduction

Considerable effort has been directed over the years in connection with attempting to optimize the design of muffler for internal combustion engines in which there is a flow of gases having a noise component entrained or accompanying the gases. There are many factors which are considered in determining whether or no a particular muffler design is a success, the most commonly considered parameters being size, weight, back pressure and, perhaps most important, noise reduction. Reductions of size offer the designers greater flexibility in the positioning of the muffler and also, the possibility in its use on other combustion engines.

Existing exhaust systems have attained a noise reduction level, which is satisfactory for today's requirements, but the future NVH standards demand lower noise levels, which will be tolerated in parallel with the increase in standards as to reduction of pollutants in exhaust gases. Another factor that competes directly with noise reduction is the effect of the muffler on engine

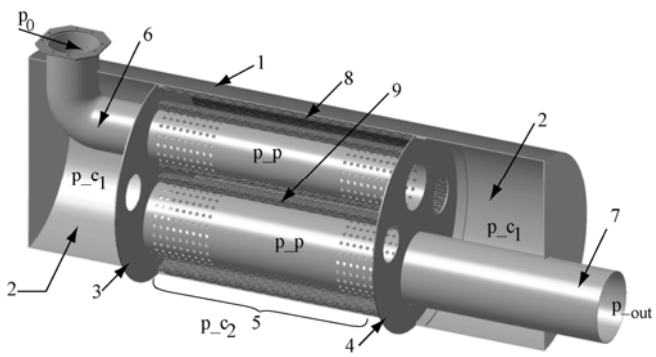
performance. More particularly, mufflers inherently impede the flow of exhaust gases from the engine. This obstacle creates a backpressure between the engine and the muffler, with a negative resulting effect upon the power production of the engine. Hence, increasing backpressure as a result of noise and weight reduction solutions decrease the engine efficiency and will defeat the effects of these improvements. Automotive designers therefore must make design decisions that will achieve a selected noise level while minimizing backpressure and its effect on the engine performance.

Muffler geometry

Mufflers are radiating structures emitting sounds into the surrounding space. Modelling the acoustics of a muffler implies the mathematical descriptions of the pressure wave propagation and the analysis of damping for propagation of harmonic acoustic waves. Mathlab and Simulink are valuable platforms used to develop simulation finite element type programs used in acoustic waves modelling. FEM programs like Nastran or Fluent can be also used to model the pressure wave propagation into a muffler.

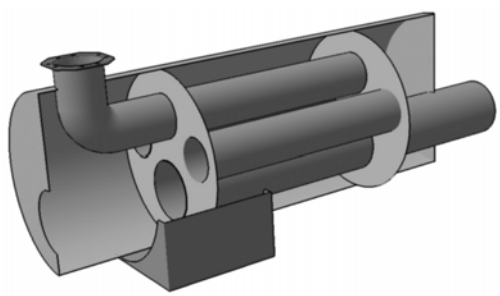
In Fig.1 and 2 are shown two muffle with semblable 3D geometries used to meet the customer demands.

Fig.1: Muffler- 3D geometry representation



For this application we have choose a classical silencer construction with two expansion chamber 2 and a middle resonance chamber 5 known as a low frequency tuning chamber [2]. These chambers are formed from the muffler shell 1 with two internal baffles 3 and 4 which also support two pipes (tubes) 6 and 7 used to conduct the exhaust gaze. The inlet tube 6 will extend through the inlet chamber 2 and the central chamber 5 and will enter into the outlet chamber 2. The inlet tube must be of solid wall construction through the inlet end chamber but will be perforated in the central chamber of the muffler. Similarly, the outlet tube 7 opens in the inlet chamber 2 and passes through the central and outlet chambers 5, respectively 2. The outlet tube is typically of solid wall construction in the outlet chamber 2 and perforated in the central chamber. The communication of the flow between these tree chambers is made with circular perforations in the baffle walls or with one or two transfer tube as can be seen in Fig.2.

Fig.2: Muffler-with two expansion and one resonance chambers and internal transfer tubes



The transfer tube(s) may be also perforated, as it passes through the resonance chamber. The resonance chamber is packed with a sound absorbing material 9 around the passing tubes and around the shell wall, 8. Typical absorbing materials used in muffler construction are fibreglass, steel fibbers or ceramic fibbers. Fiberglas at high temperatures and high speeds tends to blown out from the absorbent coating and in time, will degrade the acoustic characteristics of the muffler.

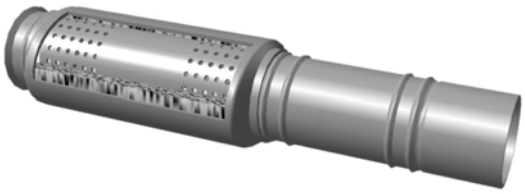
Many muffler design parameters can affect the acoustic behaviour as the back pressure evolutions. Between them, the most important are the chamber sizes, the number and diameter of the perforations, tube diameters, wall thickness, and the offset position of the tubes in respect with the muffler centreline, Arbukle (2002). Same rules must be kept in mind when design a muffler.

Hence, the varying size chambers each have their own noise attenuation characteristics. More particularly, the small chambers are efficient in attenuating high frequency noise, while the larger chambers tend to be effective in attenuating low frequency noise. However, the resonance chamber is slightly larger than either expansion chambers.

The perforations of the tubes in the region of the resonance chamber contribute to the sound attenuation of the muffler. The size and density of these holes must be selected to achieve the desired attenuation of low frequency noise produced by the exhaust gases passing through the tubes.

High frequency tuning chamber can be obtained with little space consumption by surrounding the central tube portion by a solid wall, Lee (2001), generally having a circular or tubular structure as can be seen from Fig.3.

Fig.3: High frequency tuning chamber



The external added tubular member is provided with pinches adjacent fixed in the tube rims in order to achieve a secure positioning. The inters pace between the tube and the high frequency tuning chamber wall is filling with a sound absorbing material as fibreglass.

Modelling equations

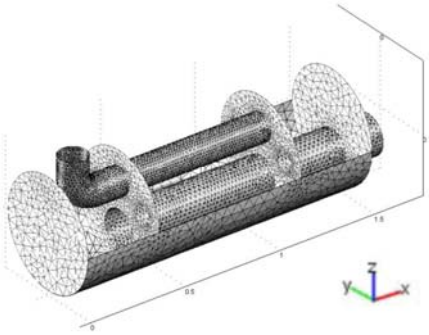
The model equation most frequently used in muffler simulation is a slightly modified Helmholtz's relation for acoustic pressure, p_{ac}:

$$\nabla \cdot \left(-\frac{\nabla p_{ac}}{\rho} \right) - \frac{\omega^2 \cdot p_{ac}}{c_s^2 \cdot \rho} = 0 \tag{1}$$

where ρ is the exhaust gases density which must be explicitly considered in cases that variations in density in different material exist, c_s is the sound speed and $\omega = 2 \cdot \pi \cdot freq$ being the angular frequency. This equation must be adapted to the boundary conditions, which include the external and internal walls of the muffler.

For this reasons, modelling process begins with the geometry design of the muffler in 3D space. We can use for that a lot of CAD programs like SolidWorks (used in this case), ProEngineer, Mechanical Desktop, CATIA, which can generate an output file in one of the graphical format accepted from FE meshing programs (igs, iges, stl, vrm, etc.). All these programs offer the meshing options for the 3D geometries with different levels of accuracy and refinement. In Fig.4 is shown the meshing used in FE modelling for the selected muffler geometry.

Fig.4: Meshing geometry for the tree chambers muffler



Tree different boundary equations are necessary for the outer wall of the muffler, Davis (1980), at the baffle walls between the expansion and resonator chambers, and for the tubes walls. The sound pressure variables are noted for these bounds with p_{c1}, p_{c2}, respectively p_p. At the outlet boundary, the radiating wave plane is described by equation:

$$\left(-\frac{\nabla p}{\rho}\right)\cdot \mathbf{n} - \frac{i\cdot\omega}{c_s\cdot\rho}\cdot \mathbf{p} = 0 \tag{2}$$

At the inlet boundary is a combination of incoming and outgoing plane waves described with equation:

$$\left(-\frac{\nabla p}{\rho}\right)\cdot \mathbf{n} - \frac{i\cdot\omega}{c_s\cdot\rho}\cdot \mathbf{p} + 2\cdot\frac{i\cdot\omega}{c_s\cdot\rho}\cdot \mathbf{p}_0 = 0 \tag{3}$$

where p_0 is the outer pressure applied at the muffler input and ***i*** is the imaginary unit.

Replacing variables with the notes one results the following equations:

$$\nabla\cdot\left(-\frac{\nabla p_{c1}}{\rho_0} + q_s\right) - \frac{\omega^2\cdot p_{c1}}{c_s^2\cdot\rho_0} = 0 \tag{4}$$

for the expansion chambers with ρ_0 =1.25, $c_s = 343\ m/s$ and q_s dipole source. Similarly for the resonance chamber:

$$\nabla\cdot\left(-\frac{\nabla p_{c2}}{\rho_0} + q_s\right) - \frac{\omega^2\cdot p_{c2}}{c_s^2\cdot\rho_0} = 0 \tag{5}$$

and for the pipes:

$$\nabla\cdot\left(-\frac{\nabla p_p}{\rho_0} + q_s\right) - \frac{\omega^2\cdot p_p}{c_s^2\cdot\rho_0} = 0 \tag{6}$$

In order to appreciate the noise attenuation, a damping variable is defined as the ratio between the acoustic energies on the muffler outlet and inlet using relation:

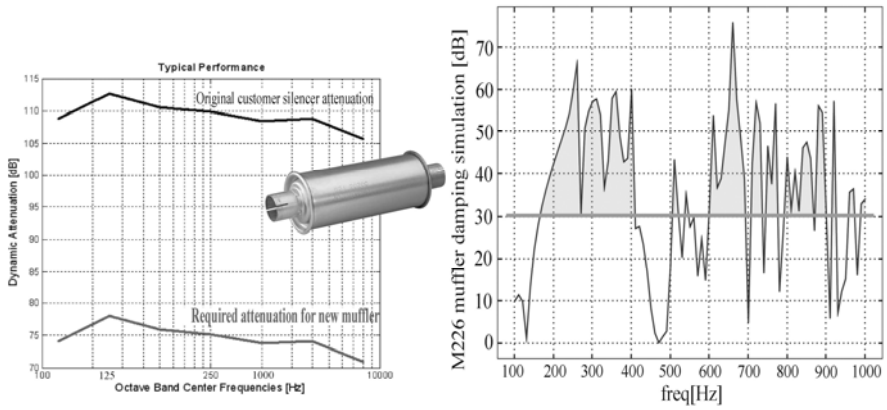
$$ac_d = 10 \cdot \log\left(\frac{w_{outlet}}{w_{inlet}}\right) = 10 \cdot \log\left(\frac{\int_{\partial\Omega} \frac{|p_{out}|^2}{2 \cdot \rho \cdot c_s} \cdot dA}{\int_{\partial\Omega} \frac{|p_0|^2}{2 \cdot \rho \cdot c_s} \cdot dA}\right) \quad (7)$$

Simulation results

The objectives ob this project consist in founding muffler architectures, which will improve the existing customer silencer by at least 20 dB. As can be seen from Fig.5 It must be known that a coarse meshing as can be seen in fig. 4 implies 29182 elements and 47776 degree of freedoms and the simulation time on a Pentium 4, 2.8 GHz with 1 Gb memory is approximately 5 hours without the consideration of tubes perforations. The frequency range was 100 – 1000 Hz with 10 Hz working interval. In normal meshing mode, the number of elements is 53836 and it became 80461, 109769 and 178933 for the fine, finer, respectively extra fine meshing mode necessary to simulate the perforations in tubes. All this resolutions beginning with the normal mode override the computing and memory capacities and are not possible to be run on the existing computer.

It must be known that a coarse meshing as can be seen in fig. 4 implies 29182 elements and 47776 degree of freedoms and the simulation time on a Pentium 4, 2.8 GHz with 1 Gb memory is approximately 5 hours without the consideration of tubes perforations. The frequency range was 100 – 1000 Hz with 10 Hz working interval. In normal meshing mode, the number of elements is 53836 and it became 80461, 109769 and 178933 for the fine, finer, respectively extra fine meshing mode necessary to simulate the perforations in tubes. All this resolutions beginning with the normal mode override the computing and memory capacities and are not possible to be run on the existing computer.

Fig.5: Dynamic attenuation for the customer muffler



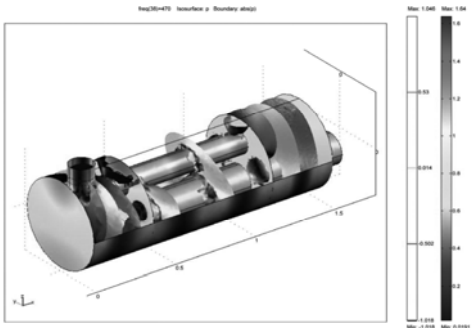
The attenuation characteristic for the proposed muffler is depicted in figure 6. It can be seen that the 30 dB objective can be reached for most of the frequency ranges, the worse behaviour being recorded in the 400-500 Hz range with the 470 Hz the resonance frequency. This plot reveals that the damping is better at higher frequencies with the exception of several deep peaks throughout the selected frequency range. The dips correspond to the resonance frequencies for different parts on the muffler system.

By choosing adequate sizes for the tree chambers, these levels can be significantly reduced. It must also consider the attenuation in the low frequency range added by using the resonance tube perforations and absorption materials.

In order to enhance attenuations in frequencies higher than 900 Hz, additional piggyback chamber like that of Fig. 3 could be used. Better results are obtained by replacing the muffler wall fibreglass coating with steel or ceramic fibbers but the production prices will be higher.

The acoustic pressure plot varies with the resonance frequency selected, Katari (2004). For, example, at the 470 Hz the pressure plot is shown in Fig.6 with the real values of the pressure being plotted as isosurfaces, and the absolute value of the pressure being displayed as a boundary plot on the inner walls of the muffler.

Fig.6: Projection on the x-y plane of the acoustic pressure solution at 470 Hz resonance frequency



The dip in the damping around the 470 resonance frequency is caused by the resonance in the central chamber 5. For other resonance frequencies it can be seen the resonance in the expansion chambers, for example in Fig.7 for the 590 Hz, and Fig.8 for 700 Hz.

Fig.7: Projection on the x-y plane of the acoustic pressure solution at 590 Hz resonance frequency

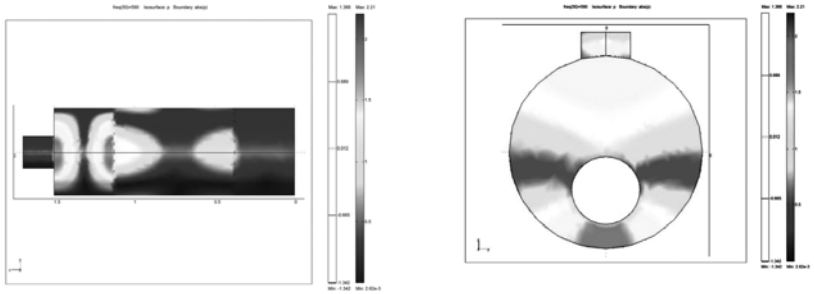
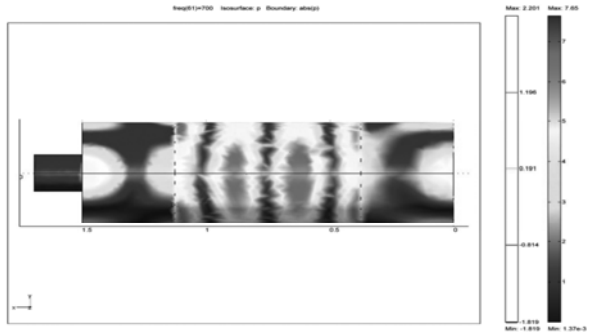


Fig.8: Projection in x-y plane of the acoustic pressure solution at 700 Hz resonance frequency



Conclusions

The advantages of the finite element simulation as a design tool in the muffler design become clear, especially its accuracy in all frequency range and its resultant high reliability and availability, as well as its ability to record all the negative resonance frequencies.

The measure range of 100-1000 Hz with 10 Hz tick interval is sufficient to determine the muffler attenuating behaviour in most disturbing acoustic interval.

Accurate resultants can be obtained without the time, material and cost spends only by replacing some programming parameters in the computer system modeller. Test and analysis time has been short so dramatically that development engineers must use these FE simulations extensively.

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Projet pilote du Touring Club Suisse: Rouler au gaz naturel

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Résumé

L'objectif de l'essai pilote était de tester l'aptitude à l'usage quotidien des voitures au gaz, surtout le comportement en mode «gaz», l'autonomie, le réseau de stations, le processus de remplissage et les réactions du public. L'essai a été effectué dans 15 sections du Touring Club Suisse (TCS) avec 26 voitures. Deux questionnaires ont livré des appréciations supplémentaires. Il n'y a pratiquement pas de différences dans l'utilisation entre l'essence et le gaz. Le réseau de stations à gaz en plaine est suffisant pour pouvoir toujours rouler au gaz. Il existe (trop) de systèmes différents entre les stations-service et surtout entre les pistolets. Les Fiat (Multipla et Punto) et l'Opel Zafira ont une motorisation trop faible. Le rayon d'action au gaz est un peu modeste, en combinaison avec l'essence très bon. Le public considère l'utilisation du gaz comme dangereuse (risque d'explosion). Toutes les voitures au gaz testées peuvent être utilisées dans la vie quotidienne.

Mots-clefs : *Bi-fuel, carburant, consommation de carburant, gaz naturel, voiture au gaz naturel, voiture bivalente.*

Abstract

Pilot project for Touring Club Switzerland (TCS): Driving on natural gas.

The objective of this pilot test was to test the suitability for daily use of natural gas powered cars and thus provide the public with the means for deciding whether to opt for passenger cars with two power supplies. These so-called bivalent vehicles can run on natural gas as well as on gasoline. They are less pollutant when running in natural gas mode than in gasoline mode. The test above all focused on vehicle behaviour in gas mode, its mileage, the service station network, the filling process, public reaction and drivers' attitudes before and after having used a gas-powered car.

This practical test was performed in 15 sections of the TCS with 26 cars. The cars were subjected to very different conditions: some were driven as professional vehicles while others as demonstration vehicles. For a period of one year starting in June 2004, 8 Fiat Puntos, 3 Fiat Multiplas, 10 Opel Zafiras and 5 Volvo S60s were driven on Swiss roads.

Two questionnaires, one distributed to the participants at halfway and the other at the end of the project, provided information on the cars, natural gas stations, filling and general observations as well as proposals for improvements to promote sales of natural gas powered vehicles.

There was almost no difference between using gasoline and gas. 87% of the mileage of the 26 cars was done with natural gas. The network of gas stations in low-lying areas was sufficient to allow cars to drive on gas all the time. There were (too many) different systems at the service stations and above all differences between pistols. The Fiat Multipla, Fiat Punto and Opel Zafira were too low powered. The driving range with gas is rather low, but very good in combination with gasoline. Drivers quickly became used to driving on natural gas. The public considered the use of gas as dangerous (risk of explosion). All the gas-powered cars tested can be used on a daily basis. The most important criteria for purchasing a gas-powered car are an enough powerful engine, a greater driving range with natural gas, gas stations also in surrounding regions, a larger range of gas-powered models.

Key-words : *Bi-fuel, fuel, fuel consumption, natural gas, natural gas powered car, bivalent car.*

Objectifs

La branche suisse du gaz naturel a décidé de porter le nombre de stations distribuant du gaz naturel à 100 d'ici à 2006/07. Cette mesure devrait entraîner une sensible augmentation de l'effectif de voitures fonctionnant au gaz.

Le projet d'étendre le réseau de stations offrant du gaz naturel a incité le Touring Club Suisse (TCS) à tester l'aptitude des voitures au gaz à l'usage quotidien.

Avec cet essai pilote, le TCS offre à ses membres et à un large public les bases de décision qui leur permettront d'opter éventuellement pour une voiture de tourisme à double alimentation. Ces véhicules dits bivalents peuvent rouler aussi bien au gaz naturel qu'à l'essence. Lorsqu'ils fonctionnent au gaz, le cas sans doute le plus fréquent, ils sont encore moins polluants qu'en mode essence. Dans cet essai pratique, le TCS s'intéresse surtout au comportement des voitures fonctionnant au gaz, à leur autonomie avec différents modes de conduite, au réseau de stations, au processus de remplissage du réservoir de la voiture, aux réactions du public ainsi qu'à l'attitude du conducteur avant, pendant et après avoir utilisé une voiture au gaz.

Méthode

Cet essai pratique a été effectué dans 15 sections du TCS avec 26 voitures (8 Fiat Punto, 3 Fiat Multipla, 10 Opel Zafira et 5 Volvo S60). Ces voitures étaient soumises à des régimes très différents: certaines roulaient comme voiture de service et d'autres comme voiture de démonstration.

Pour simplifier l'organisation du projet, les voitures ont été mises à disposition aux sections du TCS avec un loyer mensuel forfaitaire «tout

compris». Y inclus étaient les frais de location, les impôts automobiles, les assurances casco complète et responsabilité civile, les vignettes autoroute, les pneus d'hiver et les frais administratifs à l'exclusion des frais du carburant.

Les frais directs étaient couverts par les loyers mensuels pour chaque voiture et par une subvention de gazmobile sa, centre de compétence suisse pour l'utilisation du gaz naturel comme carburant. Les importateurs Opel, Fiat et Volvo ont apporté leur contribution au projet en proposant leurs voitures à des conditions de location particulièrement avantageuses.

Tous les véhicules étaient immatriculés dans le canton de Lucerne avec des plaques LU 200 0xx. Ils étaient tous peints en gris métallisé et portaient des autocollants «TCS roule au gaz naturel» et «www.vehiculeagaz.ch» (en allemand : «TCS fährt Erdgas» et «www.erdgasfahren.ch»).

Figure 1 : Lancement du projet (juin 2004)

Figure 1 : Start of the project (june 2004)

Figure 2 : Lancement du projet (juin 2004) - Edgar Schorderet, président central du TCS

Figure 2 : Start of the project (june 2004) - Edgar Schorderet, President of TCS

Une personne, le plus souvent le conducteur le plus fréquent, était responsable pour une voiture. Le soutien technique était assuré par 12 consultants techniques, qui ont été nommés par l'industrie gazière de la région.

Une fois par mois, chaque responsable de voiture a envoyé au Centre technique du TCS à Emmen/Lucerne un rapport pour sa voiture contenant les kilomètres parcourus, la consommation de carburant et les événements spéciaux.

Toutes les voitures étant immatriculées au nom du Centre technique du TCS à Emmen, les amendes envoyées au TCS ont été transmises aux responsables de voiture «pour règlement direct».

Le 25 juin 2004, le projet a été lancé avec un événement médiatique au Centre technique du TCS à Füllinsdorf près de Bâle qui possède la première station à gaz du TCS (figures 1 et 2). L'essai d'une année s'est terminé en juin 2005.

Résultats

1. Organisation

La majorité des responsables de voiture s'est comportée de manière coopérative. Ils ont répondu aux petites tâches demandées (remise des rapports mensuels, questionnaires remplis et renvoyés). Certains par contre ont répondu seulement après plusieurs avertissements.

Au total seulement 8 incidents ont été notés avec les véhicules (4 accidents légers et 4 dégâts de bris de verre).

L'état des véhicules a beaucoup varié lors de la restitution et des travaux supplémentaires ont été nécessaires dans certains cas.

2. Prestations kilométriques et consommation de carburant

Au total les 26 véhicules ont parcouru près de 400'000 km. Le plus grand nombre de kilomètres a été fait avec une Volvo S60 (31'400 km), le moins avec une Fiat Punto (5'500 km). En moyenne, chaque véhicule a parcouru 15'400 km par année.

La consommation totale a été de 4'200 litres d'essence et de 19'600 kg de gaz naturel, ce qui équivaut a une quantité d'essence de 29'400 litres. Cela veut dire que les 26 véhicules ont parcouru 87% des trajets avec du gaz naturel.

Les prix du gaz naturel étaient entre CHF 1.38 (contenant une partie de biogaz, neutre en CO_2 et pour cela libéré de l'impôt sur les carburants) et CHF 2.06 par kilo de gaz. 1 kg de gaz naturel correspond à 1.5 litre d'essence. Les prix correspondent donc à un prix au litre d'environ CHF 0.95 à 1.38. En moyenne, le prix du kilo de gaz naturel s'est situé environ à CHF 1.55/kg resp. 1.04/l.

Voici la consommation moyenne de carburant par modèle (sur la base de la quantité d'essence + quantité de gaz naturel reconvertie en équivalent essence)

Opel Zafira	7.88 l/100 km	(Min. 7.00	Max. 8.88)
Fiat Punto	6.83 l/100 km	(Min. 4.89	Max 8.33)
Fiat Multipla	9.50 l/100 km	(Min. 9.11	Max. 9.72)
Volvo S60	10.12 l/100 km	(Min. 9.30	Max. 11.11)

Une répartition spécifique de la consommation en gaz naturel et essence n'était pas possible, car cela aurait demandé un recensement détaillé du kilométrage parcouru avec chacun des deux carburants. Ceci n'était malheureusement pas possible dans le cadre d'un tel projet.

Figure 3 : Fiat Punto

Figure 4 : Fiat Multipla

Figure 5 : Opel Zafira

Figure 6 : Volvo S60

3. Appréciation des participants (questionnaire)

Les 42 questionnaires renvoyés (partiellement plusieurs questionnaires par voiture) permettent les appréciations suivantes:

Réaction de l'entourage

- En général très positif
- Doutes à cause du risque d'explosion des bouteilles de gaz (des tests de crash et des essais de combustion ont montré que ces doutes ne sont en aucun cas justifiés)
- Doutes à cause de l'admission des voitures au gaz naturel dans les parkings souterrains. Des voitures de tourisme au gaz naturel (CNG) sont admises sans restriction, l'accès des voitures au gaz liquifié (LPG) par contre est strictement exclu.
- Stations à gaz naturel
- Réseau de stations à gaz très différent selon la région
- Stations à gaz partiellement difficiles à trouver
- Instruction pour le remplissage facile à comprendre
- Trop de systèmes différents de pistolets

- Remplissage sans problèmes
- Grandes différences de prix entre les stations à gaz
- Véhicules en général
- Pratiquement pas de différences dans l'utilisation entre l'essence et le gaz
- Fiat Punto, 1'200 ccm (figure 3)
- Bonne impression générale (forme carrosserie, intérieur, boutons de commande)
- Bonne relation coûts-profits
- Coffre trop petit (à cause des bouteilles de gaz)
- Motorisation trop faible
- Accélération et reprise un peu faible
- Un peu moins bruyant au régime avec gaz qu'avec essence
- Rayon d'action avec gaz naturel un peu petit (selon constructeur: 220 km au gaz, 750 km avec essence)
- Fiat Multipla, 1'600 ccm (figure 4)
- Bonne impression générale (forme carrosserie, intérieur, boutons de commande)
- Carrosserie ne faisant pas l'unanimité
- Coffre assez grand (bouteilles de gaz sont placées sous le plancher)
- Bon rayon d'action avec gaz naturel (selon constructeur: 420 km au gaz, 430 km avec essence)
- Motorisation trop faible
- Accélération et reprise un peu faible
- Consommation un peu haute
- Opel Zafira, 1'600 ccm (figure 5)
- Bonne impression générale (forme carrosserie, intérieur, boutons de commande)
- Bonne relation coûts-profits
- Voiture de famille pratique
- Motorisation un peu faible
- Accélération et reprise un peu faible
- Rayon d'action moyen avec gaz (selon constructeur: 350 km au gaz, 180 km avec essence)
- Volvo S60, 2'400 ccm (figure 6)
- Très bonne impression générale (forme carrosserie, intérieur, boutons de commande)
- Très bonne relation coûts-profits

- Limousine de voyage agréable et confortable
- Motorisation suffisante
- Bonne accélération et reprise
- Très bonne insonorisation
- Rayon d'action petit avec gaz naturel (selon constructeur: 230 km au gaz, 320 km avec essence)

4. Echo médiatique et activités d'informations

Ces essais pratiques ont provoqué un grand nombre d'articles dans les médias (divers journaux, magazines, journal Touring, bulletins de section, pages internet du TCS et autres, SF2 (télévision suisse) et TV régionales). Plusieurs interviews à la radio ont également informé les auditeurs.

5. Essai de crash et d'incendie du TCS et de l'ADAC

En automne 2004 le TCS et l'ADAC (club automobile allemand) ont effectué un test de crash et d'incendie avec une Opel Zafira CNG (au gaz naturel). Lors de ce test effectué selon le standard d'Euro NCAP, l'Opel Zafira CNG a obtenu 9 points sur 16 au maximum. Ainsi le résultat du modèle CNG est comparable à celui du modèle de base qui a obtenu 10 points. Seules les contraintes sur les occupants sont légèrement plus élevées à cause du poids supérieur du modèle CNG qui provoque une déformation plus importante de l'habitacle du véhicule. Les fixations des bouteilles à gaz restent à leur position initiale et les protègent ainsi de façon idéale contre tout dommage. Même après le crash frontal tout le système reste entièrement étanche. Les soupapes de sécurité ferment complètement les bouteilles et dans le pire des cas, seulement une petite quantité de gaz contenue dans les conduites peut s'échapper.

Aussi dans le cadre d'un test d'incendie très sévère, où le véhicule a complètement été détruit, les systèmes de sécurité ont parfaitement fonctionné. Le gaz a brûlé de façon contrôlée, évitant ainsi une augmentation dangereuse de la pression dans les bouteilles.

6. Critères pour l'achat d'une voiture de tourisme à gaz naturel (questionnaire)

En août 2005, après la clôture du projet, tous les responsables de véhicule ont reçu un deuxième questionnaire. Ce dernier contenait 19 critères qui devaient être classés selon leur importance.

Après évaluation des 36 questionnaires et à la question «Que faudrait-il améliorer afin de vous motiver à acheter une voiture au gaz naturel, resp. bivalente essence/gaz ?», voici les 10 points les plus importants:

- plus de stations-services dans le Plateau
- motorisation plus puissante
- autonomie plus grande avec le gaz naturel
- stations-service aussi en région rurale

- gamme de modèles à gaz naturel plus grande
- prix du gaz
- aide financière lors de l'achat (contribution d'encouragement)
- plus de stations-service à l'étranger
- informations concernant la sécurité (explosion)
- systèmes de remplissage (pistolet) standardisés

Conclusions et recommandations

Toutes les voitures à gaz utilisées peuvent être utilisées dans la vie quotidienne.

- La Fiat Multipla, la Fiat Punto et l'Opel Zafira ont une motorisation trop faible.
- Le rayon d'action avec le gaz est modeste, par contre en combinaison avec l'essence très bon.
- Les conducteurs se sont rapidement habitués à rouler au gaz naturel.
- Le réseau total de stations à gaz est suffisant pour pouvoir toujours rouler au gaz.
- Grandes différences de prix du gaz entre les stations ce qui est difficile à comprendre.
- Il existe (trop) de systèmes différents entre les stations-service et surtout entre les pistolets.
- Le public considère l'utilisation du gaz comme dangereuse (risque d'explosion).
- Le test de crash et d'incendie du TCS et de l'ADAC démontre que le danger d'explosion n'est pas plus élevé pour un véhicule au gaz naturel.
- Le projet pilote a suscité beaucoup d'intérêt et provoqué un écho médiatique considérable.
- Surtout lors d'un kilométrage annuel élevé, rouler au gaz est une alternative économiquement très intéressante en comparaison avec un véhicule diesel ou essence.

1. Recommandations à la branche suisse du gaz naturel

Continuer d'augmenter le nombre de stations-service, surtout en région rurale.

- Mieux communiquer le prix avantageux du gaz naturel.
- Indiquer le prix du gaz naturel sur les panneaux des stations-service en CHF par litre d'équivalent essence et non pas en kilo.
- Mieux communiquer et standardiser les aides financières proposées lors de l'achat d'un véhicule roulant au gaz.

- Standardiser les systèmes, resp. pistolets de remplissage.

2. Recommandations aux importateurs suisse d'automobiles

Offrir des modèles avec une motorisation plus puissante.

- Augmenter le rayon d'action pour rouler au gaz.
- Augmenter la gamme de modèles pouvant rouler au gaz en général.

Remerciements

Les auteurs remercient tout particulièrement gazmobile sa ainsi que les importateurs de Fiat, Opel et Volvo pour leur aide financière.

The acceptance of an acceleration advisory tool for more energy-efficient car driving

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Abstract

The traffic sector is responsible for a large proportion of all energy used, as well as the total emissions. The speed and acceleration profiles of drivers have significant effects on the emission from vehicles. A driver-support tool might thus have a positive effect leading to a decrease in emissions and fuel consumption. In this study a product called Traffic Budgeter (TB) was tested in vehicles used by the Swedish postal service. The TB gives advice through resistance in the accelerator pedal when the driver tries to accelerate at an undesirable level of acceleration. The aim of this study was to investigate whether drivers accepted the product and how they used it. The TB was installed in four postal delivery cars used by 20 postmen working in three districts. Questionnaires were filled in by the drivers before and after the test period, and three in-depth interviews were carried out to determine the level of acceptance and usage of the advisory tool.

Keywords*: acceptance, fuel consumption, driver support tool, postal delivery vehicle,*

driving behaviour, qualitative research and data logger

Introduction

Various driver-support tools are becoming more common in today's vehicles. The type of tool varies from those that provide the driver with information, for example, a navigator, to more complex systems that may even take control of the vehicle in dangerous situations (Hancock and Parasuraman, 1992).

The importance of providing adequate and accurate information about the product when drivers are introduced to a new system is enormous. A prerequisite for the successful introduction of new in-vehicle technology is acceptance by the driver. If the drivers do not accept the new product they may not use it, and the economic investment is wasted (van der Laan et al., 1997). According to Papillon (2004) there are three important components that determine drivers' acceptance of new techniques in vehicles: the aim of the

technique, knowledge about the technique, and the drivers' attitude to being supervised by the system and the matter of personal privacy.

When discussing driver-support tools most people first think of IT support to increase traffic safety or facilitate logistics. Another application, not yet studied to any large extent, is in environmental support, for example, for reducing fuel consumption and emissions. Research shows that where, when and how one drives have great importance on the fuel consumption. A study in Lund, southern Sweden, shows that 46% of all journeys longer than 5 minutes were not driven in the most fuel-efficient way (Ericsson et al., 2005) and according to Ericsson (2000) the street type in combination with driver category has a significant influence on driving behaviour.

About five years ago, the majority of the postmen employed by the Swedish postal service (Posten AB), were trained in eco-driving to reduce fuel consumption. Initially there was a decrease in fuel consumption, but after a while the drivers returned to their old driving habits (Sollerud, 2005). This led to the question of whether support tools were available to reduce fuel consumption, and the joint project AAP (Acceleration Advisory tool Postal), between Posten AB, the Lund Institute of Technology at Lund University and Imita AB, which was started during spring 2005. The aim of the AAP project was to evaluate the Traffic Budgeter which aims to reduce the fuel consumption thought preventing drivers from accelerating too rapidly.

According to El-Shawarby (2005) and Ericsson (2001) frequent use of high acceleration rates over a driven distance has an increasing effect on fuel consumption and emissions. According to El-Shawarby (2005) a high rate of acceleration results in a rich fuel-to-air ratio, thus bypassing the catalytic converter and increasing vehicle emissions. On the other hand, eco-driving courses recommend drivers to accelerate comparatively fast up to the desired speed (Huldén, 2000). According to Johansson et al. (1999) the driver should accelerate in each gear until the engine speed reaches the point at which the engine torque is at its highest, when practising eco-driving.

This study focused on the acceptance of the Traffic Budgeter in the AAP project. The aim was to determine if the drivers accepted the TB and to evaluate how they used it. To do this, questionnaires was filled in by the drivers before and after the test period and three in-depth interviews were carried out to measure the acceptance and usage of the advisory tool. The results of the questionnaires before and after the test period show the attitudes based on expectations and experience, which according to Levelt (1997) usually differ. The main aim of the interviews was to obtain a deeper qualitative understanding of the drivers' opinions regarding their acceptance and use of the tool.

Methods

The Traffic Budgeter is an advisory tool that causes resistance in the accelerator pedal when the driver tries to accelerate too rapidly. It is possible to press by this resistance if necessary for traffic safety reasons. Each car was equipped with a data logger that registered the speed, time, date, engine

speed, distance and coordinates with 5 Hz. Data were recorded in four cars in three postal districts for 6 weeks without the advisory tool being activated and 6 weeks with the tool activated. During this time a total of 20 drivers were involved in the trial. Before setting off in the vehicle, the driver was instructed to enter a personal identification number, a route number and a code for the weather. The differences in driving patterns and fuel consumption were analysed.

According to a literature study by van der Laan (1997) there is no standard way of measuring drivers' acceptance. The number of methods of measurement is almost as many as the number of studies. In this study, a questionnaire before and after the trial, and three interviews were performed.

1. Questionnaire

The postmen were asked to fill in questionnaires before and after the test. The questionnaires were distributed and collected by the postal company and the response rate was high; in total 19 before and 11 after the study. The difference before and after the study can be explained by the fact that not all the postmen used a car equipped with the TB.

The questions were mainly of closed format. The choice between open and closed format depends on the general research problem (Rosengren et al., 1992). In this study, the open questions were studied in the interviews. The layout and design of the questions were similar to those employed in evaluating the ISA (Intelligent Speed Adaptation) system (Falk et al., 2002). Most of the questions were answered on a scale from 1 to 5, where 1=very bad, …, 5=very good (an Osgood scale), i.e. the response scale is bipolar (Forward, 2006). The questionnaire was divided in three main topics: general questions about fuel consumption and emissions from vehicles, questions about the acceleration advisory tool and some personal questions. The final questionnaire had 14 questions, many of which had subsections.

Interviews

To obtain a deeper understanding of how the drivers used and accepted the TB, the questionnaires were complemented with interviews. The number of interviews was limited to three test drivers due to time constraints. When constructing the questions for the interviews, some of the results from the questionnaire conducted before the test period were used.

1. The Interview Guide

The structure of the questions was to some degree meant to be open-ended, i.e. the researcher sought the individual's experience of a phenomenon's qualities and knowledge of consistence that just in some way is controlled by the researcher. Some parts of the questions were meant to be half closed, i.e. the researcher asked for the interviewee's opinion in more or less predefined terms and the relation between the different concepts (Lantz, 1997). In this study the questions about acceptance were mostly open-ended and the questions about usage mostly half closed.

At the beginning of the interview some general questions were asked to obtain background variables (Lantz, 1997) about employment at the postal service and how the company had developed. The idea was to make the interviewee relaxed and comfortable by talking about something familiar, but also to get the feeling if the test period led to any specific changes for the interviewee. The next part of the interview was intended to provide a better understanding of the occupation and the routines, for example, the different routes driven, how the cars were used and maintained, but also about the social relations at work. Later it was asked whether the TB had been discussed at work. The questions were asked from different perspectives based on: 1) the thoughts and experience of the interviewee regarding the TB, 2) the thoughts and experience other users had about the TB according to the interviewee, 3) how the interviewee described the TB to people outside the company and what opinion they formed about the TB according to the interviewee, and 4) whether the TB had affected other road users and the way in which this had been manifested. The idea of the indirect questions with different perspectives was to investigate and verify the interviewee's own opinion (Kvale, 1997). At the end of the interview a couple of summarizing questions were asked.

2. The Selection of Interviewees

The interviewees were chosen from among the drivers who had been driving with the TB, i.e. a criterion selection (Bengtsson et al., 1998), and one person was chosen from each district who had driven the most in that district, i.e. a strategic selection (Bengtsson et al., 1998). Districts were chosen to obtain a broad point of view regarding the acceptance and usage of the TB. It may be hypothesized that the test drivers' opinion could be influenced by the other drivers in the district. The gatekeeper, i.e. the mediator between the researcher and the interviewees (Bengtsson et al, 1998), was the director of the district office.

3. The Analysis

Each interview took about an hour and was recorded on tape. Afterwards they were transcribed. As the aim was not to investigate sociolinguistic aspects, "umms" and "ahhs" etc. were not transcribed (Kvale, 1997).

The answers obtained from the interviews were read through to find similarities, differences, contradictions, unexpected answers and important key words that the interviewee used more than once. A matrix was created with 19 fields of study on the y-axis and the three interviewees on the x-axis. Concise interview expressions used by each interviewee were then entered into the matrix, i.e. concentrations of sentences (Kvale, 1997). The fields of study in the matrix were divided into the test drivers' acceptance and their usage of the TB. To protect the identity of the interviewee and to make for easier reading, the quotes given below have been slightly edited while retaining their meaning.

Results

The results presented below regarding the drivers' acceptance and use of the TB is the outcomes of the questionnaire before and after the trial, and three in-depth interviews.

The questionnaire conducted before the trial revealed that the general attitude towards an acceleration advisory tool was neutral or fairly good, Figure 1. After the trial the attitude was less positive, decreasing from a mean value of 3.37 to 2.45 (1=very bad, 2=fairly bad, ..., 5=very good). Upon comparing these results with the frequency of driving with the TB it is seen that drivers who used the test car more frequently were more positive than those who tried the system only one to five times, Figure 2.

Figure 1. Responses to the questionnaire regarding attitude to the tool before and after the test period.

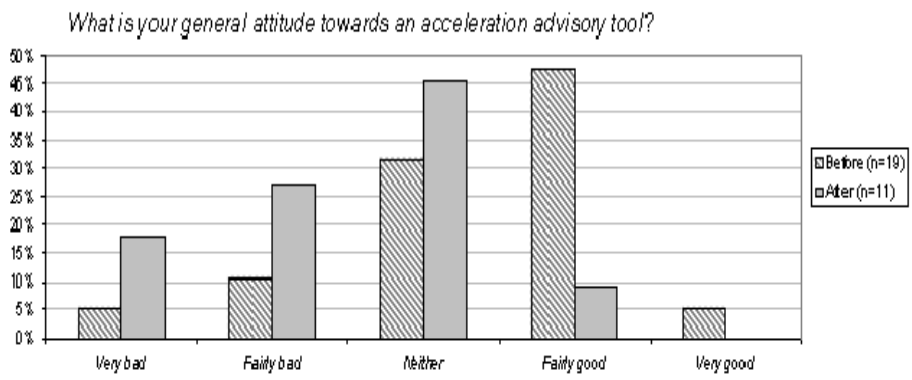

Figure 2. The relation between a positive attitude and the number of times the drivers had tried the system. On the y-axis 1=very bad, 2=fairly bad, 3=neither, 4=fairly good and 5=very good.

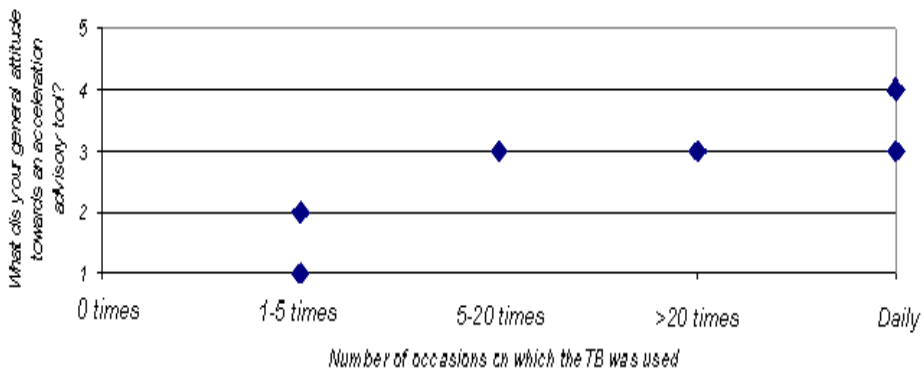

Figure 3. Mean values of eight factors from questionnaires before and after the test.

In the questionnaires the drivers gave their opinions on eight specific factors and whether they believed that these factors would change after the TB had been installed, Figure 3. The mean value obtained from the questionnaire conducted before the trial showed that the drivers believed that driving time would increase, while traffic safety, irritation and stress would remain essentially unchanged, the feeling of being controlled would increase, the enjoyment of driving would decrease, the level of alertness would be unchanged and the fuel consumption would decrease. A study with the Wilcoxon signed rank test was performed to determine if the opinions regarding these factors showed any significant changes after the test period with the TB. Ten of the 11 completed questionnaires after the test could be used in the Wilcoxon test. Of the eight factors, only traffic safety (decreased) and fuel consumption (increased) showed significant ($P<0.1$) differences between the questionnaires before and after the test period.

The in-depth interviews provided a more balanced picture of what makes drivers state that the TB led to a lower level of traffic safety after the test. In both the questionnaires and the interviews one district, located in the third largest city of Sweden, was responsible for the decrease in traffic safety. In situations with high traffic flow, when the distance between cars is small, the resistance of the TB was described as “stubborn” and “annoying” and also in some situations as “dangerous” by the interviewee, i.e. the driver was worried that the car behind him would run into him. Another situation in which the interviewee felt unsafe was when he wanted to adapt to the general traffic flow during rush hours. These situations resulted in an increase of pressing by the resistance. The other two interviewees, who were driving mostly in rural areas or a residential district, did not agree with the opinion that the TB made it difficult to adapt their speed when turning into another street or that it in other ways felt unsafe to drive with the TB installed. The following quotation is from an interviewee who mostly drives in rural areas: “*In situations when I needed full acceleration it’s been alright. It hasn’t restrained me at all*”.

Even though the resistance of the accelerator pedal was described as stubborn and sluggish, it came to light in one interview that driving behaviour become more smooth and calm with the TB installed:

Researcher: "What do you think the general opinion would be if the postal service extended the project and installed a TB in every car?"

Interviewee*: "*There's always opposition to new things. Perhaps there'd be some opposition in the beginning, but I think that after a while they'd get use to it, plus they'd notice that their driving became smoother."

No general rule about when drivers pressed by the resistance could be identified, but some answers in the interviews indicated that this was more frequent when the driver felt that he was in an uncertain situation, was worried about disturbing other road users, or when he was in a hurry. For example, become the press by more frequent when the driver was about to turn onto a road with high traffic flow or when about to overtake. When the distance between stops was short, one interviewee said that there wasn't any point in overriding the resistance.

Why the opinion about fuel consumption changed after the test period is difficult to say. One opinion was that "the fuel consumption of the test car was quite low already before the test started, and it's not possible to decrease the consumption much more".

The use of indirect questions worked well. In almost all questions regarding the views of others they expressed the same opinion as the interviewee, but in one question about what others would think regarding whether the TB would have reduced fuel consumption the interviewee said: *"Since I believe that the system will save fuel, the people I told about it will believe it too".*

Conclusions

This paper describes how postmen accepted and used the Traffic Budgeter. The TB gives advice through resistance in the accelerator pedal when the driver forces the pedal to an undesirable rate of acceleration. Two questionnaires were filled in by the drivers, before and after testing the product for 6 weeks, and three in-depth interviews were conducted.

Results from the questionnaires showed that the general opinion regarding the TB tended to be more negative after the test period. However, when taking into account the extent to which the driver had actually tested the TB, it was found that those who had driven more frequently with the TB installed (> 20 times) tended to be more positive to the system than those who only tried it a few times. From the in-depth interviews it was found that the level of acceptance also seemed to depend on the traffic situation in which the driver usually found himself. In general, it appears that drivers are more positive towards the TB when they are driving in environments with low traffic flow. The

interviewee who often drove in areas with high traffic flow tended to feel anxiety regarding traffic safety and was worried about being run into from behind.

Situations when the drivers more frequently press by the resistance, according to their own opinion, seemed to be when they felt themselves to be in an uncertain situation, were worried about disturbing other road users or when they were in a hurry. Thus, traffic conditions play an important role in the extent to which the driver followed the advisory tool. Drivers also stated that the distance between stops affected their behaviour, i.e. for short distances it did not seem worthwhile to accelerate up to high speeds. Further research will focus on differences in fuel consumption, travel time and other parameters describing driving patterns with and without the TB.

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Emissions measurement in a diesel vehicle operated with diesel/biodiesel blends on a specific driving cycle

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Abstract

In this study, animal fat methyl ester and a commercial automotive diesel fuel (ULSD) were investigated in a diesel vehicle operated in real driving conditions at proportions of 2 % and 5 % respectively. The fuels were characterised by determining their major physicochemical properties according to the European Standards EN 590 and EN 14214. A light duty passenger vehicle with diesel engine of 2.0 litre displacement was utilized to conduct on-board emission measurements on a specific driving route infrastructure including altitude differentiation, humps, and various alternations on driving conditions, such as frequent accelerations and decelerations. This study demonstrated that the addition of biodiesel in a conventional diesel engine substantially reduces emissions of smoke opacity and unburned hydrocarbons (HC). On the contrary, biodiesel blends showed an increase in nitrogen oxides (NO_x) emissions, especially at certain parts of the driving route (uphill driving), and fuel consumption with respect to the baseline diesel fuel.

Keys-words*: biodiesel, animal fat methyl ester, diesel engine, exhaust emissions, diesel vehicles, ULSD.*

Introduction

Biodiesel, defined as the mono-alkyl esters of fatty acids derived from vegetable oils or animal fats, is a strong candidate alternative fuel for combustion in compression ignition diesel engines. Biodiesel appears to be the type of fuel that can penetrate to European transport sector the easiest, given that no significant changes in the infrastructure (refueling stations, fuel storage and distribution) are needed. More importantly, changes in the automotive

combustion engine technology are not required, provided that biodiesel is mixed with conventional diesel, up to a certain blending ratio.

Emissions from vehicles are affected by the driving patterns which mainly depend on traffic conditions. “Driving Cycles” are used to assimilate driving conditions on a laboratory chassis dynamometer for the evaluation of fuel consumption, the exhaust emissions and emission coefficient. There are two major categories of driving cycles, legislative and non-legislative. According to legislative driving cycles, Exhaust Emission Specifications are imposed by governments for the car Emission Certification. Such cycles are the FTP-75 used in the USA the NEDC used in Europe and the 10-15 used in Japan. Non-legislative cycles, such as, ARTEMIS European driving cycles by Andre (2005) and Athens Driving Cycle (ADC) by Tzirakis et al (2005), find broad application in research for energy conservation and pollution evaluation.

There are two ways of developing a driving cycle. One is composed from various driving modes of constant acceleration, deceleration and speed (like the NEDC and ECE), and is referred as modal or polygonal. The other type is derived from actual driving data and is referred as “real world” cycle. Such cycles are the FTP-75 and the ADC. The real world cycles are more dynamic, reflecting the more rapid acceleration and deceleration patterns experienced during on road conditions. This more dynamic driving in real world conditions results into higher emissions compared to those under the standard emission (modal) test cycles.

In this study, methyl ester from animal fat (AFME) was used as diesel fuel in 2% and 5% blends with a reference diesel fuel which was also used pure. The baseline fuel was an ultra low sulphur diesel (ULSD) fuel containing 15% GTL, available in the Greek fuel market. The reference fuel is complying with the 2008 sulphur content specifications (10 mg/kg maximum) and its major physicochemical parameters were exposed according to the present fuel quality requirements for diesel vehicles (EN 590-Directive 98/70/EC). Neat animal fat methyl ester fulfilled the European Standard EN 14214. For the purpose of this paper, a small size passenger vehicle with IDI diesel engine of 2.0 litre displacement was utilized to conduct on-board exhaust emission measurements in a specific driving route infrastructure including altitude differentiation, humps, and various alternations on driving conditions, such as frequent accelerations and decelerations. The specific real-world driving cycle, which is the peripheral route of the University campus, was developed by recording driving conditions using several instrumented vehicles. The test results proved that the addition of biodiesel into the reference diesel fuel increased NO_x emissions slightly increased fuel consumption with respect to the baseline fuel. It was observed that as the concentration of biodiesel increased the amount of the emitted NO_x was also increased. On the contrary, smoke density (opacity) and unburned hydrocarbons (HC) for both blends were significantly decreased. Especially the HC emission levels were below the measuring accuracy of the gas analyser. This study confirmed that the driving route infrastructure correlated with the emissions of NO_x as they affected by the uphill driving, the altitude, the accelerations and decelerations. To conclude,

some quality parameters of the biodiesel might affect the emissions of NO_x, such as the iodine number and the density of the fuel.

Experimental procedure

1. Test Fuels

The investigation employed a total of three fuels in the present study. A commercial ultra low sulphur diesel fuel (ULSD) containing 15% GTL, from the Greek fuel market complying with the specifications of the EN 590 European standard for the year 2008 (sulphur content 10 mg/kg). This ULSD fuel was produced by severe hydrotreatment of atmospheric gasoil. A possible alternative supply of high quality ultra low sulphur diesel fuel is the synthetic fuel derived from natural gas, via the Fischer-Tropsch synthesis, known as GTL. The GTL process can be summarised as follows: Natural gas is reformed into synthesis gas, which is converted into high molecular weight waxes via the Fischer-Tropsch synthesis. Wax is hydrocracked into lighter product that has very good quality as blending component in the diesel fuel pool. The main advantages of GTL fuel is the zero sulphur content, the zero aromatics content (it contains normal and branched paraffins) and the very high cetane number. Biodiesel blends at proportions of 2% and 5% respectively by volume were also used. The blend ratios were selected based to the principles set in Directive 2003/30/EC of the European Parliament and of the Council, and on the targets Greece set for the penetration of biodiesel (2% v/v in 2005 and up to 5% v/v by 2010). The blends were properly mixed and mechanically agitated prior to each test to ensure fuel homogeneity. The major physicochemical parameters of all fuels examined in this work are presented in Table 1.

2. Test Vehicle

In this study, a passenger vehicle with a 2.0 litre IDI diesel engine was employed to measure the engine performance and the exhaust emissions during practical driving conditions. The engine was 4 cylinder IDI diesel engine equipped with a turbocharger with an inter-cooler system, with bore x stroke of 86.0x85.0 mm, compression ratio of 23.0:1, maximum output of 61 kW/4000 rpm and maximum torque of 174 Nm/2000 rpm.

Table 1: Physicochemical properties of the test fuels.

Property	Test Method	ULSD	AFME	B2	**B5**
Kin. Viscosity at 40 °C	EN ISO 3104	2.83	4.62	2.87	2.90
Dyn. Viscosity at 40 °C		2.31	3.96	2.34	2.37
Density at 15 °C	EN ISO 3675 EN ISO 12185	0.8335	0.8747	0.8336	0.8344
Flash Point (°C)	EN 22719	68	> 120	75	78
Sulphur Content (ppm w)	EN ISO 20846	4	15	5	6
Nitrogen Content (ppm w)	ASTM D 4629	79	148	68	85
Pour Point (°C)	ASTM D 97	- 25	+14	- 28	- 29.5
Cloud Point (°C)	ASTM D 5773	+3	+19	4	7
CFPP (°C)	EN 116	- 19	+10	- 18	-14

Sulphated Ash Content (wt %)	EN ISO 6245	< 0.01	< 0.01	< 0.01	< 0.01
Water Content (ppm w)	EN ISO 12937	93	300	82	105
Distillation Temperature	EN ISO 3405				
IBP (°C)		181		187	189
T 50 (°C)		271		272	276
T 90 (°C)		336		337	340
FBP (°C)		364		365	363
% Recovery		97.6		98.8	97.7
Carbon Residue (w/w %)	EN ISO 1370	1.2	0.0164	0.002	0.0039
Gross Heating Value (cal/g)	IP 12	10695	9553	10662	10561
Iodine Number	EN 14111		61		
Acid Number (mg KOH/g)	EN 14104		0.15		
Alkaline Metals Na+K (mg/kg)	EN 14108 EN 14109		< 1, 0.9		
Phosphorus Content (mg/kg)	EN 14107		1		
Cetane Index	EN ISO 4264	53.9		54.7	55.1
Aromatics (wt%)	IP 391	20.61			
Mono-		16.30			
Di-		4.28			
Poly-		0.03			
Monoglyceride content %(m/m)	EN 14105		0.16		
Diglyceride content %(m/m)	EN 14105		0.01		
Triglyceride content %(m/m)	EN 14105		0.1		
Total glycerol %(m/m)	EN 14105		0.06		
Lubricity WSD1.4 (μm)	ISO 12156-1	420	162	118	221

3. Driving Route Description

The driving route infrastructure includes altitude differentiation, humps, and various alternations on driving conditions, such as frequent accelerations and decelerations. The specific real-world driving cycle was developed by recording driving conditions using several instrumented vehicles. The speed limit within the campus is 40 km/h. The vehicle accelerates from the starting point to 30 km/h before it reaches the first hump which overtakes with 15 km/h. The top speed between the humps should not exceed the designated speed limit. 1st to 2nd gear change is done at 25 km/h and 2nd to 3rd at 35 km/h or at 2500 rpm. Between specific humps the speed was kept to 25 km/h or 30 km/h due to either uphill driving or the small distance between the humps. The downhill driving of the route accounts to 2332 metres and only of 668 metres was uphill driving. However, the steepest upward slope was 12.99 % and the steepest downward 6.8 %. This driving cycle was developed for comparison purposes only, as the driving conditions were stable enough (i.e. no heavy traffic, traffic lights, etc). In order to accomplish accurate results the vehicle was driven around the peripheral route several times, where its driving characteristics were monitored.

Results and Discussion

4. Fuels Characterisation

The baseline diesel fuel employed in this study was complying with the European Specifications EN 590. Major advantages were the high cetane number and the low aromatics content. Animal fat methyl ester presented an

incline in terms of some quality parameters. More specifically, sulphur content was detected to be higher than 10 ppm. Past studies recommended that feedstock from slaughterhouse waste fats as hairs contain sulphur. Nitrogen content in the methyl ester was found to be relatively high. The reason for the high levels on nitrogen could indicate material left from processing, or incomplete clean up, Kinast (2003).

Phosphorus is derived and depends from the feedstock and is limited to 10 ppm maximum in biodiesel as it may damage catalytic converters. Alkaline metals result from the metal catalyst used in the transesterification. Metals are linked with ash formation in the combustion chamber. Both alkaline metals and phosphorus were within the specifications, Graboski et al (2003).

The iodine number is a measure of the degree of unsaturation of the fuel. Biodiesel viscosity, as well as, CFPP directly correlates to the iodine number. Saturation of fats (low iodine number) was found to be linked to cetane number. At high saturation, the cetane number is improved due to high parafinic content, thus engine operability is improved. However, high saturation gives poor low temperature characteristics, where in this case CFPP was found to be +10 °C, Kinast (2003).

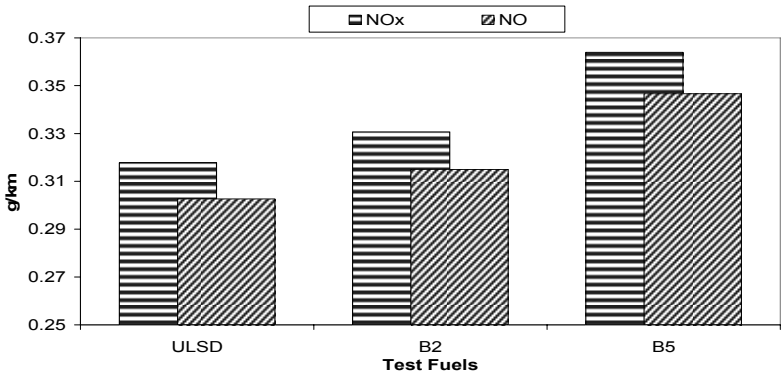
Distillation characteristics for the ULSD and both blends provide differences in the initial boiling point which was higher for the blends, due to the higher boiling point of methyl esters, and in the final boiling point which was slightly lower for both blends. The presence of high boiling point components influences solid deposit formation, Graboski et al (2003).

5. Emissions Evaluation and Fuel Consumption Measurements

A small size vehicle was utilized to conduct on-board exhaust emission measurements in a real-world driving cycle as described above. A total of three fuels were employed and the major pollutants emitted were investigated. Unburned hydrocarbons and carbon monoxide emissions were lower than the measuring accuracy of the gas analyzer.

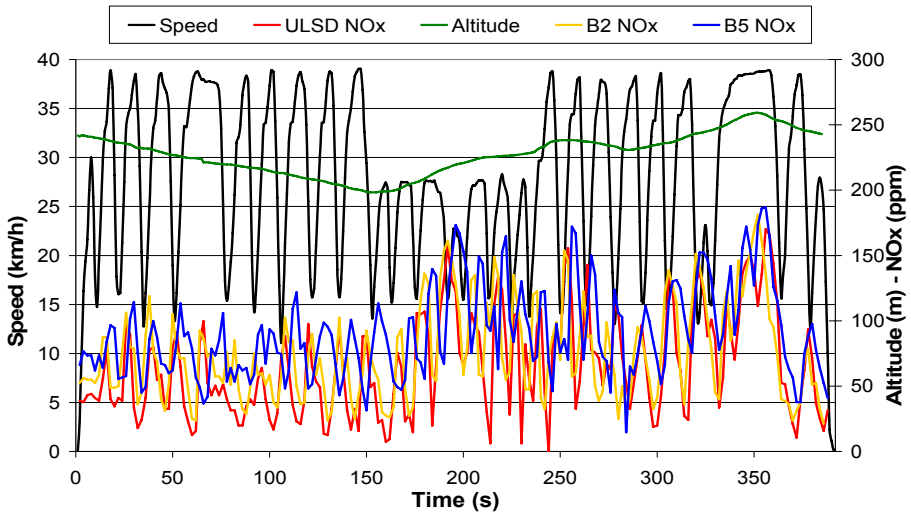
Emission results of NO_x ($NO+NO_2$) presented a slight increase for both blends with respect to the base diesel fuel. Emissions of NO_x were higher as the concentration of biodiesel increased into the ULSD. Figure 1, shows the NO_x increase for all fuels; however this increase was not significant as some of the properties of the specific biodiesel linked with low formation of NO_x emissions compared to methyl esters produced from other feedstock types, McCormick et al (2001). NO production is favoured by high temperatures and by high excess oxygen concentrations. Highly saturated methyl esters, produce significantly less NO_x emissions than those of high unsaturated content. It is possible that the double bonds participate in some combustion or pre-combustion chemistry to increase NO_x. Furthermore, methyl esters of shorter chain length and fully saturated provide less impact in NO_x emissions, Graboski et al (2003), Senda et al (2004), Akasaka et al (1997).

Figure 1: NO+NOx emissions increase.



Emissions of NO_x were also influenced by the infrastructure and the driving conditions of the real-world driving cycle. NO_x emissions showed an increase as the vehicle was accelerated and especially at uphill driving. The increase in NO_x emissions was higher, specifically at certain parts of the route, as the concentration of biodiesel was increased into the reference diesel fuel. A speed-time-altitude-NO_x graph (Fig. 2) clearly illustrates the effect of the route infrastructure on NO_x emissions.

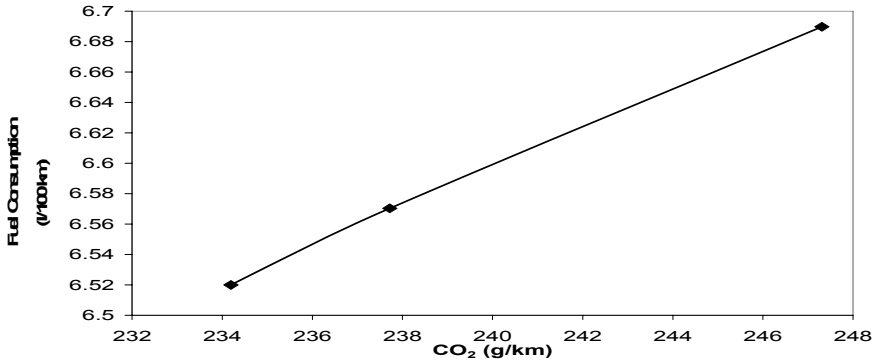
Figure 2: A speed-time-altitude-NOx illustration for the test vehicle.



Although, carbon dioxide cannot be considered as a pollutant, the release of CO_2 has been determined to be the agent that is most responsible for causing the greenhouse effect, Prakash (1998). In this study, the emissions of CO_2 increased with respect to diesel fuel. CO_2 emissions directly correlate with fuel consumption as shown in Figure 3. As the emissions of CO_2 increased an increase in fuel consumption was obtained. It can be seen from Table 2 that fuel consumption in l/100 km, was slightly higher for both blends compared to the reference fuel. The increase in fuel consumption was understandable since the animal fat methyl ester have lower heating value and significantly higher

density than the ULSD. Since the fuel delivered in the cylinders on a volumetric basis, a higher mass flow rate is pumped to the cylinders with the blends for the same fuel volume, Graboski et al (2003).

Figure 3: Fuel consumption increase with the increase of CO_2 emissions.



Emissions of smoke density (opacity) appeared significantly low as the concentration of biodiesel increased into the diesel fuel (Tab. 2). Modern diesel engines emit extremely low black smoke; however in this case, the addition of biodiesel slight reduced the smoke opacity.

Table 2: Mean values of the exhaust emissions of the vehicle.

Mean Values per cycle	Smoke density (opacity) (%)	NO_x (g/km)	CO_2 (g/km)	Fuel Consumption (l/100 km)
ULSD	0.80	0.318	234.195	6.52
B2	0.79	0.331	237.719	6.57
B5	0.77	0.363	247.310	6.68

Conclusions

In this study, animal fat methyl ester was blended with an ultra low sulphur diesel at proportion of 2 and 5% respectively. The ULSD and both blends were tested in a diesel vehicle operated in a specific driving cycle. The experimental results are described as follows:

Most of the quality parameters of the test fuels were within the specification limits and did not seem to affect the engine operability.

NO_x emissions slightly increased as the concentration of biodiesel was increased into the baseline diesel fuel due to higher combustion temperature and the presence of fuel oxygen.

It is possible that the NO_x emissions were influenced by some of the physicochemical properties of the biodiesel, such as the iodine number.

It was observed that the emissions of NO_x were influenced by the infrastructure of the driving cycle. The driving route showed an increase in NO_x as the vehicle was accelerated especially at uphill driving.

The addition of biodiesel decreased smoke opacity emissions.

CO_2 emissions were higher as the addition of methyl ester was increased into the reference diesel fuel. The increase in CO_2 emissions directly correlated with the increase in fuel consumption.

Biodiesel blends caused a decrease in fuel economy with respect to diesel fuel. This was due to the fact that biodiesel has lower heating value and higher density compared to the ULSD.

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Environmental impact of Electric Vehicle Traction Batteries: A comparison using LCA

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Abstract

An environmental analysis of several electric vehicle battery technologies (Lead-acid, Nickel-Cadmium, Nickel-metal hydride, Sodium nickel-chloride, Lithium-ion) was carried out in the context of the European end-of-life vehicles directive (2000/53/EC). A comprehensive environmental score based on a life-cycle approach, was defined for each of the mentioned battery technologies through the combined use of the SimaPro® software and of the life cycle impact assessment (LCIA) method Eco-indicator 99. Allocating a single-score makes it possible to determine the battery technology to be used preferably in electric vehicles as well as to indicate how to enhance the overall environmental friendliness of electric vehicles.

***Keywords**: Electric vehicles, battery technologies, environment, life-cycle analysis*

Introduction

Urban air pollution, fossil fuel depletion and global warming are issues which could be tackled partly through the implementation of battery and hybrid electric vehicles [1]. These vehicles offer solutions to the previously mentioned problems independently of the electricity production mix and are even more beneficial when electricity is produced using renewable energy sources [2]. The electric vehicle battery is often considered as a major environmental concern, be it pertinent or not. The environmental impacts of the different battery types should thus be compared. This assessment was performed in the SUBAT-project. This project evaluates the necessity or opportunity to keep nickel-cadmium traction batteries for electric vehicles on the exemption list of Directive

2000/53 on End-of-Life Vehicles. The project delivers a life cycle assessment of battery technologies for battery-electric and hybrid electric vehicles (lead-acid, nickel-cadmium, nickel-metal hydride, lithium-ion, sodium-nickel chloride...). The impacts of the different technologies are compared to allow the definition of the most environmentally friendly battery technology for electric vehicles.

Methodology

LCA makes it possible to study the environmental impacts of a product throughout its complete life cycle from raw material acquisition through production, use and final disposal [3]. It is the only efficient approach to compare the complete environmental burden of different products. This is due to the fact that different products may present environmental burdens in different parts of their life cycle. As an example, fewer resources may be used for one product compared to another product during the use phase, but this may be at the cost of more resources used during another phase [4].

The main limitation of life cycle assessment is that it is never completely exhaustive; consequently, the (optimal) degree of detail to which the assessed life cycle is modelled influences the degree of precision and correctness of a study.

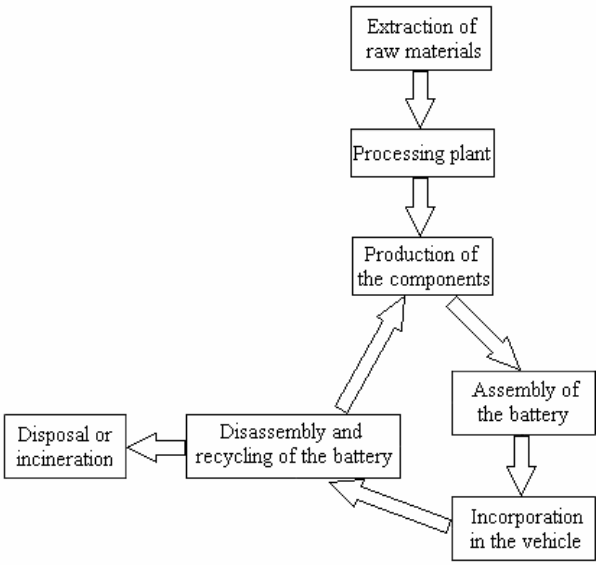
This study was performed according to the ISO standards designed for LCA (ISO 14040-14043).

1. Assumptions

After the inventory and modelling of the available battery technologies and before introducing the model in Simapro®, an appropriate functional unit must be defined. Considering different batteries have various lifetimes and provide varying numbers of charge-discharge cycles, the lifetime of the battery appears not to be an appropriate functional unit. After evaluating different functional units it was decided to choose a functional unit corresponding to a battery enabling the car to cover a given distance with one charge. This “one-charge range” was set to 60 km when driving up to 80% depth-of-discharge of the battery. Furthermore, the environmental comparison will be based on the impacts of a battery pack enabling the vehicle to cover a 180.000 km lifetime range, corresponding to 3.000 (60km) cycles. Depending on the technology, the required number of batteries needed for the functional unit was determined. The battery is inserted in a car with a net weight of 888kg (excl. the battery, incl. the 75kg driver). The considered time period is corresponding to the current state of technology. The related other life cycles (buildings, trucks, roads, etc.) have not been included. Self-discharge was not considered because of the great dependence of self-discharge on the way the vehicles are used. Neither was the maintenance because of the assumption this impact is comparatively small. The European (EU-25, 2003) electricity production mix has been taken as a reference. It has been considered that the recycled materials have the same quality as the original materials. A collection rate of 100% and a recycling rate of 95% were used for the recuperated materials (except for the lead-acid

recycling technology, which is more mature and where the lead metal recycling rate is 98.3%). It was assumed the electrolyte is neutralized before disposal (except for lead-acid where 90% is collected and recuperated, while 10% is neutralized before disposal).

Figure 6: Schematized life cycle of an electric vehicle battery.



The functional unit interacts with nature in the following life stages of the battery:

- Extraction of raw materials,
- Processing of materials and components,
- Use phase of the battery,
- Recycling of discarded batteries,
- Final disposal or incineration

2. Impact assessment

The inventory analysis is based on information available in literature, information obtained by interrogating the industry and information obtained through databases. The obtained data allowed drawing up a process tree of each life phase and to use mass balances to link the subsystems to each other. As an illustration, a process tree for the lead-acid battery is presented in Figure 7.

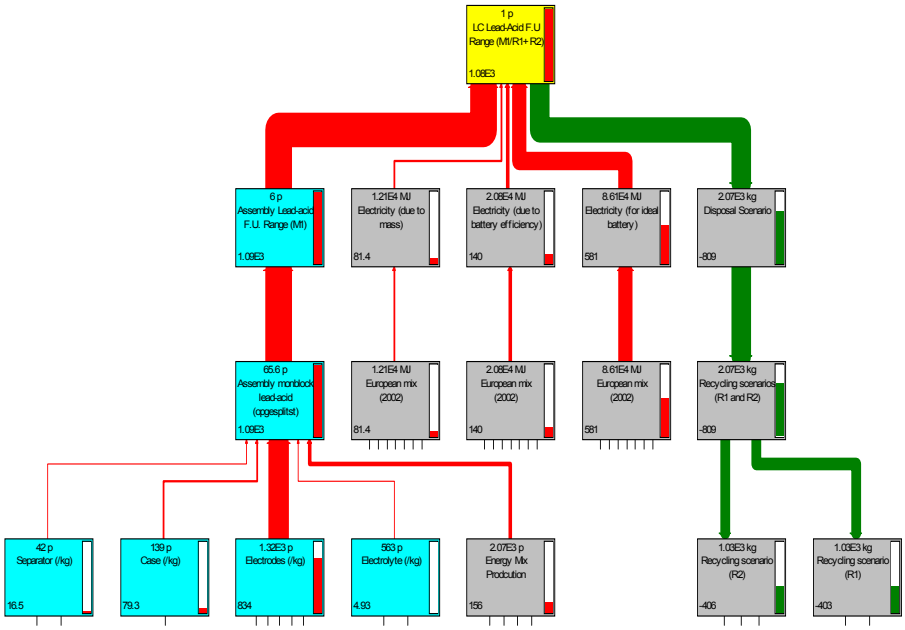
The analysis of the use phase of the batteries can be divided in 3 parts. First of all, the use phase was studied for a hypothetical “ideal” battery (mass = 0 kg, energy efficiency of the battery = 100%). This corresponds to the energy used to move the car (excl. the battery). In a second phase, the influence of the varying masses and energy efficiencies of the battery technologies have been included in the analysis. The energy use of the car depends on the battery

mass. Variations of the energy consumption were calculated using the Vehicle Simulation Program (VSP) [5].

A number of life cycle impact assessment methodologies exist and the choice of the method applied for LCA is an important decision [6]. In this study, the chosen LCIA method is Eco-indicator 99 (hierarchist perspective) as it is a widespread and broadly accepted methodology [7,8,9].

This study aims at defining which type of traction battery for electric vehicle applications is the best from an environmental perspective. This analysis is performed considering the complete battery life cycle. The important number of calculations needed to perform an LCA requires software.

Figure 7: Illustration of a lead-acid process tree with SimaPro®.



Based on technical and commercial relevance, a number of battery technologies were chosen and have been analysed quantitatively: lead-acid, nickel-cadmium, nickel-metal hydride, sodium-nickel chloride and lithium-ion. Some environmentally relevant technical data are presented in table 1.

The results obtained through SimaPro® and eco-indicator 99 are expressed in eco-indicator points. One eco-indicator point corresponds to one thousandth of the annual environmental damage of an average European inhabitant. To allow straightforward comparison of the environmental rating of the battery technologies, the results were all compared to the impact of the lead-acid battery.

Table 1: Battery properties

	Specific Energy (Wh/kg)	Number of cycles	Energy efficiency	Losses due to heating
Pb-acid	40	500	82.5%	
NiCd	60	1350	72.5%	
NiMH	70	1350	70.0%	
Li-ion	125	1000	90.0%	
NaNiCl	125	1000	92.5%	7.2%

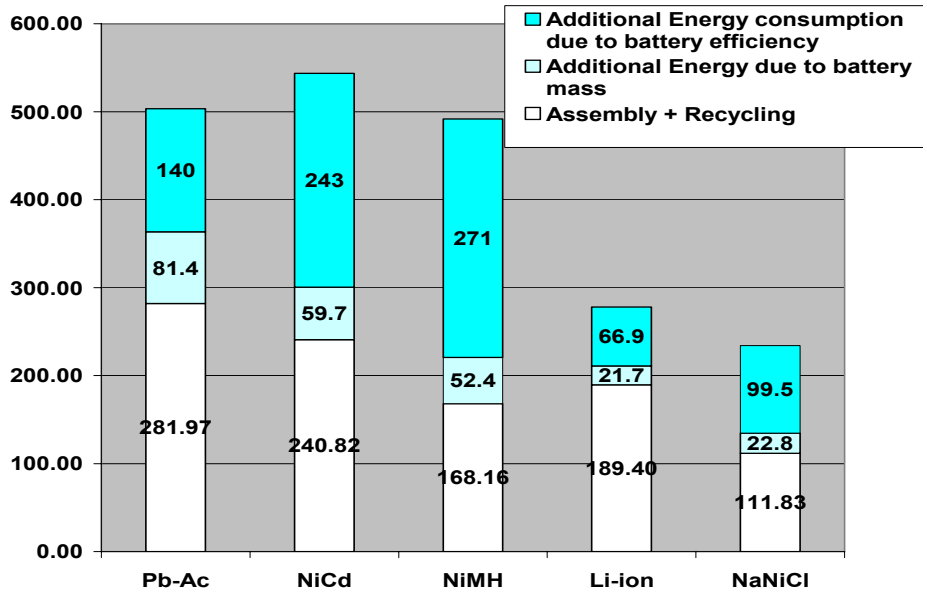
Results

1. Environmental impact assessment

A part of the environmental impact is induced by the energy losses in the battery and by the energy losses due to the additional mass of the battery (table 2 and figure 3). This impact is dependent on the way electricity is produced. In the present calculations the EU-25 electricity production mix has been used. This impact could be strongly decreased by using renewables more intensively.

When excluding the use phase completely, it appears the lead-acid battery has got the highest impact, followed by nickel-cadmium, lithium-ion, nickel-metal hydride and sodium-nickel chloride. Recycling compensates a significant part of the environmental impacts of the production phase.

Figure 8: Environmental impact including losses due to battery mass and efficiency.



Including the effects of the losses due to the battery (efficiency and mass) to the environmental analysis, three technologies have higher environmental impacts. Inclusion of the batteries' energy efficiency (table 1) results in a higher environmental impact for nickel-cadmium and nickel-metal hydride batteries and in a lower one for lithium-ion batteries as compared to the others.

Table 9: Environmental scores (Eco-indicator points) of the life stages of the batteries.

	Production	Additional Energy	Recycling	Total
Pb-acid	1091	221	-809	503
NiCd	861	303	-620	544
NiMH	945	323	-777	491
Li-ion	361	89	-172	278
NaNiCl	368	122	-256	234

2. Sensitivity analysis

A sensitivity analysis assessed the effects of assumptions (concerning average battery composition, energy consumption, etc.) and of possible variations in the collected data on the results. This analysis was performed by varying the assumed parameters. The variations included calculations using different relative sizes of battery components (10% more weight of a component, compensated by an equivalent decrease of another component). This influenced the proportional masses of the electrodes, electrolytes and cases. Other modifications included recycling efficiencies and rates, as well as required energy to produce or recycle batteries.

Figure 3 summarizes the relative environmental scores and the results of the sensitivity analysis. It only includes results originating from production, recycling and the energy losses due to battery mass and to battery efficiency. Energy use in the hypothesis of an ideal battery is not included, as this parameter doesn't vary from one battery technology to another. Moreover, this energy use is to be allocated to the use of the vehicle and not to the battery. Figure 4 represents the relative environmental impacts of the different battery types, considering the lead-acid as a reference set to 100. The results obtained during the sensitivity analysis are all included in the error bars in figure 4.

The assumptions didn't have any significant influence as the conclusions remain the same within the error bars. This reveals the model used in this study is reliable and robust. Data concerning environmental impacts of the electrolytes of lithium-ion batteries were very difficult to obtain, as these electrolytes are very specific and new. No realistic data were obtained concerning energy consumption during manufacturing of the sodium-nickel chloride batteries. As a consequence, the environmental impacts of both the lithium-ion and the sodium-nickel chloride batteries could be slightly higher than shown in figure 4.

Figure 9: Graphical overview of the relative environmental scores (incl. sensitivity analysis).

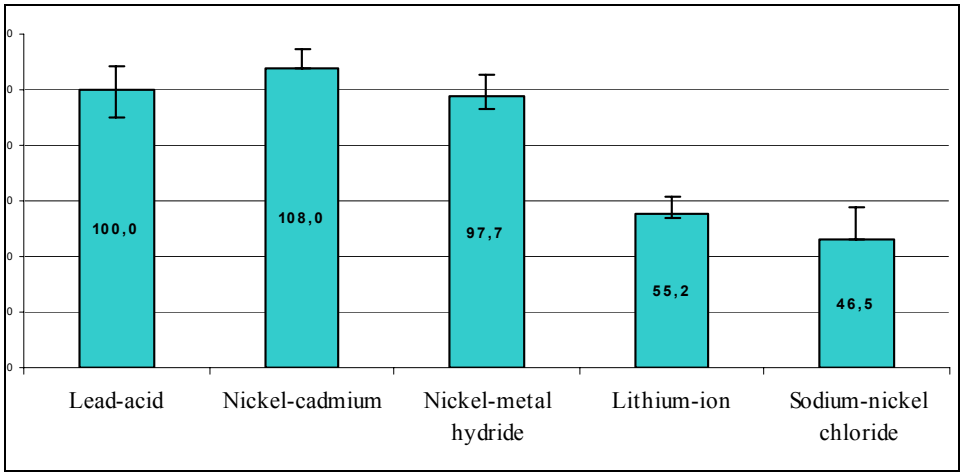
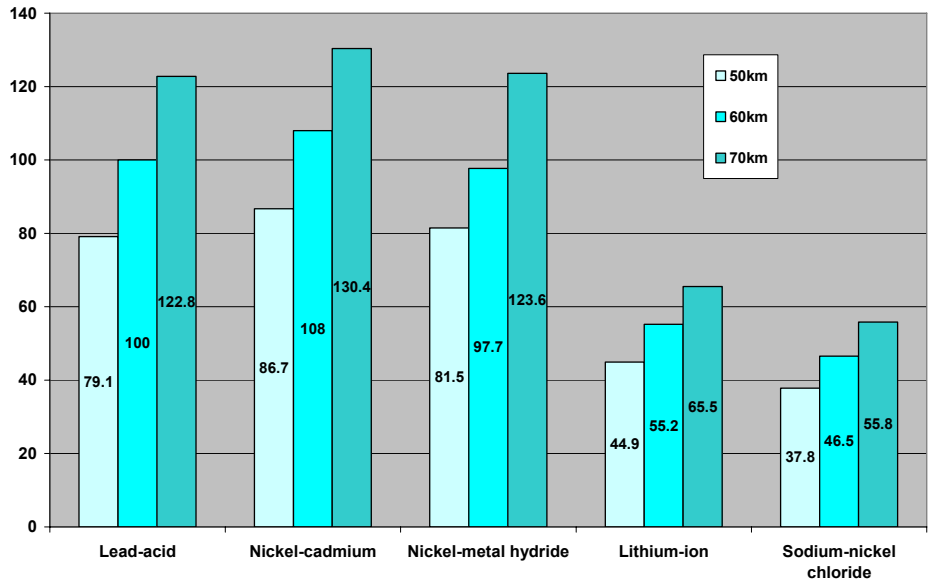


Figure 5: Graphical overview of the environmental impacts of the batteries.



Finally, an environmental analysis was performed assuming “one-charge ranges” of 50 or 70 km instead of 60 km. The results of the changes in the “one-charge range” are discussed separately from the other results of the sensitivity analysis, as they imply different functional units. These are thus not to be directly compared in order to evaluate comparable products.

The environmental impacts of the batteries allowing other “one-charge ranges” are shown in figure 5. It appears the absolute environmental impacts

are different from the previous ones, but the main trends, and thus the conclusions, remain valid within each of the assessed “same-range batteries”.

Conclusions

Implementation of large-scale and efficient collection and recycling of the batteries compensates the impacts of assembly and production to an important extent.

Following environmental ranking (decreasing environmental impact): “lead-acid, nickel-cadmium, lithium-ion, nickel-metal hydride, sodium-nickel chloride” is obtained when excluding energy losses occurring during battery use (due to battery efficiencies and additional masses of batteries).

When analysing the global results, the following environmental ranking is obtained (decreasing environmental impact): nickel-cadmium, lead-acid, nickel-metal hydride, lithium-ion and sodium-nickel chloride. Three battery technologies (lead-acid, nickel-cadmium, nickel-metal hydride) have comparable environmental impacts. Taking the sensitivity analysis into account, these technologies thus have higher environmental impacts than lithium-ion and sodium-nickel chloride batteries.

Calculations performed with batteries allowing different ranges, lead to the same conclusions. In other words, three technologies (lead-acid, nickel-cadmium and nickel-metal hydride) have a similar environmental burden, which is higher than the burdens of the other two technologies, lithium-ion and sodium-nickel chloride. The results could be mitigated due to the great rareness of environmental data concerning some aspects of lithium-ion and sodium-nickel chloride batteries.

The environmental impacts of the batteries of electric vehicles are small (whatever the used battery technology might be) compared to the environmental burden caused by internal combustion vehicles. This should be kept in mind when reading this study which should thus be seen as an indication on how to even enhance electric vehicles environmental friendliness.

Acknowledgments

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Propulsion Systems for Electric and Hybrid Vehicles-State of the Art, Research and Development in Romania

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Abstract

During the last years, in all countries, urban transport raised specific problems and caused important political, social and environmental harms : pollution, noise,stress The authors of the paper are among the promoters of research activities in the field of electrical vehicles in Romania Starting from the propulsion system (electric motor+driver) we developed several prototypes of electrical and hybrid vehicles, in order to be prepared to win the race for imposing in Romania a clean urban transport and offer to the manufacturers a solution for electric and hybrid vehicles with high performances and low price, as in the future there will be a huge market for zero emission vehicles in the EU countries.

Keys-words*: electric vehicles, zero emission transport, propulsion systems, clean transport, environmental protection*

Introduction

During the last years, in all countries, urban transport raised specific problems and caused important political, social and environmental harms: pollution, noise, stress. That is why research and technological development activities are encouraged to provide clean and efficient transport. The laws regarding environmental protection are aiming limiting greenhouse gas protection. Romania, also, wishing to integrate in the EU, must and wishes to follow the same direction. Unfortunately the progress is not so easy to make, especially from financial reasons. The mentality of people is another point to be considered.

The best answer to the problems of environmental pollution is the electric vehicle (EV), as an alternative mean of transport. That is why, in the last twenty years, the electric vehicle was re-discovered. Unfortunately, despite providing

major environmental benefits as well as promoting new traffic management system, electric vehicles have not yet succeeded to assert on the car market and convince the prospective users, due to low power density of on-board electric sources, high cost and lack of infrastructure. For long-term, fuel cells seem to be a solution, and for sort-term most experts consider the hybrid electric vehicles (HEV) to be the best opportunity.

The promotion of EV in Romania

Romania, with over 23 million people is a good market in S-E of Europe and especially for vehicles. Its fleet is old enough to have high emissions and consumption. The infrastructure, also, is inadequate. Considering these and the necessity to approach the EU requirements, our country tries to improve its transportation system and the environment protection.

The authors of the paper are among the promoters of research activities in the field of electrical vehicles. ICPE created in 2000 a Consortium to promote an electric vehicles programme in Romania (EV Consortium). It comprises universities, research groups, industry, local authorities and government factors interested in electric vehicles development, production and promotion. The Consortium organized annual EV workshops in Pitesti since 2001, contact-exchanges between interested parts, research cooperation and other promotion activities. A target is to involve the local authorities, the government factors and the civil society in order to have a mass campaign in supporting the EV promotion. Details may be found on the site: *http://www.icpe.ro.*

Also, in 2005, was founded AVER – a non-governamental association that wishes to promote electric vehicles in Romania. The authors of the paper are among the first 10 members of the association.

Romanian Research Projects in EV Field

First models of EV were built in Romania in the 70's: a van, a car, a bike and many manipulators. The projects received a good attention and had a good financial support. The prototypes worked well, but economic and technological factors prohibited a mass production. After 1989 the governmental support diminished and the projects were stopped.

In present time, based on its skill in electric motors and drives, ICPE started to redefine the importance of EV and coagulated EV Consortium and EV association AVER (in 2005). Few research programmes started with governmental support and with contribution of private companies. The authors participate to some projects and the results are presented below.

EV Consortium organized exhibitions, demonstrations and drive tests, especially on the occasion of the workshop "EV-2005", held in Pitesti, in October 2005. The demonstration was a real success and gained the interest not only of the scientific community of Romania, but also of public and governmental authorities, urban transport companies and vehicle manufacturers. That is encouraging for the future of our research work,

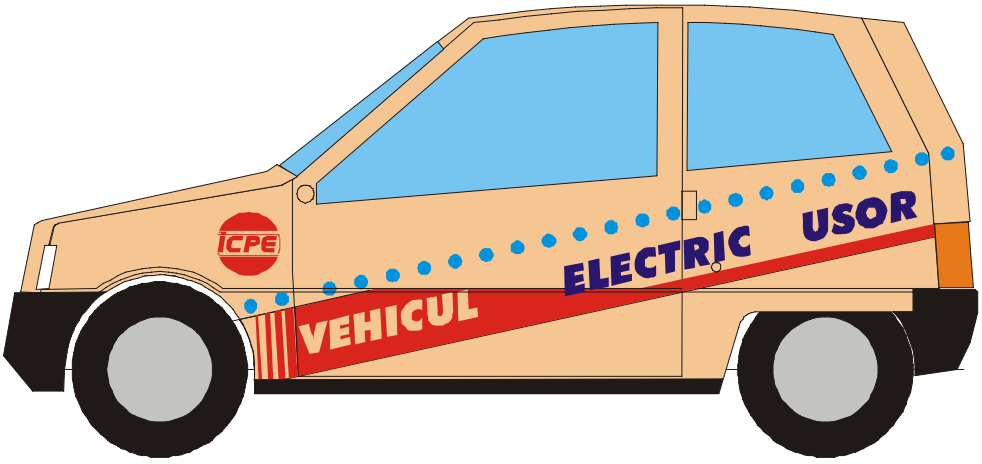
because if the authorities and manufacturers are interested in promoting a clean and efficient transport with electric and hybrid vehicles in Romania, there will be an opportunity to promote the propulsion systems we carried out.

1. Light Electric Vehicle LEV-1

This first prototype is a light electric vehicle (LEV-1) designed to be a successful product, as a safe, affordable, environmental friendly effective mode of transportation. The LEV-1 (fig.1) is a four-wheel platform, with 25km/h maximum speed, equipped with a DC propulsion system, offering to the manufacturer the possibility of building several variants of electric cars. The LEV-1 has high efficiency, low weight, high safety and reliability, appealing design and affordable price/performance ratio, that's why it may be one of the first solution for an electric car successfully manufactured in Romania.

Technical characteristics of the propulsion system are:

- D.C. permanent magnet motor with a continuous power P=5 kW and maximum speed, n=2000 rpm
- Supply voltage: 120 V
- Electronic converter
- Regenerative breaking
- Technical characteristics of the LEV-1 are:
- Maximum velocity: 25-30 km/h
- Load: 1-2 persons and max. 100 kg luggage
- Autonomy: 2 hours at maximum speed
- Possible applications are:
- Airports
- Fairs and exhibitions
- Commercial centers
- Entertainment parks
- Sport grounds/centers
- Health resorts
- Down-town



2. Electric Car Sharing Application

Another project, EV-S, is an electric vehicle designed to be utilized in Car-Sharing system in Bucharest. The figure 2 presents the vehicle's photo during the demonstration meeting at the workshop "EV-2003"and "EV-2005", held in Pitesti, Romania. Car Sharing is a new concept for urban transport in Eastern Europe and Romania is the first country that is going to integrate it.

Integration of electric cars in the car sharing system may be a real solution to convince individual users of the advantages of electric cars. They can drive and utilize the car without being the owner, and so they can see the advantages of driving a silent car, that offers practically the same opportunities as a combustion car for urban transport, is easy to drive and cheap to feed.

EV-S is made based on a current production Romanian car. Its engine was substituted by an electric propulsion system: a DC motor, power converter and batteries. The prototype kept the main transmission. In order to can evaluate the dynamic behavior the prototype kept also, the gearbox and the clutch. The actual solution was choused according to some restrictions, including financial ones, and is in evaluation. The maximum speed of 60 km/h is not a discomfort for urban transport, and the autonomy is of 2 hours, that allows the user to drive one day.

Technical characteristics of the propulsion system are:

- D.C. rare-earth permanent magnet motor, with a continuous power P=10 kW and maximum speed n=2000 rpm
- Supply voltage: 180 V
- Electronic converter
- Regenerative breaking

The tests were carried out during two month on private roads. The experimental results ensure the EV the following performances:

- Maximum speed: 80 km/ph(with two persons) and 65 km/h with four persons
- Autonomy: 2 hours

At this moment the prototype is prepared to do the approving tests in order to be allowed on public roads.

3. Electric Buses – a Solution for Urban Transport

As car numbers continue to rise, the pressure on urban space and the deterioration of the local air quality become more and more a problem, which the cities are faced with. Another project the authors of the paper started is : “Electric Bus for Passengers “, designed as a modern transport service developed especially for delimited spaces, such as fairs and exhibitions. The project started with ROMEXPO as partner, beneficiar and co-financial agent, interested in developing an ecologic alternative for tranport passengers when organizing a fair or exhibition..

R.A.T.B. , a transport operator from Bucarest, is another partner in the project, wishing to study the possibility of implementing electric urban transport in Bucarest.

In the project, at the end of 2006 will be presented an electric bus, with the following main technical caracteristics:

Technical characteristics of the propulsion system are:

- D.C. permanent magnet motor with a continuous power P=15 kW and maximum speed, n=2000 rpm
- Supply voltage: 190 V
- Electronic converter
- Regenerative breaking
- Technical characteristics of the bus are:
- Maximum velocity: 25-30 km/h
- Load: 12 persons

4. ECOTRANSDELTA – A Solution for Sustainable Transport with Electric Propulsion Systems in the Danube Delta

The objectives of the comunitary policy are focused on preserving ,protecting and improving the quality of the environment and of human life as well as rational and preventive usage of natural resources. This policy is based on the principle of preventing the environmental disasters,because nowadays on Earth the pollution has raised in such manner to endanger even life on our planet.

Considering that:

One of the major short term objective of Romania is to fulfill the conditions for EU integration,where environmental policy is very important but also very hard to achieve because of the economic environment.

Natural protected environments(such as The Danube Delta) are in real danger because of fauna and flora periclitation due to pollution ,problem that emerges also in leisure areas(such as Vidraru Dam) in Romania and in some EU countries

Implementation of environment-friendly transport system(water/land) is a trend in the EU

promoting a transportation system based on electrical driven vehicles seems to be the optimal solution.

That is why ICPE has started in a consortium a project in a national researh programme that aims to offer a solution for the Danube Delta, carrying out prototypes of d.c. propulsion systems for light electric vehicles and for boats.

The servomotors components of the propulsion system are permanent rare earth magnet d.c. servomotors, in the range of 0,3- 10 kW, supply from baterries (24 V; 48 V; 120 V; 196 V) and conceived and designed for transport.

Other Contributions in EV Field

In Romania there are competences not only in electric vehicles, but also in specific parts. ICPE is specialized in design and small series production of DC and AC motors and drives, special electric machines (alternators, resolvers, etc.). There are also high competences in digital control (microcomputers, microcontrollers, DSP, etc.), traffic management, power supplies and converters.

EV Market in Romania

EV market for road vehicles is not born yet. Only one dealer want to start to sell EV imported from India (REVA). The big French producers (Renault and PSA) refused the contact with the Romanian EV market 3 years ago and the Romanian member of Renault Group, Dacia, seems to be not very close to the idea of EV.

Conclusions

Although implementation of clean and efficient transport in Romania is, at present stage, only a target, by developing propulsion systems for electric and hybrid vehicles we hope to be prepared for the moment when the market will generally accept the zero-emission vehicle (ZEV) as an ordinary product.

Characterisation of emissions of the complete RATP bus fleet and network Methodology

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Abstract

The aim of this paper is to explain the methodology that will be used in the Parisian public transport company (RATP) to characterise pollutant emissions of its 4 000 buses driven in the whole Ile-de-France region.

This analysis work will be done in two phases.

The first one consists on analysing the bus fleet in order to determine a statistic representation of it. Measurements of regulated pollutants will be done with a static instrumentation on about 400 buses (approximately 10% of buses in use) as a function of type of bus and fuel, age, mileage, presence or not of a post-treatment, of air cooling…

The second phase consists on characterising the geographic distribution of emissions measurements. It will be done on real driving conditions with an on board dynamic system.

Previous works, done as a part of ARTEMIS European project [André et al 2005, André et al 2004] allows us to connect driving conditions and engine parameters of urban buses to the network and the urban context, and then to link them to pollutant emissions measured in this phase.

Then, association of results obtained during these two phases will lead us to completely characterise pollutant emissions of an important bus fleet in a large urban scale.

Keys-words*: bus fleet, emissions, pollutant, characterisation.*

Introduction

In France, as in a great part of European countries, emissions of vehicles in cities are largely liable of pollutant and greenhouse gases emissions. Public transports constitute a real alternative face to passenger cars. A better estimation of real emissions of bus transport mode can be very interesting in comparison with emissions of passenger cars, trucks and captive sources. Bus is the most emissive public transport mode in comparison with tramway, metro or regional trains. That's why this study concerns especially this mode in Paris.

Nowadays, we know theoretical emissions factors of vehicles through the Euro technology of their engine and their acquiring date. But we don't know how they change after several months of exploitation, as a factor of type of use (driving conditions), type and regularity of maintenance, age and mileage of vehicle. This work will help us to quantify emissions of an entire fleet on real driving conditions.

Buses emissions are usually measured via a vehicle test bench. Nevertheless, these costly and complex measurements are done in a particular configuration, at a precise period which are not representative of the complete fleet and all the driving configurations that can be met in an urban environment.

Analysis of the fleet

RATP's bus fleet is the biggest and the cleanest bus fleet in France with around 4 000 buses. Since 1994, considering that public transports should be exemplary in the fight against pollution, RATP launched a program of research and experimentation. It takes into account all the parameters acting on bus emissions and every technologies and fuel sources possible. The main objectives were:

Reducing emissions and particularly diesel particle emissions for buses exploited with intent to answer the expectations of institutions and customers;

Using alternative energies and evaluating their feasibility and potential.

Table 1: RATP's bus fleet composition.

Tableau 1 : Composition de le flotte de bus RATP.

Energy	Number of buses	Approximate percentage / complete fleet	Comments
Electric	12	<1 %	Midi-buses
Diesel	3557	87 %	88% equipped with a particle trap / Oil with very low sulphur proportion
NVG	90	2 %	
LPG	57	1 %	
Aquazole	311	8 %	Emulsified diesel fuel
Diester Green Fuel	64	1 %	Diesel fuel laced with about 30% of green oil

After having retained most relevant technical solutions and bringing it into operation, the composition of the fleet is now the one described in the table I. The statistical study of the fleet takes into account the type of fuel used as mentioned in the table I and also parameters exposed below:

1. Type of bus and motorization

Buses are classified as a function of their passenger capacity – mini, midi, standard or long buses which is directly in relation with the type of engine.

2. Euro technology

From 0 to 4, pre-Euro engines are not more represented in the RATP's bus fleet. The only 356 diesel Euro 0 buses will we scrapped in the next years.

3. Age & Mileage

The average is about 6.5 years. Buses are scrapped at a maximum of 15 years. Oldest buses will be studied under priority with the aim to characterize most pollutant vehicles.

During the lifetime of a bus, it covers about 400 000 to 500 000 kilometres. Mileage seams to be an important parameter, in relation with type of maintenance.

4. Particles filter

Each diesel bus is equipped with a post-treatment system (particle filter and/or catalyst). This equipment is present on newest vehicles and is fitted back in oldest ones. The study will also allow evaluating the effect of the four types of particle traps (2 types with 2 generations for each) in pollutant emissions. Traps are also fitted back on green fuel buses.

5. Air-cooling or air-conditioning

Presence or not of mechanic ventilation, air-cooling or air-conditioning has an influence on fuel consumption, that's to say on pollutant emissions. This parameter will be taken into account measuring the emission with the system on operation or off.

The whole fleet will be classified according to the parameters listed here and 10% of each class will be tested in the measurement phase.

Static emissions measurements

This phase consists in measuring statically pollutant emissions of 10% of the bus fleet with the help of the DMPP[1] based on Autonat cycle (cf. figure 1)

[1] DMPP : Diagnostic Moteur Performance Pollution

created by CRMT[2]. The aim of this system is to measure systematically pollutant emissions with mobile equipment. Measurements are done during a simplified 12 seconds cycle of accelerations and decelerations. The software associated to the mechanism allows repeating systematically measurements (cf. figure 2). It is made up of:

Figure 1: Autonat cycle

Figure 1 : Cycle Autonat

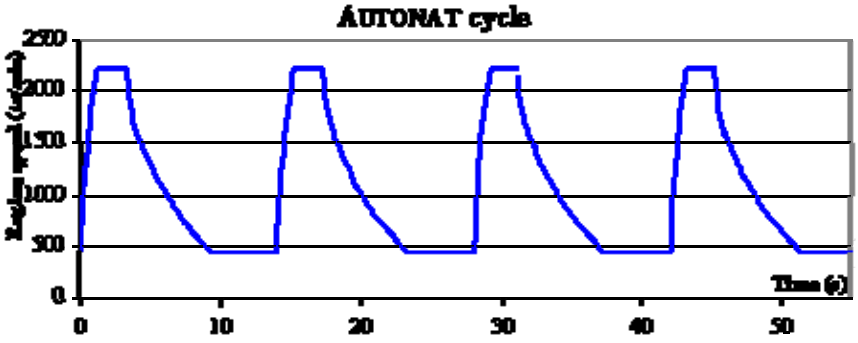
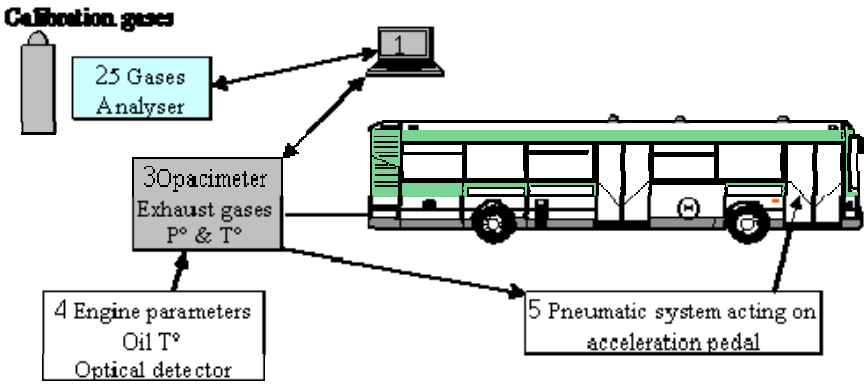


Figure 2: Description of DMPP measurement process

Figure 2 : Description du système de mesure DMPP 3 - Dynamic on board measurements



A pneumatic system which operates rapidly on the acceleration pedal. It is managed via a computer which allows to reproduce the cycle identically,

An instantaneous gas analysers (carbon monoxide CO, carbon dioxide CO_2, oxygen O_2, total hydrocarbons THC and nitrogen oxides NO_x) connected to the same computer,

An instantaneous full flow opacimeter,

[2] CRMT : Centre de Recherche en Machines Thermiques (www.crmt.fr)

Temperature measurement of exhaust gas and engine oil,

A data management and processing system.

Particles and gases are not measured in the same time but with the same cycle. Each measurement will be done three or four times in order to obtain reproductive data.

This system could measure pollutant emissions on a large and representative part of the fleet classified before. Then, characterisation of the global fleet emissions power will be done.

A dynamic emission control system supplied and managed by the CRMT will allow us to measure the pollutant emissions on board. It is composed of a flow metre linked to a detector by a heated sampling line. Measured parameters are:

Gaseous pollutants: carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), total hydrocarbons (THC), oxygen (O_2),

Exhaust gas flow,

Functioning of engine (regime, pedal position),

Kinematics parameters (vehicle speed and geographic position with a GPS),

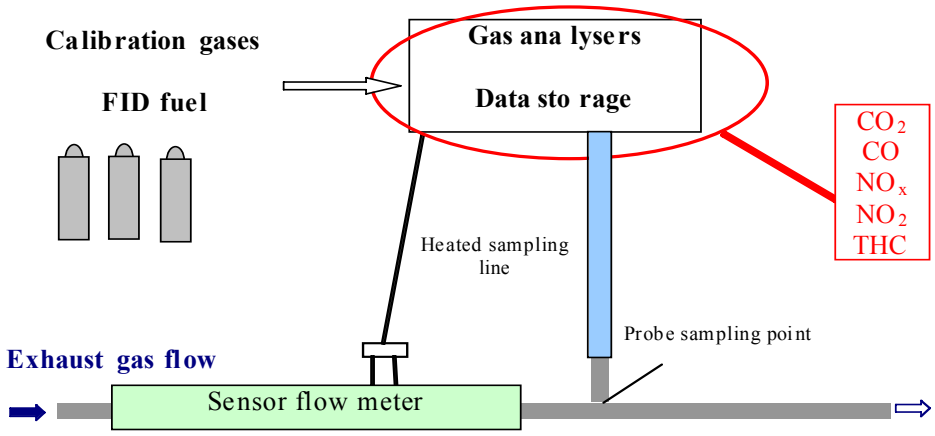
Experimental conditions (pressure, temperature).

Collected data will be stored, *i.e.* emission raw, emissions in gram per kilometres and experimental conditions. Time resolved measurements are used as a function of time or distance and can be cumulated in g/s or g/km.

Measurements will be done with a recent bus, representative of the actual and nearest fleet: a standard bus with Euro 3 motorization. Registrations of engine parameters in relation with pollutant emissions will be done on two lines representative of the city centre for the first one and of more rapid traffic on the circular line for the second one. Then, matrix will be built linking emissions and engine behaviour.

Figure 3: Description of CRMT on board measurement process

Figure 3 : Description du système de mesure en embarqué CRMT



Simulation and calculation of emissions

Results obtained during the previous phase will be used to re-calculate pollutant emissions in the different driving conditions in the Ile-de-France defined during a previous work [1,2]. It is divided in three driving cycles.

The first one is representative of city centre type of circulation. It illustrates the heterogeneity of the operation conditions in Paris with a first part representative of a concentrated communal housing area, with high-density housing and very congested traffic. The commercial speed is low, about 12 km/h. The second part is representative of a highly dense population area near primary roads with a high traffic. In this case, commercial speed is around 15 km/h.

The second cycle corresponds mainly to the traffic encountered on the suburban bus lines. It is also composed of one phase of link between the bus centre and the beginning or the end of the line. The aim is to take into account the specifically rapid driving conditions of this phase. Average speed is higher than previous cycles, about 19 km/h.

The third and last cycle corresponds to traffic conditions encountered in suburban area (isolated housing areas and lines crossing main roads with very high traffic), the average speed is about 20 km/h.

Conclusion

This paper exposes the methodology which is used to quantify the real emissions of a bus fleet of more than 4 000 vehicles driven in a big agglomeration as Ile de France region.

This work will need over one year of measurements to cover about 400 vehicles disseminated in 25 maintenance sites. It is intended to characterise precisely emissions of pollutants of a bus fleet in a real urban context. The vast database obtained will be a source for RATP but also for ADEME and each organisation concerned by pollutant emissions of vehicles and pollution of cities.

Acknowledgments

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Mass and submicronic size distribution of the aerosol in a parisian metro station

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Abstract

RATP has been running for almost two years a vast experimentation concerning PM_{10} mass concentration monitoring and chemical analysis in 20 underground metro stations. Given the growing interest for fine and ultrafine aerosol, one of these sites was equipped at the same time with two different instruments for investigating the aerosol size distribution.

A metro station was equipped with a real-time PM_{10} mass concentration monitor and a sequential sampler to collect particles on filters for further chemical analysis. Besides one electrical low pressure impactor and one scanning mobility particle sizer were used for measuring the station aerosol distribution.

A lab van parked outside the station has been provided with the SMPS for 48h in order to get the Parisian submicronic size distribution.

The use of two instruments operating with different principles and with different characteristics enabled a comparison of data given by both techniques. The comparison was done for particle concentration over a common size range 29-260 nm. It appeared that results given by ELPI and SMPS were extremely well correlated all along the experiment despite differences in the amplitude. It was showed a similar size distributions of outdoor and indoor aerosol.

Key Words : *Aerosol, particles, distribution, metro*

Introduction

For many years, RATP (Parisian public transport) has been monitoring air quality in the underground stations of its railway system. This monitoring consists in a continuous follow-up of the levels of several gaseous parameters and of the weight concentration of the PM_{10} fraction of the aerosol taken in two stations. Besides, since last year, RATP is launching a broad survey aiming at enhancing its knowledge of the atmospheric aerosol in its underground

premises. Measurements of weight concentrations and takings on filters are carried out during four weeks in some especially representative RATP RER and Metro stations. Those takings are followed by lab chemical analyses. An outside location is monitored in parallel and in the same way as the underground site to make up a reference point. Such a survey makes it possible to quantify the PM_{10} levels and to assess which kind of aerosol RATP employees and passengers are submitted to. During one of those tests, two additional analysers were implemented at platform level to assess the granulometric distribution of particles in suspension in the air of the selected station.

Experimental protocol

1. Selection of the station to be equipped

During recent years, aerosol survey campaigns were already carried out in two underground stations. The station selected for our investigation differs from those formerly surveyed by a few criteria likely to alter the physical and chemical nature of its aerosol.

- A 60-m³/s extracting fan is located in the tunnel adjacent to the station,
- Trains are steel-wheeled,
- Braking shoes are made of a composite material.

Besides, the station layout is simple and the station is located under a fairly busy road in Paris. At last, it belongs to a 20-stations panel representative of the underground network and the aerosol taken inside should be featured on the occasion of a broad measurement campaign. Our survey has been carried out in that context.

2. Experimental protocol

The selected station has been equipped during four weeks. Two sites were installed : one in the middle of the platform and the second at the street level, close to a station entrance and less than 10 meters apart from a very busy crossing in Paris. Measurements tools implemented on both sites are identical and detailed hereafter.

2.1. Continuous measurement of the PM_{10} level

A Rupprecht and Patachnik TEOM (Tapered Element Oscillating Microbalance), carrying out a dynamic measurement of the aerosol weight by means of an oscillating microbalance, is programmed to record PM_{10} concentrations at 15-min intervals.

2.2. Takings of filters and physical-chemical analysis

A Rupprecht and Patachnik Partisol + sequential sampler takes the PM_{10} aerosol and dissociates the fine ($PM_{2,5}$) and coarse ($PM_{2,5\text{-}10}$) fractions by

means of a dichotomic separator. Each taking is 24-hour long. Chemical analyses subsequent to those samplings require the implementation of three different filter types according the chemical species to be analysed.

Pallflex PTFE coated fibreglass filters, for a capillary electrophoresis analysis in order to determine the anionic and cationic concentrations (analysis performed by the Paris City Hygiene Laboratory).

Whatman quartz filters to determine organic and elementary carbon by infra-red spectrometry (analysis performed by the Paris City Hygiene Laboratory).

Polycarbonate filters (porosity = 0,8 µm) for the multi-element analysis of non-soluble elements by the PIXE process (Particle induced X-ray emission, analysis performed by the Nuclear Survey Centre at Gradignan, near Bordeaux).

Each third day, each type of filter is used as a filtering medium in accordance with the outside takings.

2.3. Analysis of the granulometric distribution of the aerosol (Fischer and Mazoué, 2002)

During twelve days, two additional analysers were located along the TEOM and the Partisol + at the platform level. Indeed, it sounded necessary to enhance our knowledge on the metro aerosol by investigating its granulometric distribution and concentrations in submicron sizes.

For that purpose, we implemented :

- A *Dekati* ELPI (electrical low pressure impacter). The operation of this appliance can be broken down into three phases. First, the aerosol, sampled through a PM_{10} taking head, is loaded by corona effect. Then, it is submitted to an inertial low-pressure ranking through a cascade impacter. This impacter is made of twelve stages which make it possible to separate particles from 30 nm to 10 µm in diameter. Finally, loaded particles are detected on each stage by means of an electrometer. Therefore, this appliance is able to provide a response in real time. For our study, the acquisition period was set to 15 s.
- A *TSI* SMPS (differential analyser of electrical mobility). This appliance associates two successive measurement media. The sampled aerosol is equally loaded by passing through a cloud of bipolar ions and then it is separated into an hundred of classes by means of a differential mobility analyser (DMA) which selects particles according to their electrical mobility, while the numerical concentration of the range is measured immediately after each separation by means of a condensation nuclei counter. We programmed the SMPS to make it sweep the range in 180 s, and then to acquire the mean distribution of five successive distributions (t = 15 min).

Results

1. Weight measurement and chemical speciation

1.2. Weight concentration

Thanks to the 15-min interval follow up of the PM_{10} weight concentration in an underground station, it is possible to get the average profile of each environment from Monday to Friday. The outside profile matches those conventionally measured on Parisian sites with a steady increase from 6:00 to 10:00, to reach values slightly greater than 50 µg/m³ and culminating between 40 and 50 µg/m³ in the afternoon. Inside the station, the concentration follows the conventional profile systematically noticed during former measurement campaigns in underground. Two 200-µg/m³ peaks respectively appear at morning and evening rush hours, while during slack hours the concentration comes back below 150 µg/m³. During night stoppage of traffic, PM_{10} concentration tends to catch up the outside one which is then a few tens of µg/m³. It should be noted that during this test, the fine fraction ($PM_{2,5}$) counts for less than half of the PM_{10} concentration.

RATP matches train traffic to the attendance of each line. Thanks to internal statistical data, it has been possible to show a correlation on a 30-min time period between the PM_{10} concentration and the operating parameters of the station. This is valid for the number of passengers entering the station and for the number of trains passing by the station too. Indeed, there are respective correlation coefficients of 0,88 and 0,82 between the PM_{10} concentration and each of these two series of data.

1.3. Chemical composition

The three types of chemical elements analysed during that campaign have made it possible to explain a major part of the chemical composition of $PM_{2,5}$ and PM_{10} aerosols. The aerosol taken outside shows the composition usually found in the Paris air, i.e. ionic and carbon fractions counting for more than 2/3 of its weight. However, the function of the trace elements is lower than 10 %. If we consider the aerosol taken inside the station, the weight contribution of ionic and carbon elements drops in spite of a light increase of the organic carbon content. Globally, only the metallic elements are more present in the station aerosol than in the outside one. This observation seems to indicate that particles are generated underground.

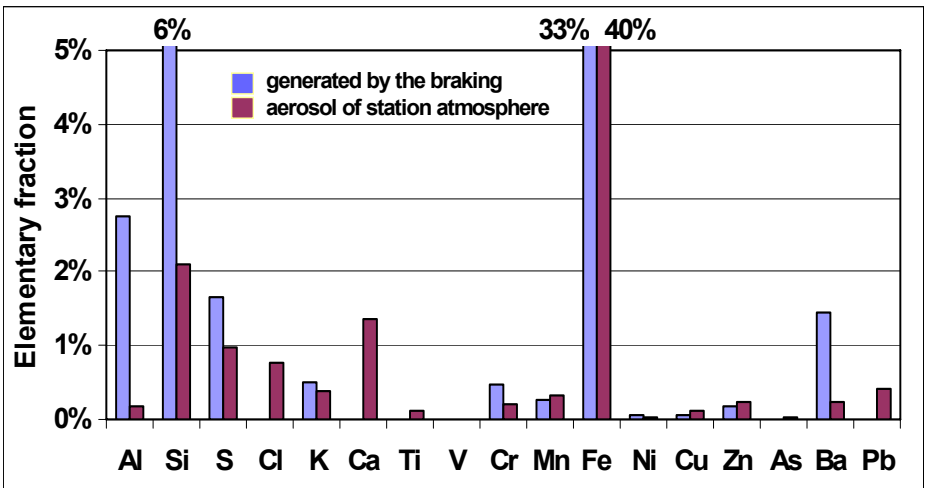
1.4. Signature of the PM_{10} aerosol by the emissions generated by braking (cf. fig. 1)

An aerosol survey has shown that, as far as we refer to the PM_{10} concentration braking is really an internal source. It is desirable to compare the elementary composition of emissions by the braking shoes (Lesaint, 1999) and of that one of the aerosol sampled during of our test, in order to consider the contribution of the braking to the dust deposited in station. It appears that every element generated by braking is detected in station. However, elementary

fractions of the aerosol in station are not identical to those of the emission. That is the reason why braking is not sufficient to explain concentration of every metallic element. There is at least one additional network-related PM_{10} source, which should explain the presence of elements such as titanium or lead which are present neither in the composition of the composite material of the braking shoes nor in the aerosol taken outside.

Figure 1 : Weight fraction of metallic elements in the aerosol

Figure 1 : Fraction massique des éléments métalliques de l'aérosol



2. Numerical granulometric distribution **(Fischer, 2003)**

2.1. Three-hour distribution

The selection of the SMPS measure range – partly made on the basis of the first outputs given by the ELPI – between 7 and 305 nm, has enabled us to define the granulometric distribution of the aerosol accurately. The first observations of three-hour distributions on a day show a decrease in the numerical concentration during night stoppage of traffic for every analysed dimension. Besides, as it could be imagined, maximum concentrations occur between 6:00 and 12:00. The most significant fact, resulting from the survey of those eight curves representing the average three-hour distribution, is that the mode remains roughly steady, i.e. always comprised between 35 and 40 min during a day.

2.2. Comparison of the responses of the two methods

This test was a first investigation of the granulometric distribution of the aerosol in the atmosphere of a station of our network and with two appliances operating according to different concepts. It was decided to compare the global numerical concentration on a shared part of their measurement range, i.e. between 29 and 259 nm. Data processing was carried out for one day from the 15-min data. Profiles follow each other practically perfectly, since the correlation coefficient linking the two series is 0,98. However, there is a difference in

amplitude between the two responses, which is likely due to the lack of knowledge of the density of the aerosol in the station atmosphere. Indeed, both appliances require this parameter entered before calculating distributions. In both cases, it was decided to take d = 1. Then, responses of both appliances follow the law [ELPI] = 0,67 [SMPS].

2.3. Comparison of concentrations inside and outside the station

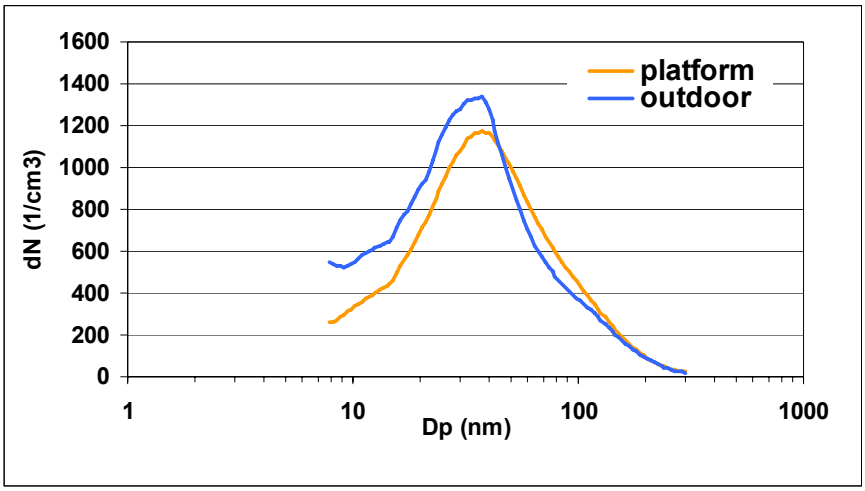
On the occasion of this 12-day test, it was decided to put the SMPS during 48 hours in the lab truck in order to assess the granulometric distribution of the aerosol outside the station. Drawing on a same figure profiles of the numerical concentration outside the station in the 29 – 259 nm range and of the concentration inside the station simultaneously measured by the ELPI and multiplied by the inverse of the here above coefficient shows that the sudden changes measured outside by the SMPS are not passed on to the underground station. Indeed the amplitude of variations in station is very smoother. However, profiles follow each other. Apparently a transfer exists from an atmosphere to the other. Granulometric distributions should be compared to each other.

2.4. Comparison of granulometric distributions inside and outside the station

Figure 2 shows the mean profiles obtained by means of SMPS in both environments. The profile of the underground aerosol represents a 12-day mean while the profile of the outside one has been calculated from the 15-min data of two days.

Figure 2 : Numerical granulometric distribution

Figure 2 : Distribution granulométrique en nombre



However, profiles are very close to each other in terms of amplitude and, therefore, of concentration for each granulometric range. It can be seen too that mode values of respective aerosol profiles are close to each other. Those remarks reinforce the assumption of a link between the environments and of an aerosol transfer, at least in this size range.

2.5. Correlation between traffic and numerical concentration

The PM_{10} concentration continuously measured in metro stations has the advantage of being well correlated to some operating parameters such as train traffic or the number of passengers entering the station.

We took advantage of this survey to look whether a correlation exists between the increase in numerical concentration in particles underground and that one of the number of trains passing through the station. This part of the test was implemented early on in two mornings when the operation is resuming. Considering the line of the variation of the correlation coefficient according to the granulometry, it can be noticed a low correlation for particles smaller than a score of nm. This observation should be relativized since the SMPS condensation nuclei counter has not an optimum counting efficiency below 20 nm. This could be the origin of the lack of apparent correlation. However, as soon as the size exceeds a few tens of nm, a very better correlation is noticed between the numerical concentration in particles in suspension and the number of trains passing through the station. This verified with ELPI data too for bigger granulometries.

Conclusion

Thanks to this four-week long test, we were able to measure that PM_{10} concentration is higher inside the station than outside. Besides, a marked correlation can be noticed between PM_{10} concentration and the metro operation. As far as the chemical composition of this aerosol of the station atmosphere is concerned, it is very little altered by soluble elements such as sulphates and nitrates featuring the aerosol of the outside atmosphere. An enhancement in organic carbon featuring the presence of an internal source has also been noticed. The PM_{10} aerosol mainly contains metallic elements partly due to the emissions by train braking. However there are unidentified sources which should likely contribute to the remainder of those elements and explain the presence of other elements, such as lead for instance.

The implementation during 12 days of ELPI and SMPS at the platform level has for the first time made it possible to define the numerical granulometric distribution of the aerosol of the atmosphere of a network station. It features a peak between 35 and 40 nm all the day long and is similar to the distribution of the aerosol of the outside atmosphere, which evokes a transfer of the submicronic aerosol from an atmosphere to the other. Finally, we were able to show that operation resumption leads to an increase in numerical concentrations of the aerosol above a score of nm.

One additional test performed at the beginning of the year 2006 (Daniel, 2006) gives a new piece of information about the contribution of the outside atmosphere to the submicronic aerosol in the underground network.

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Représentativité spatiale d'une station de mesure

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Résumé

Une définition de la représentativité spatiale d'une station de mesure de la pollution de l'air par le NO_2 est énoncée puis testée sur l'agglomération rouennaise pour l'année 2000. A partir d'une notion empirique (une station de mesure est représentative d'un point géographique si les concentrations aux deux sites sont proches), nous formalisons mathématiquement la représentativité. Le problème est traité par des techniques de krigeage ; il revient alors à majorer l'erreur d'estimation. En utilisant son écart-type et l'inégalité de Bienaymé-Tchebychev, on peut sélectionner les points qui satisfont la notion de représentativité. La mise en œuvre pratique permet de produire des cartes de zones de représentativité des stations. On peut aussi déterminer la station la plus représentative d'un point donné et l'écart associé. Enfin, pour chaque zone, on peut aussi indiquer des probabilités de dépassement d'un seuil.

Mots-clefs : *Représentativité, cartographie, géostatistique, variabilité spatiale, pollution de l'air.*

Abstract

Reims 2006: Spatial representativeness of an air pollution measurement

The notion of representativeness is mentioned in many legislative texts on air quality monitoring. The work presented here (Anne CORI 2005-training) aims at defining the spatial representativeness of a measurement station with regard to the annual average of NO_2, then test this definition by applying it to the city of Rouen for the year 2000.

The work was carried out in the spatial probabilistic framework of geostatistics, which is well suited for such tasks. The definition of representativeness is written as follows: a measurement station is representative of a given geographical location if the concentrations at these sites are sufficiently similar. Since pollution is only measured at the station, the problem is dealt with by using kriging techniques; the next step is to increment

the estimation error. By using its standard deviation and Bienayme-Tchebychev inequality, we can select the points that satisfy the notion of representativeness. There will then be a good chance (for a fixed risk) of seeing the difference of their concentration with that of the station becoming sufficiently low.

The practical implementation of these theoretical definitions is to produce maps of areas representative of the stations. It is also possible to determine, for any point of a region, the most representative station and its associated difference (by assigning an acceptable risk to it). Lastly, for each area, it is also possible to indicate the probabilities of overshooting a threshold.

The intuitive definition chosen to express representativeness results in several possible areas (as a function of the choices made). The definition of areas around stations must be combined with the determination of the accepted risk, and the maximum tolerated difference between the concentrations in the area and the station. Full spatial knowledge of the phenomenon is primordial in order to achieve the most efficient mapping.

Keys-words: Representativeness, cartography, geostatistics, spatial variability, air pollution.

Introduction

La notion de représentativité apparaît dans de nombreux textes légiférant la surveillance de la qualité de l'air. Mais il n'existe aujourd'hui aucune définition de cette représentativité, et notamment aucun document de référence auquel les textes de loi pourraient nous renvoyer.

Il nous semble que la notion de représentativité devrait être dépendante de l'objectif recherché ; par exemple, la représentativité spatiale d'une station de mesure pour la moyenne annuelle en NO_2 devrait être assez différente de celle qui concernerait une moyenne horaire (on peut facilement imaginer, par exemple, que la direction du vent détermine une zone de représentativité qui s'allonge "sous le vent", et prend donc un sens complètement différent).

Le travail présenté ici vise – en formalisant une idée empirique – à définir la représentativité spatiale d'une station de mesure vis-à-vis de la moyenne annuelle en NO_2 sur une agglomération, puis à éprouver cette définition en l'appliquant à l'agglomération rouennaise pour l'année 2000. Il a été réalisé dans le cadre probabiliste spatial de la géostatistique qui est bien adapté à cela.

Objectifs et Méthode

1. Définitions

La notion empirique sur laquelle nous nous sommes basés pour définir la représentativité est la suivante : une station de mesure est représentative d'un point géographique donné si les concentrations moyennes annuelles en chacun de ces deux sites sont relativement similaires. La zone de représentativité de la station sera donc constituée par l'ensemble de tels points. Notons bien que

c'est un choix et que d'autres idées peuvent être émises, notamment sur les dépassements de seuil ou encore sur la "dynamique" du phénomène (par exemple, une différence peut être acceptée dans la mesure où les chroniques temporelles présentent les mêmes variations).

La notion retenue peut s'écrire mathématiquement :

(1) $$\left|Z(x)-Z(x_0)\right| \leq \delta$$

où x_0 est l'emplacement de la station (ses coordonnées : $x_0 \in X \subset IR^2$), x un point géographique quelconque, et $Z(x)$ la concentration moyenne annuelle en NO_2 mesurée en un point x. La zone de représentativité de la station est alors définie par l'ensemble des x qui vérifient cette inégalité.

Dans le cadre géostatistique, le phénomène mesuré est vu comme une réalisation d'une fonction aléatoire. Techniquement, pour estimer le phénomène, on définit alors le variogramme qui peut présenter un palier, valeur constante atteinte à partir d'une certaine portée. Au-delà de cette distance, les concentrations ne sont plus liées d'un point de vue statistique (spatial). Dans ces conditions, il parait hasardeux de dire qu'une station est représentative d'un point situé à une distance supérieure à la portée (d'un point de vue pratique, cela permet de faire en sorte que la zone de représentativité ne soit pas trop étendue, jusqu'à inclure des sites qui n'auraient plus rien à voir avec elle). Toutefois, cette hypothèse ne peut être utilisée qu'en présence d'un phénomène stationnaire (au moins localement). Dans notre cas, cela nous conduit à travailler à une échelle adaptée (l'agglomération et l'année entière) avec des types de mesures homogènes (fond urbain).

D'un autre côté, on peut se dire que, même si deux sites sont suffisamment éloignés l'un de l'autre pour garantir une absence de corrélation spatiale entre leurs mesures, le comportement du phénomène pourrait quand même être relativement identique. Par exemple, un milieu et un climat similaires devraient induire des niveaux de pollution assez semblables. En géostatistique, cela peut se traduire par l'utilisation d'une variable auxiliaire. Malgré tout, la difficulté majeure est alors de bien caractériser les environnements ainsi que leur homogénéité à travers cette variable…

Ces deux approches sont testées dans la suite du travail.

2. Formalisation

Pour une station donnée, nous cherchons donc l'ensemble des points x de l'espace géographique tels que $\left|Z(x)-Z(x_0)\right| \leq \delta$. Bien sûr, on ne peut pas résoudre directement ce problème car si $Z(x_0)$ est connu, à l'inverse tous les $Z(x)$ ne le sont pas : on ne mesure évidemment pas la concentration en n'importe quel point… A partir d'un échantillon de mesures $\{Z(x_i)\}_{1\leq i\leq n}$, les techniques de krigeage permettent d'estimer de façon optimale Z :

$$Z(x) = Z^*(x) + \varepsilon(x), \quad \forall x \in X \subset IR^2 .$$

De plus, lorsqu'une variable auxiliaire f, connue partout et bien corrélée à Z, peut être utilisée, on effectue la décomposition $Z(x) = f(x) + R(x)$, et c'est le résidu R que l'on estime :

$$R(x) = R^*(x) + \varepsilon_R(x), \quad \forall x \in X \subset IR^2 .$$

Pour que l'inégalité (1) soit satisfaite, il suffit alors que

$$|\varepsilon(x)| \leq \delta - |Z^*(x) - Z(x_0)|$$

ou que

$$|\varepsilon_R(x)| \leq \delta - |f(x) + R^*(x) - Z(x_0)|.$$

On remarque que, puisque $Z^*(x_0) = Z(x_0)$ (le krigeage est un interpolateur dit "exact"), l'inégalité est bien vérifiée pour la station ($x = x_0$) qui appartient de fait à sa propre zone de représentativité.

Le problème revient donc à majorer l'erreur d'estimation. Il va de soit que cette erreur est inconnue ; toutefois le cadre géostatistique permet de fournir son écart-type $\sigma(x)$ (l'écart-type d'estimation), ainsi que son espérance qui est nulle d'après la contrainte de non biais du krigeage.

L'inégalité de Bienaymé-Tchebychev appliquée à $\varepsilon(x)$ donne $P(|\varepsilon(x)| > k.\sigma(x)) \leq 1/k^2$, ce qui peut s'écrire, pour tout k réel :

(2) $$P(|\varepsilon(x)| \leq k.\sigma(x)) > 1 - 1/k^2$$

Lorsque la variable aléatoire (Z ou R) est gaussienne, ce qui est réaliste dans notre étude, on peut écrire de façon plus précise :

(2') $$P(|\varepsilon(x)| \leq q_\alpha.\sigma(x)) > 2.\alpha - 1$$

où q_α est le quantile d'ordre α d'une loi normale centrée-réduite.

On obtient ainsi l'implication suivante :

(3)
$$q_\alpha.\sigma(x) + |Z^*(x) - Z(x_0)| \leq \delta \quad \Rightarrow \quad P(|Z(x) - Z(x_0)| \leq \delta) \geq 2.\alpha - 1$$

Pour définir la zone de représentativité, on se fixe un risque ($1 - P$) ; à ce risque près, on sélectionnera les points qui vérifient la première inégalité : ils auront alors de bonnes chances de voir l'écart de leur concentration à celle de la station rester suffisamment petit (inférieur à δ).

3. Interprétation

D'après le membre de droite de (3), la probabilité d'un faible écart entre les concentrations dépasse un seuil fixé. Par exemple, pour un risque de 0.05 et $\delta = 5$, à l'intérieur de la zone de représentativité, on pourra dire avec une probabilité de plus de 95%, que la concentration diffère de celle de la station de moins de 5 µg/m^3, du moins dans le modèle.

On retient ainsi les points x dont les concentrations sont assez proches de celle de la station, avec un certain risque "acceptable" de se tromper – risque qui est lié au fait que, en dehors des stations, nous utilisons des estimations en lieu et place de mesures.

Classiquement, on se fixe un risque de 5%. On a alors $2.\alpha - 1 = 0.95$, soit $\alpha = 0.975$, ce qui correspond bien à un risque symétrique de 5%, et à ce moment là $q_\alpha = 1.96$.

Pour constituer la zone de représentativité, il reste à sélectionner les points x tels que

(4) $$\zeta(x) = 1.96\,\sigma(x) + \left|Z^*(x) - Z(x_0)\right| \leq \delta$$

Ici $Z(x_0)$ est connue (mesurée), $Z^*(x)$ et $\sigma(x)$ sont calculés (krigeage) et δ est fixé. Avec une variable auxiliaire, cela donnerait :

(4') $$1.96\,\sigma(x) + \left|f(x) + R^*(x) - Z(x_0)\right| \leq \delta$$

Remarque : pour un même risque fixé, k est plus important que q_α (par exemple, pour un risque de 5 %, $k = 2\sqrt{5} \approx 4.47 \approx 2.28\,q_\alpha$) ; une erreur d'estimation gaussienne permet donc d'inclure dans la zone de représentativité des points où l'écart-type d'estimation est jusqu'à deux fois plus élevé que dans la zone correspondante calculée sans l'hypothèse de la normalité de l'erreur.

Résultats et discussion

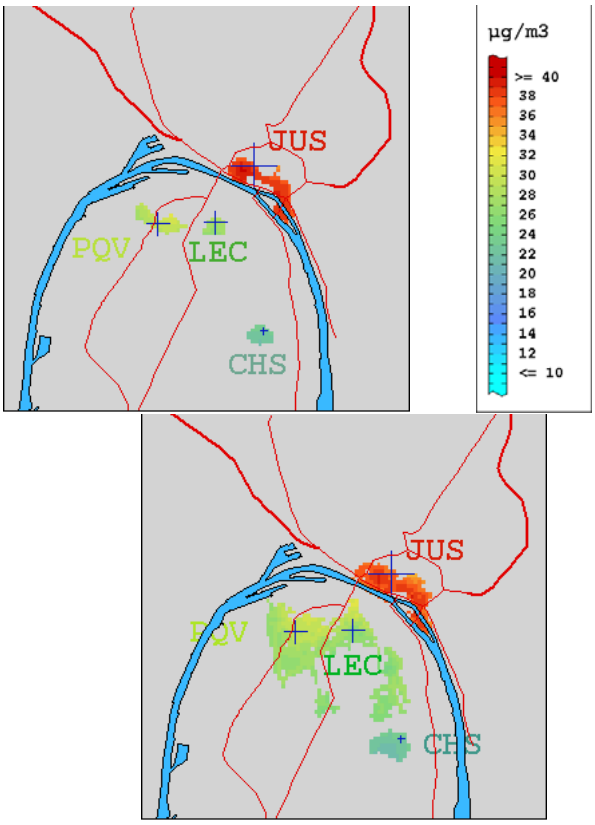
Ces définitions théoriques ont été mises en œuvre sur les résultats de mesure par tubes à diffusion, effectuées pour l'année 2000 sur l'ensemble de l'agglomération rouennaise. La campagne regroupait 80 sites équipés pendant 6 périodes de 2 semaines réparties uniformément dans l'année ; la moyenne annuelle en chaque site est considérée égale à la moyenne des 6 concentrations bi-hebdomadaires.

1. Application directe

Les cartographies obtenues (Figure 1) ne donnent pas forcément des résultats très exploitables pour plusieurs raisons que nous allons passer en revue.

Figure 1 : Ensemble des zones représentées par les stations (erreur gaussienne, δ =5µg/m^3, P =0.95) sans variable auxiliaire (à gauche) et avec variable auxiliaire (à droite)

Figure 1: Areas represented by the measurement stations with respect to annual NO_2 (on the basis of Gaussian errors, difference less than 5 µg/m^3 and assessment risk of 5%), without auxiliary variable (on the left) and with auxiliary variable f (on the right)



D'une part, on peut facilement montrer que δ ne peut pas être choisi plus petit qu'une certaine valeur, ce qui aurait pour effet de réduire la zone de représentativité à la station seule (en effet, pour un risque et un écart acceptable fixés, le membre de gauche de l'inégalité (4), $\zeta(x)$, varie entre une borne inférieure $\zeta_{\min}$ et une borne supérieure $\zeta_{\max}$; or on cherche x tel que $\zeta(x) \leq \delta$; δ ne pourra donc pas être choisi plus petit de $\zeta_{\min}$). Concrètement, une zone de représentativité à ± 2 µg/m^3 (par exemple) peut ne pas aboutir si la qualité de l'estimation spatiale n'est pas assez bonne. Dans cet exemple, il faudrait que $\sigma(x)$ soit largement inférieur à 1.

D'autre part, la difficulté d'application est largement due au fait que la zone de représentativité est très dépendante du plan d'échantillonnage $\{x_i\}_{1 \leq i \leq n}$.

Autour des points x_i qui ont à peu près la même valeur de concentration que la station x_0, on a $Z^*(x) \approx Z(x_0)$ et $\sigma(x)$ est très faible en raison de la proximité du point de donnée. Au contraire, loin de x_i, $\sigma(x)$ a tendance à être fort et donc les points vérifient difficilement l'inégalité (4), ce qui ne veut pas dire que leur concentration réelle diffère beaucoup de celle de la station ! Simplement nous n'en savons rien… De même, la condition suffisante que nous avons choisie n'est pas une condition nécessaire : il y a probablement des points dont la concentration est proche de celle de la station (à moins de δ), mais nous ne pouvons pas les détecter, notamment s'ils ont un écart-type d'estimation trop élevé, et en particulier s'ils sont trop éloignés des points de donnée.

Il s'agit là d'un "artéfact" incontournable de la méthode. D'abord, il faut accepter et bien garder présent à l'esprit le risque inhérent lié au cadre probabiliste dans lequel les calculs sont menés. Ensuite, nous pouvons évoquer diverses possibilités raisonnables qui permettent d'augmenter l'applicabilité de la méthode : par exemple, le plan d'échantillonnage peut être densifié, les zones peuvent être réduites en "coupant" à un certain pourcentage de la portée ou en ne conservant que les zones continues, le risque statistique peut être diminué, on peut intégrer une variance d'erreur de mesure, etc…

2. Rattachement d'un point à une station

Malgré les limites méthodologiques évoquées ci-dessus, des résultats intéressants sont obtenus, parmi lesquels l'obtention de zones de représentativité pouvant se superposer partiellement. Un point du territoire peut donc être représenté par plusieurs stations, mais plus ou moins bien. On peut même ajouter qu'un point est théoriquement représenté par toutes les stations. Cela ouvre diverses perspectives quant à l'étude des redondances de stations ou de l'optimisation du plan d'échantillonnage, mais aussi sur une autre façon de voir la représentativité : au lieu de chercher les points dont une station est représentative, nous pourrions inversement déterminer pour tout point du territoire la station disponible la plus représentative, et l'écart δ associé, en se fixant un risque acceptable.

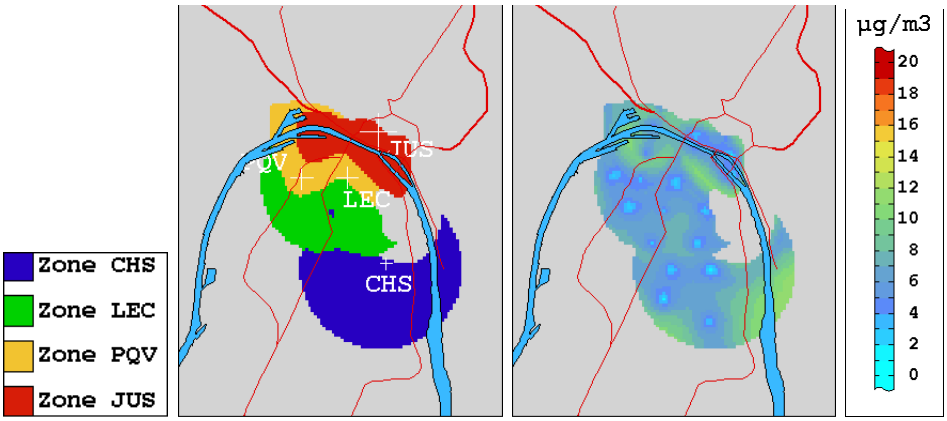
Pour cela, en chaque x, on cherche la station x_0 telle que $\zeta(x_0) = q_\alpha.\sigma(x) + \left|Z^*(x) - Z(x_0)\right|$ est minimal : et on la note $x_0^* = \arg\min \zeta(x_0)$. $\delta = \zeta(x_0^*)$ est alors l'écart maximal entre les concentrations (avec le risque choisi).

En chaque point, on peut ainsi dire quelle station est représentative à moins de δ µg/m^3 près avec un risque α de se tromper (Figure 2). Pour conserver des résultats raisonnables, on peut restreindre les zones avec la portée et/ou avec un seuil sur $\zeta(x_0^*)$. On aura alors des points qu'il est impossible de rattacher à une station, avec un écart inférieur au seuil dans ce dernier cas. Souvent ces points peuvent correspondre à des zones sous-échantillonnées,

ou à des milieux plus ou moins rares pour lesquels aucune station ne correspond.

Figure 2 : Rattachement de chaque point à une station dans un rayon de 2.75 km (sans variables auxiliaires) : ensemble des zones rattachables aux stations (à gauche), écarts maximaux par rapport à la station de rattachement (à droite)

Figure 2: Connecting each geographical point to a measurement station within a radius of 2.75km (without auxiliary variable) leads to these areas, each related to a station (on the left), with maximum differences given against the connecting station (on the right).



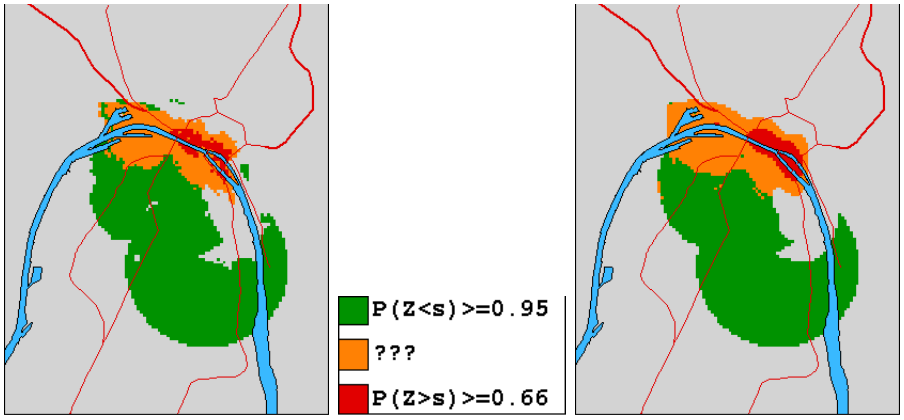
3. Risque de dépassement

Au bout du compte, on sait que $Z(x) \in [Z(x_0) - \delta\,;\, Z(x_0) + \delta]$ avec la probabilité P. Par rapport à un seuil s fixé (la valeur limite par exemple), on pourra donc dire que la concentration réelle en x est inférieure (respectivement supérieure) à s avec la probabilité P si $s > Z(x_0) + \delta$ (respectivement si $s < Z(x_0) - \delta$) ; si s est entre ces deux valeurs, alors on ne pourra rien dire.

Pour mieux faire apparaître les dépassements de seuil, on peut séparer les risques (en analogie avec les risques de première et deuxième espèces) : par exemple, $P(Z < s) \geq 0.95$ et $P(Z > s) \geq 0.66$ (Figure 3). Pour minimiser les zones d'incertitude, il faut alors que δ soit le plus petit possible.

Figure 3 : Zones de dépassement ou non de seuils dans un rayon de 2.75 km (sans et avec variables auxiliaires)

Figure 3: Areas, within a radius of 2.75 km, showing pollution overshooting a threshold with a probability of 66%, and showing pollution below the threshold with a probability of 95% (without and with auxiliary variable).



Conclusion

Une définition intuitive de la représentativité des stations de mesure a été transcrite en termes géostatistiques. Ce formalisme mathématique aboutit à plusieurs zones possibles, selon les choix effectués et la façon dont on regarde les choses, qui ne sont pas forcément contradictoires mais souvent complémentaires.

La définition de zones autour des stations doit s'accompagner de la détermination du risque accepté ainsi que de l'écart maximal toléré entre concentrations (ici les moyennes annuelles) dans la zone et à la station. Cet écart ne peut pas être librement choisi (borne min), et une connaissance spatiale du phénomène, qui soit la plus complète possible, est primordiale.

Determination of PM10 Sources in the Proximity of Roads

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Abstract

A new method is carried out to relate PM10 concentrations to different sources and fractions. It is based on standard measurements of nitrogen oxides and PM10. The portions of primary particle emissions from traffic, from heating and from secondary formation from gaseous traffic emissions can be determined. An attempt will be made to include the contribution from agriculture by this method.

Keys-words*: PM10, secondary particle formation, sources of PM10, wood burning.*

Introduction

Monitoring sites in the proximity of roads have special importance with respect to direct observation of the environmental impacts of traffic. Whereas other pollutants like nitrogen oxides, ultra fine particles and mostly also soot originate mainly from traffic sources at such sites, PM10 is only partially due to traffic. Different methods have been developed that relate PM10 concentrations to different sources and to the secondary particles formed from gas-to-particle conversion, based on standard measurements of PM10 and nitrogen oxide.

Objectives

PM10 concentrations are related to different sources and fractions by several methodical steps:

First the contribution of primary particle emissions of traffic has to be determined. For that purpose, our empirical model to treat nitrogen oxide pollution near roads was adapted, Thudium (2005a): The ratio between air pollutant concentration and initial emission is determined by topography and meteorological dispersion conditions. The starting-point of our model is that empirical ratio, which is determined for each hour from measurements (traffic, air pollution). The real dispersion conditions are empirically known and need not be estimated from parameters. A dynamic backdrop of air pollutants, variable in

time, has to be considered, originating in earlier emissions and those from other sources.

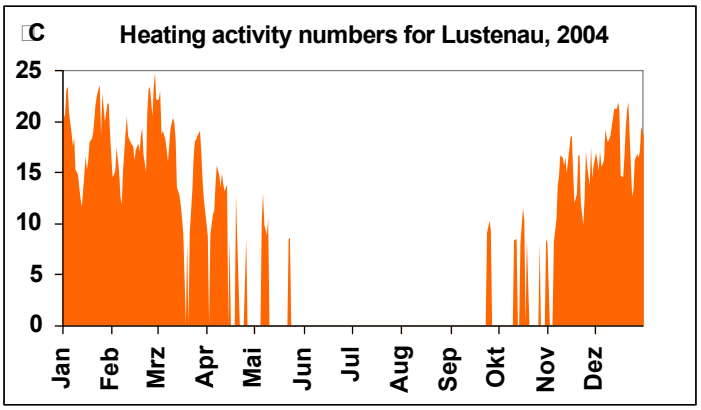
The contribution of heating is derived from the temperature dependence of PM10 concentration without the primary fraction. In this case it has to be considered that the formation of secondary particles increases with colder temperatures, what has different effects at different weekdays.

The amount of secondary particles, originating from gas to particle conversion, shows a distinctive dependence on the weekday, shifted by one day compared with the gaseous emissions of traffic. Finally singular particle events – as waste burning – can be detected.

These different steps allow determining the sources of PM10 pollutants in the proximity of roads. This is a condition for evaluating the impact of abatement strategies on PM10 concentrations. For instance, local traffic reduction only leads to a reduction of primarily emitted particles, whereas emission factor reductions cause a decrease of the primary and secondary PM10 fraction.

Furthermore, the influence of agriculture is not yet well known, especially the variability with season: Many high concentration episodes of PM10 occur during winter time, when the agricultural emissions may not be as high as in the yearly mean. A better estimation of the impact of agriculture on PM10 in its seasonal variability will be one of the next aims.

Figure 1: Heating activity numbers for Lustenau, 2004.

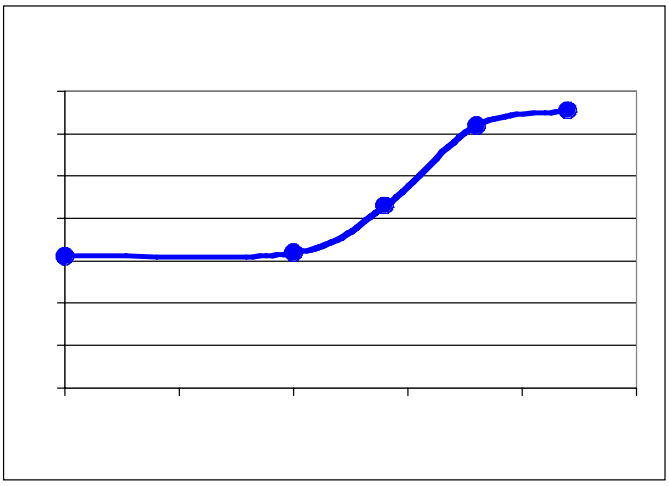


Example of an urban area

The relation of PM10 to its different sources was made for a measuring site nearby a crossroads with a large number of heavy duty vehicles in the Austrian city of Lustenau (Vorarlberg), Thudium and Grimm (2005). Under the assumption that PM10 particles primarily emitted by local traffic are spread under the same meteorological conditions as nitrogen oxide, their part at the total mass of PM10 at that station was estimated to 25%. The yearly average of PM10 at this site was 28 µg/m3 in 2004.

Considering the portion of PM10 originating in heating, the temperature dependence of PM10 concentration, based on diurnal averages, was analyzed. For that purpose, a measure for heating activity was used: The positive difference of the diurnal average temperature to 20 °C if being lower than 12 °C was used; this corresponds to the fact that people generally start heating when a certain lower temperature is reached. Figure 1 shows the yearly distribution of heating activity numbers. PM10 concentrations (without the portion of primary particles from local traffic) show a strong dependence on heat activity numbers, in figure 2 divided in classes of 4 degrees each. The portion above 15 µg/m3 is the so called 'temperature dependent fraction'. Not the whole fraction can be associated to heating: Some formation of secondary particles from the gaseous phase is intensified with lower temperature, especially from nitrogen oxide. A very useful instrument in this case is the separation in the 7 weekdays, because emissions of traffic vary strongly with weekday. We find a strong correlation (correlation coefficient of 0.97) between the temperature dependent fraction of PM10 and emission of NOx of the actual and the previous day, averaged for all weekdays over one year (figure 3). Only the intercept is related to heating, increased by an estimated quarter corresponding to the fact that some buildings in the city are not heated as much during weekends.

Figure 2: PM10 pollution and heating activity number (han) for Lustenau, 2004.



As for the remainder of the PM10 concentration, without the portion of primary particles from local traffic and not depending on temperature, a large part comes from regional traffic sources and above all secondary formation from gaseous traffic emissions. This portion also shows a strong dependence on specific weekdays: We find also here a strong correlation (correlation coefficient of 0.94) between remaining fraction of PM10 and emission of NOx of the actual and the previous day, averaged for all weekdays over one year (figure 4). The intercept amount is 'other sources' and cannot be allocated to distinguished sources. Special events are also included in this amount.

Hence the distribution of different PM10 fractions presents itself as shown in figure 5, for the whole year and for all days with a diurnal average above the limit value of 50 µg/m3. In the last case, the portion from heating is considerably higher, because days with PM10 pollution above the limit value mostly occur during winter time. This indicates that the emissions of heating should not entirely be disregarded, although the traffic emissions contribute much more over the whole year.

Figure 3: Correlation between PM10 fraction, temperature dependent, and emission of NOx of the current and previous day, averaged for all weekdays, Lustenau 2004.

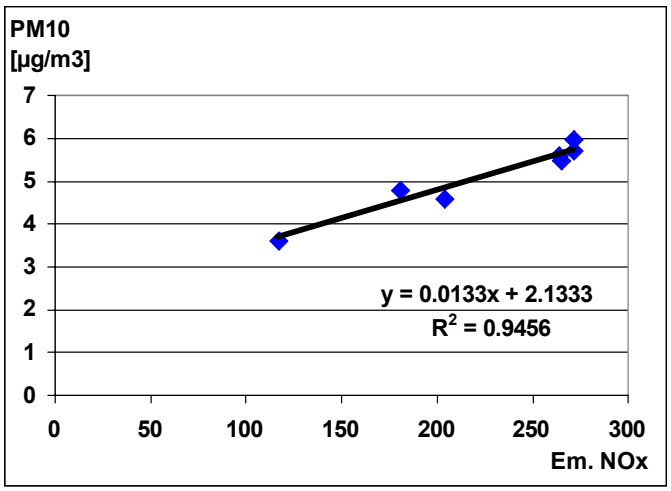


Figure 4: Correlation between the remaining PM10 fraction, without the portion of primary particles from local traffic and not depending on temperature, and NOx emissions of the current and previous day, Lustenau 2004.

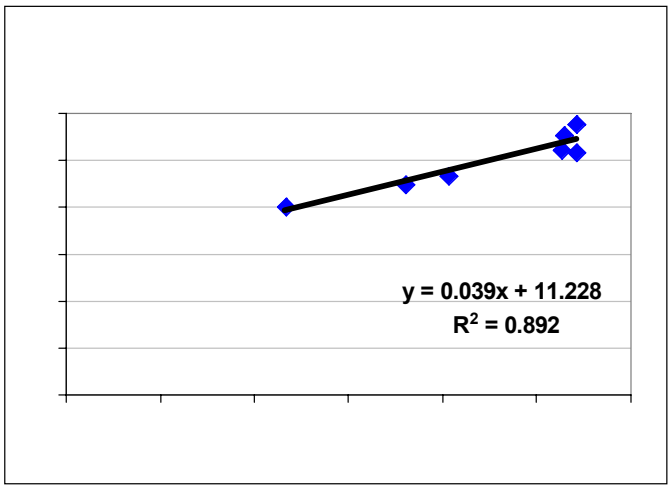
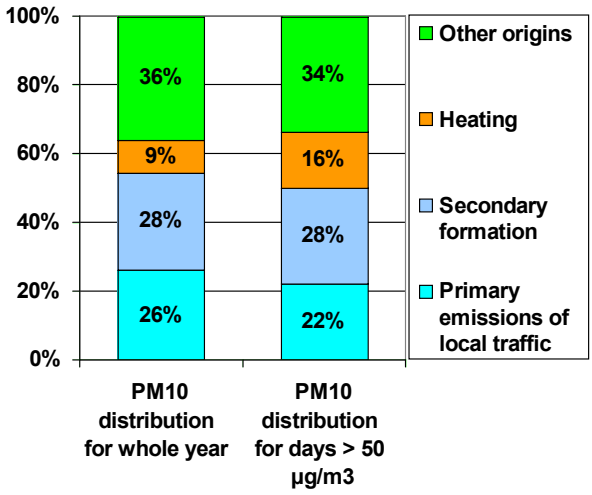


Figure 5: Origins of PM10 pollution, relative portions, Lustenau 2004. 'Secondary formation' means secondary formation of particles from traffic emissions and primary regional traffic sources.



The distribution of PM10 fractions found by this method corresponds very well with an estimation based on emission inventory performed by the environmental institute of Vorarlberg.

Example of alpine area with highway and wood burning

In this example, the relation of PM10 to its different sources is demonstrated for a measuring site in a valley in the southern Swiss Alps, Roveredo; it is situated nearby a highway with little traffic, but a quite large number of heavy duty vehicles, Thudium (2005b). In this valley, wood burning is a widespread method of heating, and different procedures in this context may be improvable. Under the assumption that PM10 particles primarily emitted by local traffic are spread under the same meteorological conditions as nitrogen oxide, their part at the total mass of PM10 at that station was estimated at 10%. The yearly average of PM10 at this site was 24 µg/m3 in 2004.

The yearly distribution of heating activity numbers (explanations see section 2) appears very similar to Lustenau (figure 1) and is not shown here again. PM10 concentrations (without the portion of primary particles from local traffic) also show in that quite a strong dependence on heat activity numbers, similar to Lustenau as shown in figure 2. However, unlike Lustenau, there is no correlation between the temperature dependent fraction (explanations see section 2) of PM10 and emission of NOx of the actual and the previous day, averaged for all weekdays over one year; this indicates that the whole temperature dependent fraction has to be related to heating: those emissions appear to dominate the temperature dependent fraction.

The remainder of the PM10 concentration, without the portion of primary particles from local traffic and not dependent on temperature, shows a dependence on weekday with a correlation coefficient of 0.74 between the remaining fraction of PM10 and emission of NOx of the actual and the previous day, averaged for all weekdays over one year (figure 6). The intercept amount is 'other sources' and cannot be allocated to distinguished sources.

Hence the distribution of different PM10 fractions presents itself as shown in figure 7, for the whole year and for all days with a diurnal average above the limit value of 50 µg/m3. In this case the part of heating related to PM10 pollution is extraordinarily high: 14% of the average of the year, even 30% for those days exceeding the limit value of 50 µg/m3. The reason for this effect is widely spread wood combustion, with may be improved by technical precautions.

The distribution of PM10 fractions found by this method corresponds very well to the EC/OC-analysis performed by the regional environmental authority of canton Grisons.

Figure 6: Correlation between the remaining PM10 fraction, without the portion of primary particles from local traffic and not depending on temperature, and NOx emissions of the current and previous day, Roveredo 2004.

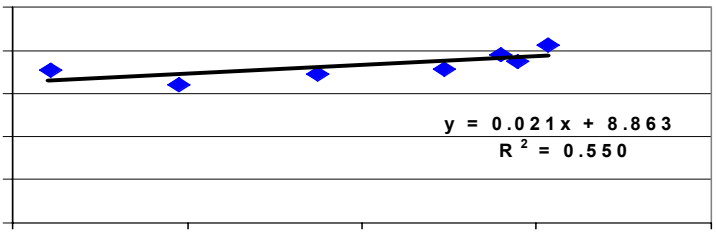
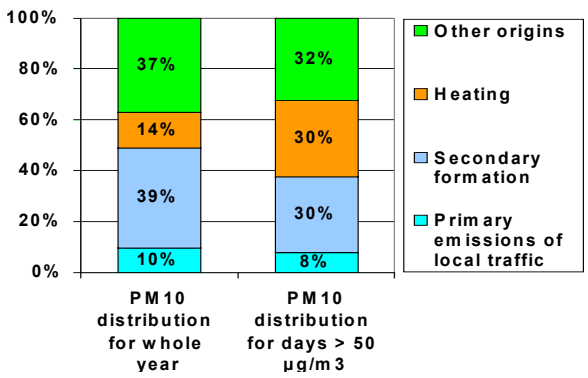


Figure 7: Origins of PM10 pollution, relative portions, Roveredo 2004. 'Secondary formation' means secondary formation of particles from traffic emissions and primary regional traffic sources.



Conclusion

The presented step by step method to relate PM10 pollution to different sources and fractions is very suitable for standard measurements of PM10 and nitrogen oxides at various sites.

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Carbonaceous species of PM2.5 from road tunnel as tracers of the real traffic emissions

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Abstract

The potential of application of speciated PM2.5 emission factors and traffic data for the estimation of the primary elemental/organic carbon (EC/OC) ratio in PM2.5 "real-world" traffic emissions is discussed. Observed values for the EC/OC ratio in PM2.5 samples collected at a road tunnel site in Milan are compared to values calculated based on literature emission factors for the two carbonaceous species and on average traffic flow data. Since emission factors span over a wide range of values, calculations are performed by means of the Monte Carlo technique in order to combine information from different authors. The same approach is also applied to compare the calculated and the observed relative contribution of resuspended road dust to PM2.5 mass.

Key-words*: Fine particulate matter, EC/OC, Tunnel measurements, Real world traffic emissions, Road dust, Monte Carlo simulation.*

Résumé

Les facteurs d'émissions du PM2.5 en termes d'espèces chimiques à base de carbone ont été combinés avec des données du trafic routier pour l'évaluation du rapport entre carbone élémentaire et organique (CE/CO) dans le PM2.5. La combinaison a été réalisée à l'aide de la technique Monte Carlo pour synthétiser les facteurs d'émissions proposés par différents auteurs dans la littérature. Les résultats sont comparés avec le rapport observé dans les échantillons de PM2.5 collectés dans un tunnel situé dans la ville de Milan. Ceux-ci représentent les émissions du trafic réel. La même méthodologie a également été appliquée pour comparer les quantités calculées et mesurées de poussière soulevée par les véhicules dans le tunnel.

Mots-clef : *PM2.5, CE/CO, Emissions du trafic routier, Tunnel, Technique Monte Carlo*

Introduction

Carbonaceous species, organic carbon (OC) and elemental carbon (EC), are one of the major components of fine atmospheric particulate matter (PM) in urban areas. In Milan (Italy), the overall contribution of particulate organic matter and elemental carbon to PM2.5 mass ranges between 38% and 42%, with the highest contribution in the winter period, Lonati et alii (2005).

The value of the OC/EC ratio has been used as an indicator of the secondary organic aerosols (SOA) formation in the atmosphere, Hildemann et alii (1991), and the primary $(OC/EC)_P$ ratio approach was proposed in order to assess the contribution of SOA to PM ambient concentration, Turpin & Huntzicker (1991). According to this approach, elemental carbon is assumed as tracer of primary organic carbon and the $(OC/EC)_P$ ratio, which is not consistent from source to source but varies between different sources, Gray et alii (1986), is the ratio for the local primary emission source affecting the measured concentrations, Cabada & Pandis (2002).

For the traffic source, the $(OC/EC)_P$ ratio, or its reciprocal $(EC/OC)_P$, may be estimated from traffic inventory data or directly measured in PM samples collected at traffic exposed sites. The former approach relies on chemically speciated PM emission factors (EFs), usually derived from dynamometer tests for single vehicles under different driving conditions, and on the composition of the circulating fleet. A reliable data set for emission factors of the carbon species and data on the actual traffic composition are required in order to properly evaluate the $(OC/EC)_P$ ratio. The latter approach, based on PM chemical speciation data, can provide information on the “real-world” traffic emissions, which describe actual traffic emissions, from the in-use vehicle fleet. In particular, PM composition data from samples collected at road tunnel sites are very useful since they are not affected by meteorological effects, which can conversely influence the composition of ambient PM data from curbside sites close to busy roads, Colberg et alii (2005). Therefore, tunnel data provide a more reliable information on the primary $(OC/EC)_P$ ratio for traffic emissions.

Since speciated PM emission factors are still scarce in literature and mostly related to U.S. studies, in this work the potential of application of the EFs-based approach is discussed by comparing the results provided by the two approaches for a tunnel site. A primary EC/OC ratio is calculated based on traffic flow data for a road tunnel in the city centre of Milan and on literature emission factors for elemental and organic carbon in traffic emitted PM2.5, then it is compared to measured data from the speciation of PM2.5 samples from the same road tunnel.

Moreover, because speciation data point out a rather large enrichment in crustal matter for the PM2.5 tunnel samples compared to average ambient air samples in Milan (8.2% vs. 3.8%), the EFs-based approach is also applied in order to calculate the relative contribution of the road dust to PM2.5 mass. The resulting estimated contribution is then compared to the observed contribution.

Materials and methods

The road tunnel considered in this work is a 250-m long tunnel in the city centre of Milan which carries a mixed light-duty and heavy-duty vehicle traffic. Traffic flow measurements for selected vehicle categories (passenger cars, light and heavy duty vehicles, motorcycles and buses), were performed on hourly basis for a representative working day from 8 AM to 9 PM. Since measurements do not provide data split between gasoline and diesel-fuelled vehicles, the fleet composition in the tunnel is determined based on ACI (Automobile Club Italia) statistics related to vehicles registered in Milan area for year 2003 (ACI, 2003).

Literature values are used for the average speciated emission factors for carbonaceous species and resuspended road dust contribution, Gillies et alii (2001), Gertler et alii (2002), Gillies & Gertler (2000). Some of these emission factors are collectives, whereas others refer to vehicle categories essentially based on fuel type (i.e., gasoline, diesel) and vehicle use (i.e., light duty, heavy duty). However, a complete match between fleet composition data and available emission factors was not possible and some simplifying assumptions were made as specified in details below.

The tunnel PM2.5 concentration data come from 12-h measurement campaigns performed in November 2002. PM2.5 samples were analyzed for carbonaceous species by TOT method and for elemental species by XRF technique: crustal matter and metal oxides contribution to PM2.5 mass was subsequently calculated as reported in Lonati at alii (2005).

Results and discussion

The actual fleet composition in the tunnel and ACI statistics for Milan area are shown in Figure 1. The vehicle fleet inside the tunnel is composed mainly by gasoline passenger cars (65 %), followed by diesel passenger cars (17%), motorcycles (8%) and commercial diesel vehicles (6%). Heavy duty diesel vehicles, namely buses and trucks constitute only the 2% of the fleet. Hourly traffic flow pattern for gasoline and LPG vehicles (passenger cars and motorcycles), light duty diesel vehicles (passenger cars and commercial diesel vehicles) and heavy duty vehicles is shown in Figure 2. Both the overall and single vehicle class traffic pattern are quite regular throughout the day, with an average traffic of about 2800 vehicles per hour.

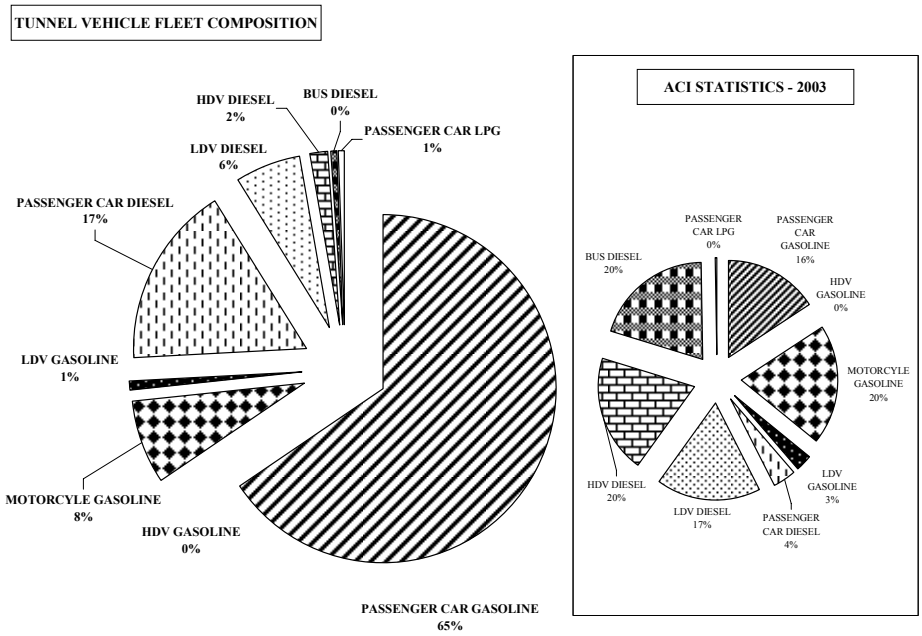
PM2.5 concentration levels inside the tunnel are in the range of 105.9-298.6 $\mu g\ m^{-3}$, with an average value of 204.7 $\mu g\ m^{-3}$. Carbonaceous components largely dominate the PM2.5 mass with a relative contribution of 34.9% ± 3.2% (70.9 $\mu g\ m^{-3}$) for elemental carbon and 23.4% ± 2.3% (47.6 $\mu g\ m^{-3}$) for organic carbon. An EC/OC ratio of 1.50 ± 0.10 is observed. Crustal matter and metal oxides account for 8.3% ± 0.9% and for 1.4% ± 0.2%, respectively.

The EFs-based approach was applied by means of the Monte Carlo technique in order to combine information from different authors. In fact, the literature emission factors span over a wide range of values, sometimes referring to particular traffic conditions and composition. By means of this technique, the variability of the proposed emission factors can be taken into

account and the calculated values can be expressed both as average value and standard deviation of the estimates.

Figure 1: Fleet composition in the tunnel compared to ACI statistics for Milan area

Figure 1 : French translation: Composition du trafic dans le tunnel et dans la zone urbaine de Milan



The daily pattern of traffic flow does not show relevant changes both in fleet composition and overall number of vehicles: hence, the EC/OC ratio can be considered reasonably constant throughout the whole day. The ratio estimated based on average daily traffic composition can therefore be compared to the 12-h averaged observed values.

A first estimate of the EC/OC ratio is obtained by applying Monte Carlo analysis to the elemental and organic carbon emission factors in the PM2.5 reported by Gillies et alii (2001). This ratio (1.58 ± 0.78) is in good agreement with the tunnel ratio.

Some authors report the elemental and organic carbon emission factors apportioned to light duty (LD) and heavy duty (HD) vehicles. Light duty vehicles generally include both gasoline/diesel passenger cars and commercial vans, and heavy duty vehicles buses and trucks. Gillies and Gertler (2000), examining several mobile source emission profile databases, observed a wide range of average EC/OC ratios (from 0.60 ± 0.53 up to 1.42 ± 2.99) for LD gasoline vehicles (LDGV). The corresponding values for diesel vehicles were (from 1.09 ± 2.66 to 3.54 ± 3.07) with the latter value referring specifically to LD diesel vehicles (LDDV). Using these ranges, the EC/OC emission ratio related to the

tunnel circulating fleet is estimated by means of the following linear combination:

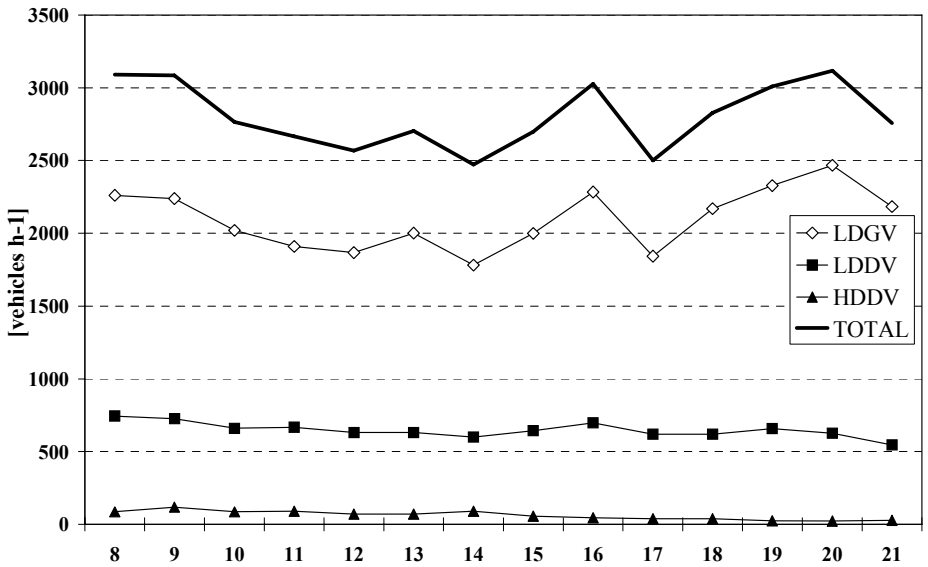
$$\left[\frac{EC}{OC}\right] = \alpha \cdot \left[\frac{EC}{OC}\right]_{LDGV} + \beta \cdot \left[\frac{EC}{OC}\right]_{LDDV} + \chi \cdot \left[\frac{EC}{OC}\right]_{HDDV}$$

[1]

where α, β, and χ represent the fraction of light duty gasoline, light duty diesel, and heavy duty diesel fraction of the vehicle fleet, 0.75, 0.23 and 0.02, respectively. Some simplifying assumptions were made for the application of the emission factors to the tunnel fleet: LDGV encompasses all gasoline vehicles (almost exclusively passenger cars) and motorcycles, LDDV encompasses diesel passenger cars and commercial vehicles, whereas for the HDDV emission factor reported for diesel vehicles was used. This method gives an average EC/OC ratio of 1.56 ± 0.59, consistent with the above mentioned experimental values.

Figure 2: Hourly traffic flow pattern in the tunnel

Figure 2 : French translation: Circulation horaire dans le tunnel



The same methodology and Monte Carlo technique were applied for comparing observed and calculated relative contribution of resuspended road dust to PM2.5 mass in the tunnel. Calculations were separately performed based on the collective speciated PM2.5 emission factors reported by Gillies at alii (2001) and on “road dust” emission factors for gasoline and diesel vehicles reported by Abu-Allaban et alii (2003a, b). According to the former approach, which consider the same elements analyzed for the experimental determination of the crustal matter and the metal oxides, these fractions account for 11% ± 2% of the PM2.5 emissions, with an overall contribution very close to the 10% observed value. On the contrary, the latter approach, where emission factors consider road dust as a whole and do not take into account its actual chemical

composition, results in an estimated contribution of 31% ± 6%, which is greater than the contribution determined in the tunnel samples. However, this difference could be partially explained by the unidentified mass (about 10%) in the tunnel samples, which is much likely constituted mainly by the oxides of the non analyzed elements.

Conclusion

Observed values for the EC/OC ratio in PM2.5 samples collected at a road tunnel site in Milan have been compared to values calculated based on literature emission factors for the two particulate carbon species and on traffic flow data. Due to its curbside position, the monitor is directly exposed to the traffic emissions and the observed EC/OC ratio is representative of the real world traffic emissions: in fact, the concentration levels inside the tunnel are not directly influenced by meteorological conditions or by emission sources other than traffic.

Since emission factors span over a wide range of values, calculations were performed by Monte Carlo simulation technique in order to combine information from different authors.

The average EC/OC ratio estimated by means of collective emission factors (1.58 ± 0.78) is in good agreement with experimental data (1.50 ± 0.10). Traffic data combined with emission factors apportioned for the main vehicle categories also results in an estimated EC/OC ratio (1.56 ± 0.59) consistent with experimental data.

The results of similar calculations for the resuspended soil particles show some differences between observed and estimated relative contribution of road dust to PM2.5 total mass at the tunnel site. In particular, apportioned emission factors are strongly dependent on traffic conditions and composition: the resulting estimated contribution largely exceeds the observed average value (3 times). Conversely, the relative contribution estimated by means of collective speciated emission factors for crustal elements and metals in PM2.5 is more similar to the average of experimental data.

In conclusion, a rather good agreement between measurements and calculated values was observed for both the EC/OC ratio and the relative contribution of soil dust to the total PM2.5 mass, even though emission factors derive from U.S. studies and may not be straightforwardly applied to the European vehicle fleet. Further studies at the European level are required to cover the lack in the speciated PM emission factors for the traffic source.

Acknowledgments

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Ambient air measurements related to traffic : evolution of VOCs over three years

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Abstract

Influence of traffic emission on air quality in European cities has widely been studied. Nevertheless, measurement campaigns are usually limited. We present here a set of VOC measurements which has been collected during 5 to 6 campaigns each year over three years. Ambient air is sampled outside vehicles, inside the traffic. Evolution of the concentrations both in urban and rural air over the 3 years are discussed, compound by compound, and compared to data from literature. Influence of traffic on concentrations is obvious. The major finding is that the concentrations of pollutants related to traffic have been decreasing between 2003 and 2005, specially in urban atmospheres, and in a lesser way, in rural areas.

Keys-words *: air quality, traffic, VOCs, greater Paris area.*

Résumé

Mesures d'air ambiant en conditions de trafic : évolution des COV sur 3 ans.

L'influence des émissions liées au trafic automobile sur la qualité de l'air a largement été étudiée. Cependant, les campagnes de mesures sont généralement limitées, dans la durée et le nombre de composés étudiés. Nous présentons ici les résultats d'un ensemble de campagnes réalisées sur une durée de 3 ans, sur plusieurs composés organiques volatils. Le prélèvement est réalisé à l'extérieur de véhicules en roulage, dans la Région Parisienne, en milieux urbain et semi-rural. L'évolution des concentrations au cours du temps est discutée, et les teneurs sont comparées aux données de la littérature. Le fait marquant est la diminution très importante entre 2003 et 2005 des teneurs pour une majorité des polluants, surtout en milieu urbain, et dans une moindre mesure en milieu rural. La diminution de la teneur en benzène des essences, ainsi que l'amélioration des moteurs et le développement des pots catalytiques, explique largement cette tendance.

Mots-clés : *qualité de l'air, trafic, COV, Région Parisienne.*

Introduction

Influence of traffic emission on air quality in European cities has widely been studied. Nevertheless, measurement campaigns are usually limited, in the number of pollutants or in the time scale. We present here a set of atmospheric measurements of volatile organic compounds which has been collected outside a car, driving in the traffic, during 5 to 6 campaigns each year between 2003 and 2005. All the parameters: compounds, sampling and analytical techniques, locations, remained the same over the three years, allowing us to study the evolution of concentrations. This evolution is discussed for urban and rural air, and values are compared to data from literature.

Experimental

Outside air inlet is fixed on the front trunk of the car, near the car air inlet. A Teflon tubing goes to the inside of the car, where different apparatus are connected. Sampling is done while the vehicle is moving, on public roads, with two different routes : one is typically urban, most of the journey takes place on the Parisian Peripherique (motorway around Paris, limited speed 80 km/h), the other one is semi-rural, in the south-west of greater Paris area (2 lanes roads, limited speed 90 km/h except in the villages : 50 km/h). The same air flow is split to the different sampling systems. The overall sampling time is around three hours.

The major VOC are : benzene and toluene, MTBE, 1,3-butadiene, formaldehyde, phenol, naphtalene. Other compounds of the same families (BTEX, aldehydes and PAH) are analysed in the same time, but will not be discussed here.

Aromatic hydrocarbons and MTBE are sampled by pumping the air through Carbotrap 300™ glass tubes, loaded with Carbotrap/ Carbosieve S III adsorbents. The sampled volume is 3,6 litres. Tubes are extracted by thermal desorption on a Perkin Elmer Turbomatrix, and analysed by GC/FID.

1,3-butadiene is sampled in evacuated Silcocan™ canisters of 6 litres. Extraction and analysis are performed within the following week. 2 litres of air from the canisters are trapped on Carbotrap/Carbosieve Perkin Elmer tubes. Tubes are thermally desorbed and analysed by GC/FID.

Formaldehyde is sampled by pumping on SEP-PAK™ : DNPH-silica gel cartridges. Sample volume is 36 litres. Extraction is done by solvent desorption. Analysis is done by HPLC with UV detection).

Phenol is sampled on 2-zones solid adsorbents of ORBO type; two tubes are placed in series. Sampling volume is 100 litres. Desorption of each individual zone is done by NaOH 0,1 N. Analysis is performed with HPLC with fluorescence detection at 274/298 nm.

Polycyclic aromatic compounds (PAH) are sampled on quartz membranes + XAD-2 resin. Sampling volume is 275 litres. Extraction of supports taken together is done by ultrasonic bath, then extract. is concentrated. Analysis is

done by HPLC/UV fluorescence with specific PAH wavelengths. On these samples, we only detect the 6 lighter PAH : naphtalene to fluoranthene.

Results and discussion

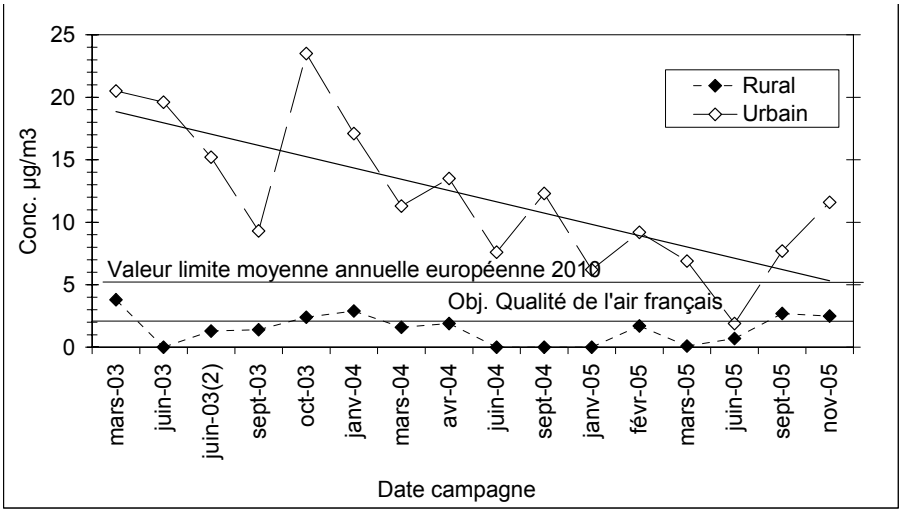
We present here the results of 16 measurement campaigns, distributed over the period March 2003 – November 2005. “ZERO” concentrations are lower than quantification limits.

1. Benzene

Figure 1 gives the benzene concentrations for urban and rural journeys.

Figure 1 : concentrations en benzène relevées sur les 16 campagnes (urbain + rural)

Figure 1 : benzene concentrations for the 16 campaigns (urban + rural)



The first observation is that benzene concentrations tend to decrease since March 03. This fact has been reported by several authors (Simon et al, Stemmler et al), as well as by the French air quality network for the greater Paris area “AIRPARIF”. This decrease is due to the reduction of benzene in gasoline, and, like for the other VOC’s, to the generalisation of exhaust catalysts on cars, since 1993 for gasoline-fuelled cars, and 1997 for diesel-powered cars. Only the last campaign - November 2005 – shows a slightly higher value than the previous ones. There has been a pollution episode at this time : AIRPARIF measurements on the edge of the Peripherique at Porte d’Auteuil, on the day of the campaign, show values which are consistent with those we measured in the traffic.

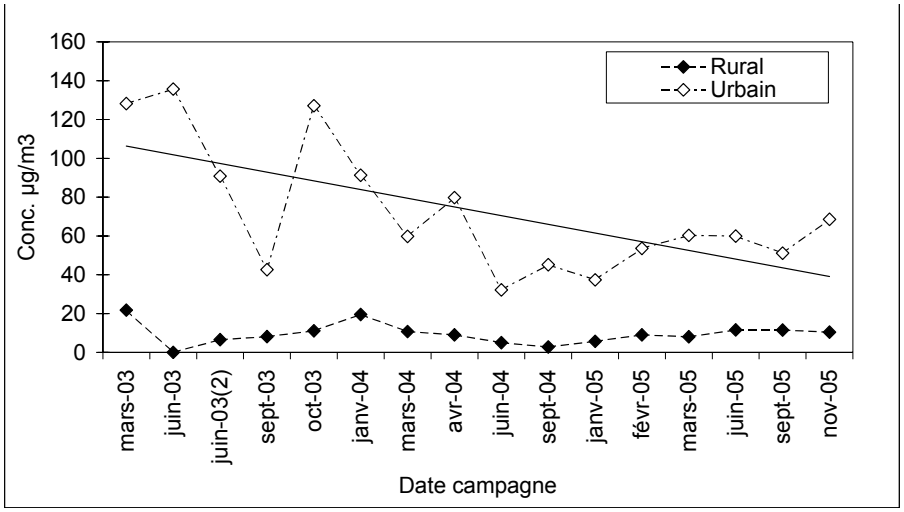
Second fact is that all urban concentrations except one, taken inside the traffic, exceed the future European Limit Value to be attained in 2010, of 5 $\mu g/m^3$ (EC Directive 2000/69/EC). This limit value is an annual mean. Fortunately, benzene concentrations are lower at night, and also lower in areas

with less cars, like quiet streets and residential areas, so the mean daily exposure, for a citizen, generally fulfils this limit value.

On the contrary, nearly all our benzene measurements in the rural area comply with the French Air Quality Guideline of 2 $\mu g/m^3$ (Décret n° 98-360 du 6 mai 1998, JORF 13 mai 1998). The decrease in concentration with time is not so obvious as for urban air, because values are lower. In fact, rural benzene concentrations were sometimes lower than our quantification limit.

Figure 2 : concentrations en toluène relevées sur les 16 campagnes (urbain + rural)

Figure 2 : toluene concentrations for the 16 campaigns (urban + rural)



2. Toluene

Figure 2 gives the toluene concentrations for urban and rural journeys.

Toluene concentrations are quite high in urban air : they vary between 32 and more than 120 $\mu g/m^3$. Such values have been reported for the same type of sampling in Birmingham (Leung & Harrison). Rural concentrations are generally in between 5 and 15 $\mu g/m^3$, which is slightly higher than other European values (Keymeulen et al, Schneider et al) but the sampling here is done in the “rural” part of the greater Paris area, therefore a small influence of the city is possible.

As for benzene, we see a overall tendency to decrease with the time since March 03. The stable values over the last year need to be confirmed. They could probably be due to the opposite effect offleet renewal with cars emitting less pollutants, and the increase of traffic, and traffic jams, in Paris and closer suburbs.

3. Toluene/benzene ratios

Table 1 gives the toluene/benzene ratio for urban air samples. Generally, for urban air sampled in cities, with a BTX pollution coming mainly from the traffic, the toluene/benzene ratio is in-between 2 and 3. It is lower when the air mass is

aged : in a Greek city, at 50 meters above the traffic, this ratio is in-between 0.7 and 0.97 (Pilidis and al). Here, sampling is done closer to the source : the car exhaust, and there is no time for the pollutants to react with the radicals presents in the air. Therefore, toluene concentrations are higher than in an older air mass.

Tableau 1 : rapports des concentrations toluène/benzène pour les 16 campagnes (roulages urbain)

Table 1 : toluene/benzene ratio for the 16 campaigns (urban routes only)

Dates	mars-03	juin-03	juin-03 (2)	sept-03	oct-03	janv-04	mars-04	avr-04	juin-04
Toluène/Benzène	6,3	6,9	6,0	4,6	5,4	5,3	5,3	5,9	4,2

Dates	sept-04	janv-05	févr-05	mars-05	juin-05	sept-05	nov-05	**Moyenne**	σ
Toluène/ Benzène	3,7	6,0	5,8	8,7	--	6,6	5,9	**5,8**	**1,2**

Tableau 2 : concentrations (μg/m^3) en MTBE et 1,3-butadiène, pour les 16 campagnes

Table 2 : concentrations (μg/m^3) for MTBE and 1,3-butadiène, on the 16 campaigns

Composé	Date	mars-03	juin-03	jun-03 (2)	sept-03	oct-03	janv-04	mars-04	avr-04	juin-04	sept-04	janv-05	févr-05	mars-05	juin-05	sept-05	nov-05
MTBE	Rural	ND	0	1	1,9	2,2	3	0	4,2	2,9	1,5	3,9	5,6	3,5	0,7	1,8	1,4
	Urbain	ND	30	16	ND	21	12	7,7	31	7,9	16	13	32	18	4,7	16	18
1,3-butadiène	Rural	0,1	0,3	0	0	0,6	0,6	0,2	0	0	0,2	0	0	ND	0,2	0,1	0,7
	Urbain	1,4	0,8	0,2	0,4	3,3	2,2	1,2	0,1	0,9	0,1	0	0,3	ND	1,5	0,4	3,0

4. Other pollutants

Table 2 gives the concentrations in MTBE and 1,3-butadiene.

For MTBE, urban concentrations vary widely from one campaign to another : from 5 to 32 μg/m^3. Rural values are more constant, and, like benzene and toluene, much lower than in urban area: they vary from zero (concentration under quantification limit) to 6 μg/m^3. There is no obvious season effect on the higher urban concentrations. This compound, which is an additive in gasoline, is not very often measured in Europe. Mean weekly values reported for Helsinki (Hellen et al) are lower than 2 μg/m^3.

For 1,3-butadiene, concentrations are low, even for urban air. Values are lower than 2 μg/m^3, except for two cases in October 03 and November 05 : for the latter, it is the same behaviour as benzene, toluene and MTBE. These values, though being measured inside the traffic, fall within the English Air Quality Objective of 2,25 μg/m^3 as an annual mean (UK National Air Quality Strategy). Rural concentrations are all lower than 1 μg/m^3. There is no obvious season effect, though butadiene concentrations should be lower in summer due to the reaction of this compound with ozone (Liu et al). There is no obvious decrease effect either, except between October 03 and February 05, but we have encountered higher values since then.

Figure 3 gives the concentration for formaldehyde. Except in January and November 05, for which urban concentrations are relatively high, urban and rural concentrations show the same tendency, and rural concentrations are 2 to 3 times lower than urban concentrations. Values are generally higher than the mean value measured in Paris in 2003, probably at background sites : 4,3 μg/m^3 (LCPP). This means that the source is anthropogenic and urban. Concentrations are lower in summer because of reactions with ozone, in air and during sampling, which causes an underestimation in formaldehyde.

Figure 3 : concentrations en formaldéhyde relevées sur les 16 campagnes (urbain + rural)

Figure 3 : formaldehyde concentrations for the 16 campaigns (urban + rural)

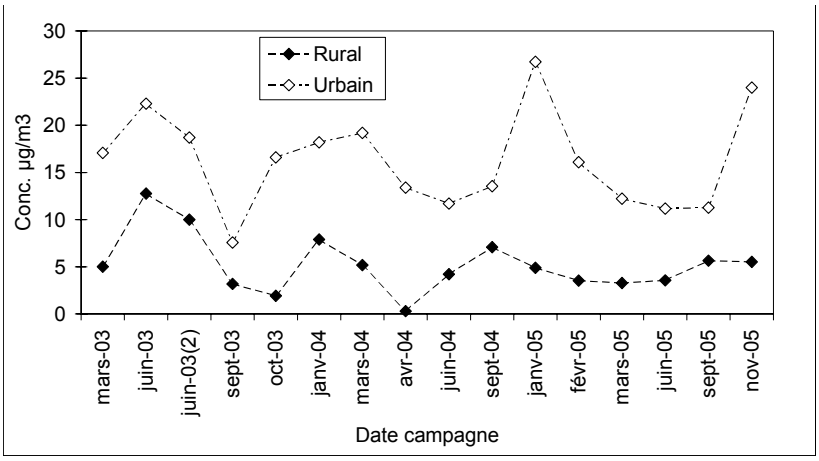


Figure 4 gives the concentrations for phenol. This pollutant is not often measured in ambient air and concentrations are generally low. Here, we report concentrations between 0 (below quantification limits) and 2 μg/m^3. Once again, urban values are higher than rural concentrations, and they both tend to decrease with time, especially for urban values. There are little data available on phenol in ambient air. Inchem monograph cites values in Paris (1978 to 1985) from 0,7 to 8 μg/m^3. Our measurements, though taken inside the traffic, do not show so high values.

Figure 4 : concentrations en phénol relevées sur les 16 campagnes (urbain + rural)

Figure 4 : phenol concentrations for the 16 campaigns (urban + rural)

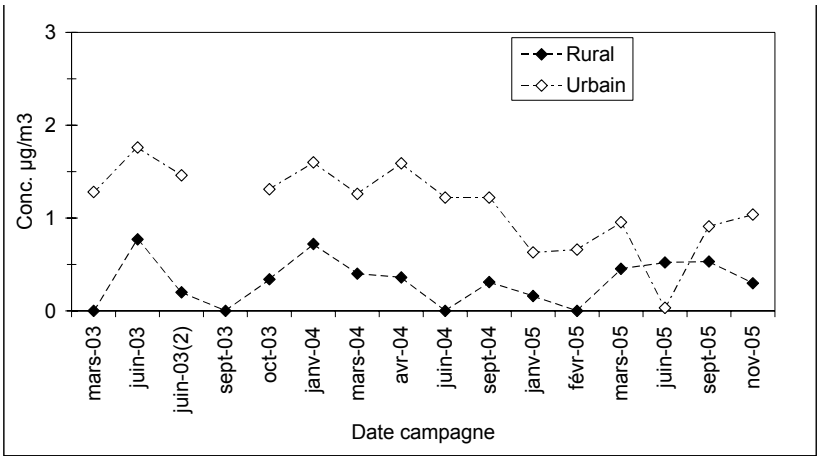


Figure 5 : concentrations en naphtalène relevées sur les 16 campagnes (urbain + rural)

Figure 5 : naphtalene concentrations for the 16 campaigns (urban + rural)

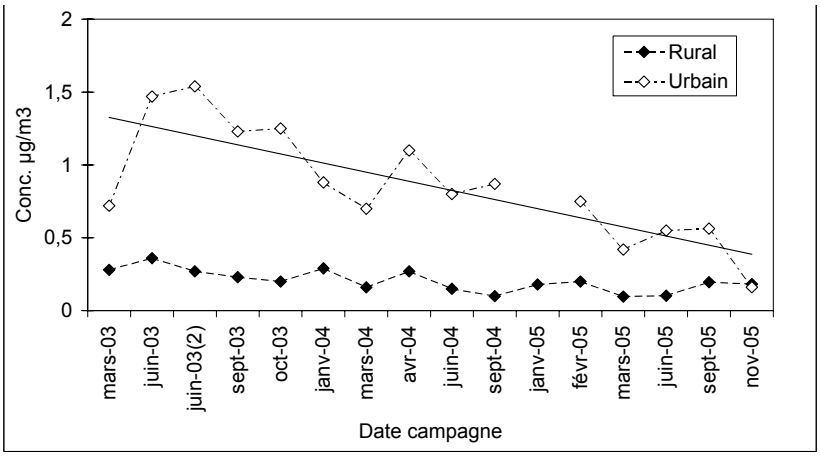


Figure 5 gives the concentrations for naphtalene. It is the lighter of the PAH, therefore the one which will have the closest behaviour to the VOCs. As for the aromatic compounds, we see clearly a decrease since March 2003, but this decrease has been going on continuously over the last year. There is an increasing number of diesel engine cars in France : more than half the new cars sold nowadays, and all the light and heavy duty vehicles, are diesel powered. The particulate matter and the PAH in the air should therefore be increasing. The observed decreasing tendency can be explained by the benefit of fleet renewal with new technologies (Filter trap, …) able to decrease the PM and gas emissions.

Conclusion

For all the pollutants that we presented here, influence of traffic as one of the major sources is obvious : rural concentrations are far lower than urban values. Though our measurements are taken right in the traffic, concentrations for several compounds are rather low compared to some of the published data. It is directly connected to an improvement in air quality in a large city like Paris.

The major finding is that the concentrations of most pollutants have been decreasing dramatically between 2002 and 2004, despite an increase in traffic, specially in urban atmospheres, and to a lesser extend, in rural areas as well. There are several causes : reduction of benzene in gasoline, improvement of engines, limitation of emissions thanks to catalysts, and renewal of the car fleet. Only formaldehyde, MTBE and 1,3-butadiene do not show this decrease, probably due to an initial low emission rate of traffic.

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High NO_2-concentrations in urban areas of Germany. The influence of traffic emissions and atmospheric chemistry

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Abstract

Although the calculated emissions of nitrogen oxides (NO_x) have been decreasing strongly, there is nearly no decrease in NO_2 concentration in many busy streets in Germany, at some sites an increase was observed in the last years. Without further reductions, in 2010 air quality limits for NO_2 will be exceeded at many streets. Therefore measures need to be introduced to attain the limits.

The introduction of effective measures needs information on the phenomenon, why NO_2 concentrations are decreasing much slower than NO_x emissions. The influence of ozone chemistry, direct exhaust emissions of NO_2, background concentrations of these pollutants need to be understood for the consecutive setting of measures. This paper analyses the influence of directly emitted NO_2 emissions and ozone chemistry on high NO_2 concentrations. It is shown that directly emitted NO_2 emissions have an increasing contribution to the local NO_2 concentrations and more attention has to be paid to them in future.

Keywords: *Air quality, NO_2, ozone, measures, direct exhaust emissions*

Background

As from January 1st, 2010, two air quality limit values for nitrogen dioxide (NO_2), which have been adopted in 1999, have to be met in the EU [EU 1999]: the one hour average concentration of 200 µg/m³ and the annual average concentration of 40 µg/m³. Exceedances of the one hour limit have only rarely been observed in Germany so far. However, the annual average concentration is exceeded today at many monitoring stations, particularly at roadside stations. Further reductions of NO_2 concentrations are thus essential to comply with the annual limit value by 2010.

The measured concentrations of NO_2 seem to be in contradiction to the successes in the reduction of NO_x emissions (total of nitrogen monoxide and nitrogen dioxide) in Germany. These emissions have decreased by about 50% between 1990 and today. This decrease is also reflected in NO_x concentrations measured in ambient air, in particular at roadside monitoring stations, but not to the same degree in NO_2 concentrations. Mainly two reasons have so far been used to explain for this unexpected increase: The reaction of ozone with NO to NO_2 (e.g. [Rabl 2005]) as well as an increase of NO_2 in the direct exhaust emissions [Höpfner 2005], [Lambrecht 2005]. In order to design efficient NO_2 reduction measures, it is necessary to understand the reasons for the current NO_2 levels as quickly as possible.

This paper presents analyses for two roadside monitoring stations in South Germany (Stuttgart and Karlsruhe). These measurement sites have been installed for monitoring purposes and are not research stations. Therefore a detailed time series of measurement data is available, but no further data on e.g. traffic or meteorology.

The analysis is organised in two parts: An intensive analysis of available air quality measurement data and a subsequent estimate of the already mentioned different influences on the pollutant concentration.

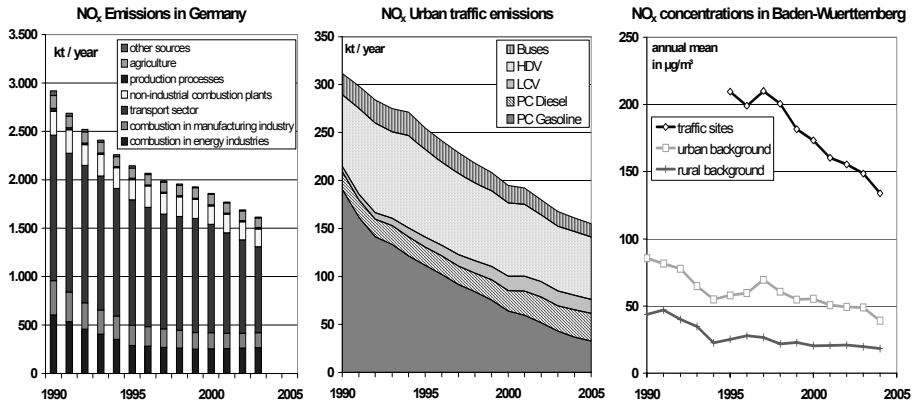
Development of emissions and pollutant concentrations in Baden-Württemberg

The emissions of nitrous oxides have been determined based on activity data (e.g. mileage of motor vehicles, use of fuels in households and power plants), used technology or exhaust after treatment and corresponding emission factors. In Germany, these calculations are brought together by the Federal Environmental Agency (Umweltbundesamt). For the transport sector, the emission calculation model TREMOD (Transport Emissions Estimation Model, [Knörr 2005]) is used.

In recent years, nitrous oxide emissions of all sources in Germany have decreased considerably – by about 45% between 1990 and 2003. About half of these emissions are from road traffic sources (Figure 1, left). This reduction is also reflected in the pollutant concentrations in rural areas (Figure 1, right).

The nitrous oxide emissions of urban traffic in Germany, which dominate the pollutant concentrations at busy streets, have decreased between 1990 and today by about 50%. Especially emissions of gasoline cars have decreased drastically (- 80%) due to tighter emission limits and the increasing share of vehicles with controlled catalytic converters which also lead to a considerable decrease in emissions. The emissions of diesel cars, however, have increased, because of the strong increase of the number of diesel cars in recent years. The share of diesel cars on urban emissions in Germany has therefore increased from 6% in 1990 to 19% in 2005 (figure 1, centre). The reduction of nitrous oxide emissions of urban traffic is reflected in the nitrous oxide concentration at main streets in Baden-Wuerttemberg.

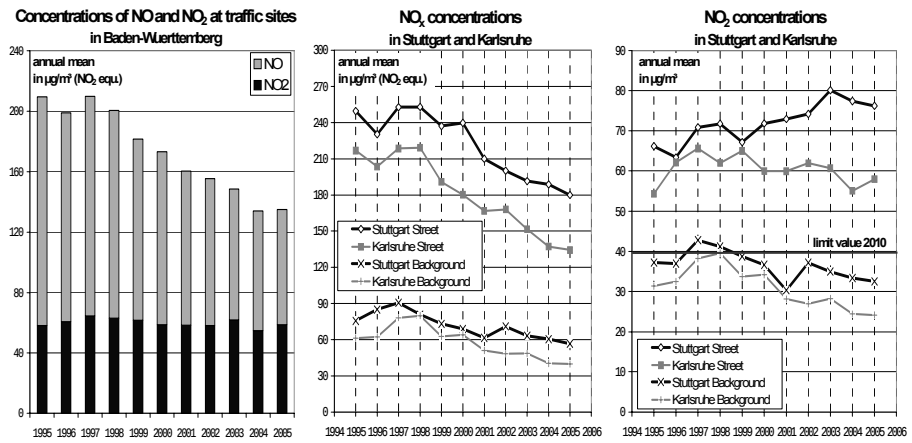
Figure 1: Emissions of all sources and inner city transport in Germany 1990 – 2005 (left, centre); Measured NO_x concentrations in the Federal State of Baden-Wuerttemberg 1990-2004 (right)



Source : Umweltbundesamt; TREMOD; LfU Baden-Wuerttemberg IFEU Heidelberg

A very different development can be observed for the concentrations of nitrous dioxide, for which the legislative limit values apply. Rural and urban background concentrations have been decreasing. However, at traffic measurement sites, only a slight reduction or even an increase of NO_2 has been observed. The limit value of 40 µg/m^3 is clearly exceeded. This contrary development has been unexpected in light of the reduction in nitrous oxide emissions and concentrations. The possible reasons have therefore been intensively studied [Lambrecht 2005a].

Figure 2: Urban NOx und NO_2-concentrations in Baden-Wuerttemberg 1995-2005



Source : Data from LfU Baden-Wuerttemberg IFEU Heidelberg

Influence of direct exhaust emissions and ozone chemistry on NO_2 concentrations

The NO_2 concentrations in streets are due to several reasons. Since NO_2 concentrations have decreased in rural areas and urban areas away from streets, this so called background concentration can not explain the increased concentrations in streets. It can therefore be assumed that road transport emissions are the main source of these increased NO_2 concentrations (additional local contribution). Two reasons have to be considered and are subsequently discussed in detail for two selected streets:

Oxidation of direct NO emissions of vehicles in the street with ozone to NO_2

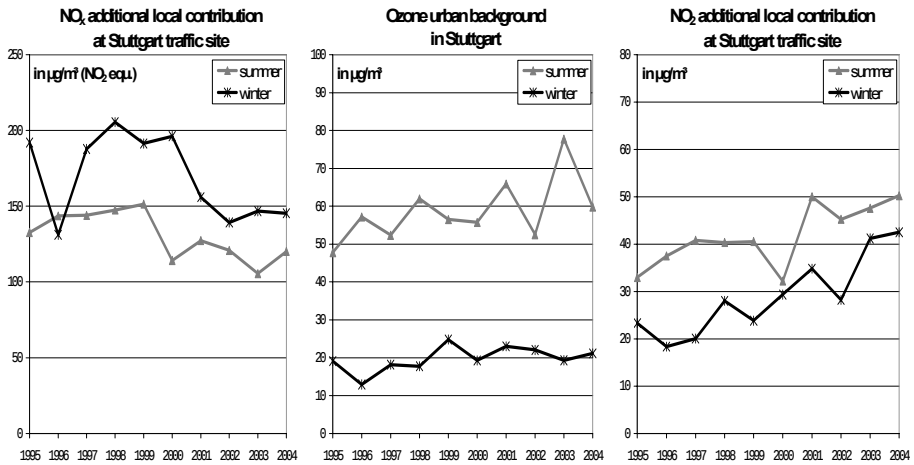
Increased direct NO_2 emissions of vehicles due to an increase in the NO_2/NO_x ratio in exhaust emissions

Influence of ozone chemistry on the additional local contribution

The chemical balance between nitrous oxides and ozone can be expressed with the following simplified formula:

$$NO + \mathbf{O_3} \rightleftharpoons \mathbf{NO_2} + O_2$$

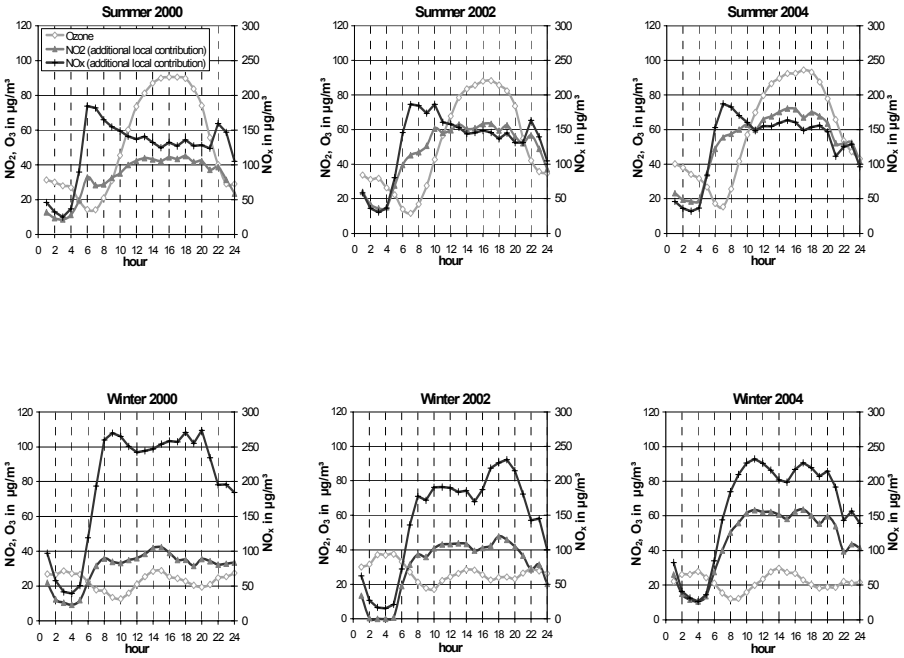
Figure 3 : Concentrations of NO_x, NO_2 and ozone in Stuttgart in summer and winter



Source : Own calculation, based on data from LfU Baden-Wuerttemberg IFEU Heidelberg

Increasing concentrations of ozone and NO can thus lead to an increase in the NO_2 concentration. Assuming the background concentration in balance, changes in the availability of NO and ozone are a factor for the formation of NO_2. The following analyses demonstrate that the ozone chemistry can not be the main reason for the increased NO_2 concentration in streets.

Figure 4: Daily development of NO_x and NO_2 concentrations (additional local contribution at traffic site) and ozone concentration (urban background) in Stuttgart



Source : Own calculation, based on data from LfU Baden-Wuerttemberg IFEU Heidelberg

The ozone concentration – which is measured in the urban background – has remained more or less stable in recent years in Stuttgart and Karlsruhe. The measured NO concentrations, however, have decreased considerably due to the decrease of exhaust emissions. An increase of NO_2 concentrations due to ozone chemistry can therefore be almost ruled out. A comparison of the concentration development in summer and winter (seasons with very different ozone concentrations) shows that the NO_2 concentrations in recent years have experienced an even stronger decrease in winter than in summer (Figure 5).

The influence of ozone chemistry and other sources can also be demonstrated at the daily developments. The NO_x concentrations of the additional local contribution very closely follow the traffic and thus shows an increase in the morning and a decrease in the night. In the past, the differences

between day and night for NO_2 concentrations were much lower. It can thus be concluded that direct emissions had a low impact. The picture changes, however, in the subsequent years. The development of NO_2 concentrations more closely follows the development of NO_x emissions and thus the development of traffic emissions. This is a strong indication for an increase of NO_2 in direct exhaust emissions.

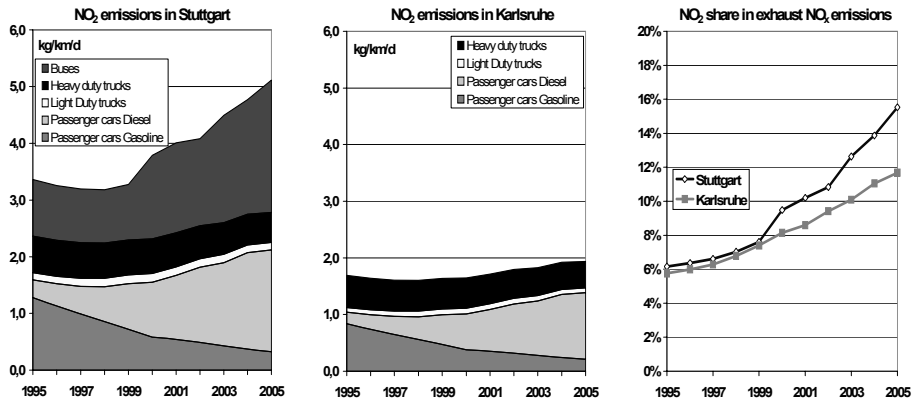
Furthermore, the comparison shows that the additional local NO_2 contribution is higher in 2004 than in 2000 although ozone concentrations are almost the same. This is another indication of the limited influence of ozone chemistry on changes in the additional local contribution.

1. Direct NO_2 exhaust emissions

Numerous studies show an increase in the share of NO_2 in vehicle exhaust emissions. Especially high values have been measured for vehicles which are equipped with oxidation catalyst (e.g. new diesel cars and buses with particle filters).

For two streets in Stuttgart and Karlsruhe, a first estimate of NO_2 emissions of road traffic has been undertaken which is based on the literature values compiled in [Lambrecht 2004]. These estimates have considerable uncertainties, but show an increase in NO_2 emissions during the last 10 years due to diesel cars and buses. The average share of NO_2 in exhaust NO_x emissions of the fleet has increased from 6% to 12% respectively 16% (Figure 5).

Figure 5: Modelled NO_2 emissions of local traffic at the traffic sites in Stuttgart and Karlsruhe



Sources : Own calculation, based on Data from TREMOD, UMEG and SSB AG IFEU Heidelberg

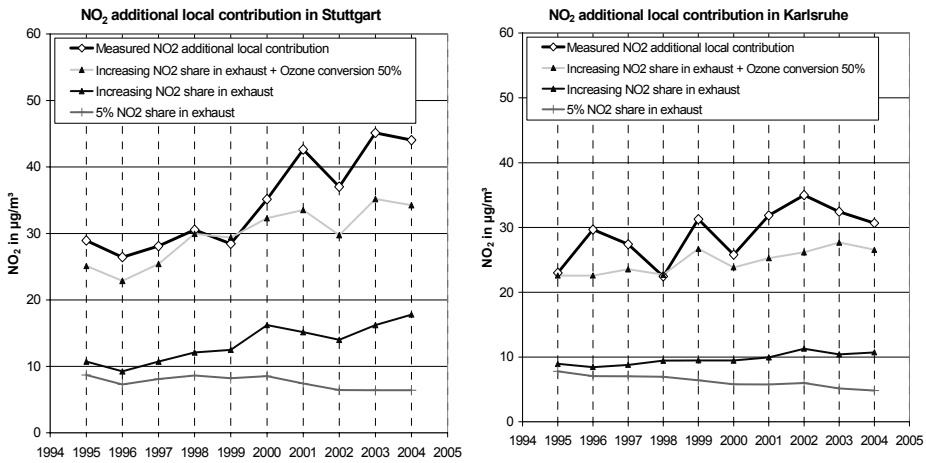
Estimate of the share of ozone chemistry and direct exhaust emissions on the additional local contribution

The share of direct NO_2 exhaust emissions and ozone chemistry on the increase of the NO_2 concentration has been estimated. It has been assumed, that

the additional local contribution of NOx at the selected measurement sites is completely due to road traffic and

on the average 50% of the available ozone is converted with NO from the vehicle exhaust to NO_2 and O_2.

Figure 6: Measured and modelled NO_2 (additional local contribution) at Stuttgart traffic site



Source : Own calculation. IFEU Heidelberg

This allows for an estimate of the NO_2 concentrations due to exhaust emissions based on the values derived above. Accordingly, in Stuttgart the contribution of direct exhaust has increased from about 10 µg/m³ in 1995 to about 18 µg/m³ in 2005 (see Figure 6). The NO_2 concentrations due to the conversion of ozone is about 14-17 µg/m³ in all years. This rough estimate can thus explain for most of the measured concentrations between 1995 and 2000.

After the year 2000, the additional local NO_2 concentrations can not be completely explained with this estimate. Besides, the actual ozone conversion rate has decreased in the last years (a traffic site in Munich shows a decrease from about 30% in 1990 to less than 30% in 2005) and will at present be lower than assumed in this analysis. Assuming that only these two mechanisms contribute to the additional local NO_2 concentrations it can be concluded that

the contribution of direct NO_2 exhaust emissions is even higher as with the rough estimate in the analysis above.

The analyses have shown that an increase in NO_2 emissions in vehicle exhaust leads to a relevant contribution to the increased NO_2 concentrations in streets. Current estimates lead to the assumption that vehicles with oxidation catalysts (new diesel cars, buses with CRT systems) contribute to the increase in NO_2 concentrations.

The presented emission factors, however, can not fully explain the total effect. It can therefore be suspected that the increase in NO_2 emissions is even stronger than hitherto assumed. Further research on the effect of exhaust after treatment systems and measurements of NO_2 emissions in vehicle exhaust as well as analyses of the relation between emissions and ambient air concentrations are necessary.

Acknowledgments

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Etude de la pollution de l'air par les particules fines (PM-10, PM-2,5 et PM-1) et évaluation des métaux lourds qu'elles véhiculent en milieu urbain à Alger

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Résumé

L'étude porte sur la pollution de l'air par les aérosols particulaires dans la banlieue urbaine à l'est d'Alger en un site à forte densité de population. Les résultats des prélèvements effectués par classe granulométrique montrent que la pollution par les particules PM-10, PM-2,5 et PM-1 est très élevée et dépasse largement les normes européennes. La teneur moyenne en PM-10 s'élève à 69,2 µg/m^3. Avec une teneur de 34 µg/m^3, les PM-2,5 constituent en masse environ 50 % des PM-10. On relève qu'environ le tiers des PM-10 est constitué par la fraction très fine des PM-1. Les PM-10 suivent une distribution bimodale et il existe une étroite corrélation entre les particules très fines et les particules alvéolaires. L'analyse des métaux lourds (Fe, Mn, Pb, Cu et Cd) montre que le plomb accuse des niveaux élevés. Le Pb et Cd se distribuent majoritairement sur les particules les plus fines tandis que les métaux de la croûte terrestre (Fe et Mn) sont enrichis dans la classe trachéobronchique (3 à 10 µm).

Mots-clefs: *Pollution de l'air, particules fines, PM-10, PM-2,5, PM-1, métaux lourds, plomb,distribution granulométrique, Alger.*

Abstract

Air pollution by fine particles (PM-10, PM-2,5 and PM-1) and associated trace metals evaluation in the urban area of Algiers.

The aim of the study is the evaluation of the ambient air pollution levels by inhalable (PM-10), respirable (PM-3, PM-2,5) and very fine (PM-1) particulates matters and some associated heavy metals in the suburban area of Algiers.

Sampling site is located at the student residence CUB 3 of Bab Ezzouar city at about 15 Km in the East of Algiers. This suburban area has a high population density of residents (about 45000 inhab./Km^2). Samples are taken using an HVS-PM-10 instrument equipped with a Sierra-Andersen cascade impactor with four stages. Sampling equipment was located on the roof of the building at 12 m high. Measurements are carried out for a period of one year from June 2004 to May 2005 (with a sampling average frequency of six daily samples a month). The results reveal that pollution by inhalable and respirable particles is very high and exceeds the European guidelines. The average content of PM-10 rises up to 69,2 µg/m^3 but values higher than 130 µg/m^3 were often reached. The respirable particles (PM-2,5) average content is 34 µg/m^3 which constitute approximately 50 % in mass of the PM-10. The ratio PM-2,5/PM-10 is a characteristic of an urban area. Moreover, it is noted that approximately one third of the PM-10 is composed of very fine fraction of PM-1. It is shown that PM-10 are distributed according to a bimodal distribution with a good correlation between the very fine (PM-1) and the respirable particules (PM-2,5). The size range analysis of trace metals (Fe, Mn, Pb, Cu, Co et Cd) associated to these particules shows high pollution by lead which is due to the very low use of unleaded fuel in Algeria. It is noticed that major part of toxic metals (Pb et Cd) are distributed on the very fine particles. The heavy metals of soil dust of earth's crust Fe et Mn are enriched in the tracheobronchic range (coarse particles 3 - 10 µm). Data of the mass median diameter and the size distribution of trace metals are also discussed. In Algeria, the vehicle fleet is rather old with a low level of maintenance and the use of leaded fuel are the main reasons of high pollutant emissions of fine particles associated to high levels content of lead particles.

Key–words: Air pollution, particulate matter, PM-10, PM-2,5, PM-1, trace metals, lead, size distribution, Algiers

Introduction

Les particules fines représentent en milieu urbain un indicateur majeur de la qualité de l'air (Schroeder et coll., 1987; Jansen et coll., 1997; Chiron et coll., 1997). De nombreuses et cohérentes leurs attribuent une forte responsabilité dans la survenue d'une vaste gamme d'effets biologiques et sanitaires (Dockery et coll., 1993; Pope et coll., 1995). Ces particules fines véhiculent principalement des imbrûlés et noyaux carbonés issus de processus de combustion, des particules secondaires issues de la conversion gaz / particules, des éléments minéraux liés à l'érosion des sols et à la remise en suspension ainsi que divers métaux lourds qui jouent sans doute un rôle important dans la toxicité de l'aérosol. En milieu urbain, le trafic routier caractérisé par une diésélisation de plus en plus forte du parc automobile, constitue une importante source émettrice de particules très fines. Les véhicules diesel et, à un degré moindre, les véhicules à essence émettent en effet majoritairement des particules très fines de granulométrie inférieure à 1µm et sur lesquelles se fixent des composés très toxiques (HAP, métaux lourds, etc.). On constate ainsi que l'augmentation des déplacements motorisés est

telle que les émissions polluantes s'accroissent, et ce malgré les progrès techniques réalisés sur les véhicules et carburants pour les limiter.

En Algérie, avec l'installation des concessionnaires et les nouvelles facilités d'octroi de crédits, le parc automobile a augmenté entre 2000 et 2005 d'environ 20%. Comme en Europe, un engouement particulier pour les véhicules diesel est aussi observé. Il en résulte ainsi une pollution qui est, en proportion, de plus en plus riche en particules très fines et donc de plus en plus toxique.

Des études récentes ont montré que le Grand Alger (3 millions d'habitants, 650.000 véhicules) est confrontée à une intense pollution atmosphérique (Kerbachi et coll. 1998, Boughedaoui et coll. 2004). La principale source d'émission est le trafic routier. Pour arriver à formuler une stratégie de prévention, il est toutefois nécessaire d'avoir des données sur les niveaux et types de pollution, les composés qu'elle véhicule ainsi que les sources émettrices. Aussi et en continuité des travaux antérieurs effectués sur les particules atmosphériques (Kerbachi et coll. 2000, 2003), nous avons déterminé les niveaux de pollution par les PM-10, PM-2,5 et PM-1 atteints à Alger en un site à forte densité de population au niveau de la banlieue urbaine à l'Est d'Alger. Une évaluation des métaux lourds associés à ces particules et leur distribution par classe granulométrique a été également effectuée.

Méthodologie

Les prélèvements journaliers ont été effectués au niveau de la cité universitaire « CUB 3 » de la commune de Bab Ezzouar située dans la banlieue sud-est à environ 15 Km d'Alger-Centre. En ce site le poste de prélèvement est implanté sur la terrasse du pavillon F à 12 m d'altitude. Ce site qui n'est pas exposé directement aux émissions des grands axes routiers peut être considéré comme étant un site urbain à forte densité de population résidente (la commune de Bab Ezzouar accuse une densité de population élevée qui est de l'ordre de 45000 hab./Km^2). Pour les prélèvements par classe granulométrique, un échantillonneur à fort débit, le HVS-PM-10 de la firme Graseby équipé d'un cascadeur Sierra-Andersen Modèle 234 à 4 étages (< 1µm, 1-1,5 µm, 1,5-3 µm, 3-7,2 µm et 7,2-10 µm) a été utilisé. Le débit de prélèvement est fixé à $1m^3$/min. Les particules sont collectées sur des filtres en fibre de verre Whatman. Après minéralisation acide des échantillons collectées, les métaux lourds Fe, Pb, Mn, Cu et Cd, qui sur le plan sanitaire ont une incidence importante, sont alors analysés par spectrophotométrie d'absorption atomique sur appareil Thermo Elemental Solaar.

Résultats et discussion:

1. Niveau et ampleur de la pollution

L'étude des particules a été effectuée sur une durée d'une année (juin 2004 à mai 2005) à raison de 6 à 7 prélèvement par mois. Les mesures ont permis d'accéder aux teneurs en PM-10, PM-7, PM-3, PM-1,5 et PM-1. Le tableau 1

résume les teneurs moyennes et extrêmes des PM-i étudiés ainsi que les rapports moyens PM-i / PM-10. On relève que les teneurs journalières varient dans une large fourchette. Ceci est dû, d'une part aux influences météorologiques et d'autre part aux variations dans l'intensité du trafic routier et autres activités humaines. Les moyennes annuelles des PM-10, PM-3 et PM-1 s'élèvent respectivement à 69,2 µg/m^3, 35,1 et 20,9 µg/m^3.

Tableau 1: Teneurs en PM-i dans l'air ambiant à Alger

Table 1: PM- i levels measured in ambient air in Algiers

Paramètres	PM-1	PM-1,5	PM-3	PM-7	PM-10
Min. (µg/m3)	5,2	11	11,5	16	19
Max. (µg/m3)	50,1	43	80,4	101	161
Moy. (µg/m3)	20,9	26,2	35,1	59,4	69,2
Ecart-type (µg/m3)	10,2	8,1	14,1	17,2	30,1
Rapport PM-i / PM-10	0,30	0,38	0,51	0,86	1

A partir du tracé du graphe log/probabilité donnant le diamètre des particules en fonction du pourcentage de la masse cumulée inférieure au diamètre, on détermine que le diamètre d_{50} de la masse médiane s'élève à 2,7 µm. Ce diamètre est légèrement plus élevé que celui rencontré habituellement dans d'autres villes (Butler, 1979). A partir de ce même graphe, on détermine la teneur moyenne en particules respirables, les PM-2,5, qui s'élève à 34 µg/m^3 , soit 97 % du taux des PM-3. La mesure expérimentale des PM-3 par le cascadeur M234 permet ainsi d'accéder avec une bonne approximation aux teneurs en PM-2,5.

Figure 1: Répartition des PM-10 parclasse granulométrique

Figure 1: Percentage of PM-10 loading each size range

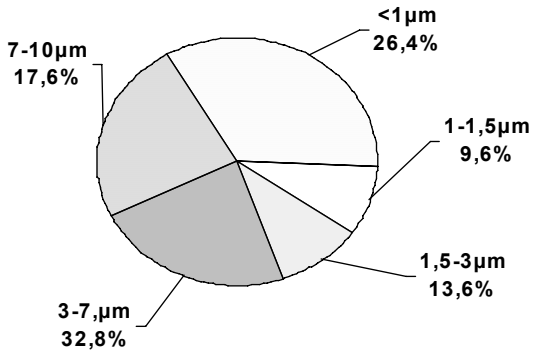
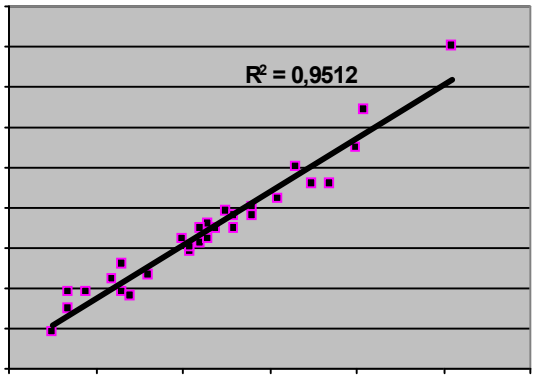


Figure 2: Corrélation PM-1/PM-3

Figure 2: Correlation PM-1 /PM-3



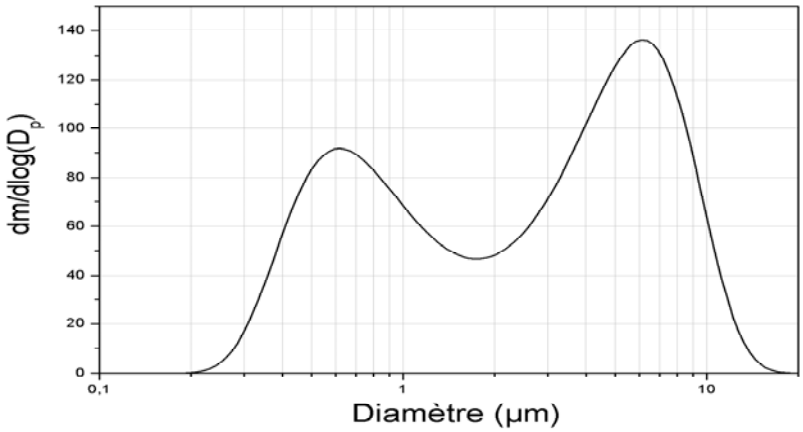
La contribution, des différentes classes granulométriques à l'ensemble des PM-10 (figure 1) montre que les particules fines de faible granulométrie sont prédominantes: la fraction respirable (PM-2,5) constitue ainsi 50 % des PM-10. La fraction très fine (PM-1) qui se dépose de manière irréversible dans les poches alvéolaires constitue plus du quart des PM-10 et environ 60 % des PM-2,5.

Globalement, on constate qu'en site urbain à forte densité de population exposée, la pollution par les PM-10 et PM-2,5 et PM-1 est très excessive. Les seuils limites en vigueur aux USA et dans l'Union Européenne (US-EPA, 1997; J.O.- CE, 1999) sont largement dépassés. Ces teneurs sont toutefois inférieures de 15 à 20 % à celles mesurées en 2002 en un site de type station trafic dans la même banlieue de l'est d'Alger [Kerbachi et coll. 2003]. Pour ce dernier site qui est fortement influencé par les émissions automobiles, le taux en particules fines PM-1 est nettement plus élevé que celui mesuré en site urbain lors de la présente étude (34 % au lieu de 26,4 %) [Kerbachi et coll. 2003].

L'examen de l'évolution des PM-1 en fonction des PM-3, montre qu'il y a une très bonne corrélation entre les deux classes de particules fines qui sont probablement de même origine anthropique, la pollution automobile (figure 2). Une corrélation moins prononcée est obtenue dans le cas de la relation PM-3/PM-10. Ceci s'explique par le fait que dans les PM-10 interviennent aussi les particules de l'écorce terrestre et celles dues à la resuspension. L'exploitation statistique des données (figure3) montre que les particules étudiées suivent une distribution bimodale centrée sur les modes 0,5 et 6µm.

Figure 3: Distribution bimodale des particules fines à Alger

Figure 3:bimodal size distribution of fine particles in Algiers



2. Evaluation des métaux lourds

Les teneurs annuelles des métaux Fe, Pb, Mn, Cu, et Cd véhiculés par les particules sont résumées en tableau 2. La figure 4 illustre leurs fractions massiques moyennes selon la classe granulométrique. Dans toutes les fractions, le fer est l'élément le plus abondant. Avec une teneur moyenne de 490 ng/m^3, il constitue 0,65 % des PM-10. Le plomb, dans son abondance, suit le fer. Il s'élève en moyenne à 246 ng/m^3 et atteint un maximum de 620ng/m^3. Ces teneurs en plomb sont relativement élevées et dépassent la nouvelle norme européenne de 0,2 µg/m^3. L'examen des fractions massiques (fig. 4) montre que le Pb, le Cd et à un degré moindre le Cu sont plus abondants dans les particules fines. Le Pb, par exemple constitue 0,55% des PM-1 et ne s'élève qu'à 0,35 % dans les PM-10. A l'inverse, le Fe et Mn qui sont issus majoritairement de la croûte terrestre, sont plus enrichis dans les PM-10 que dans les particules très fines (fig. 4).

Tableau 2: Teneurs atmosphériques en métaux lourds associés aux PM-i

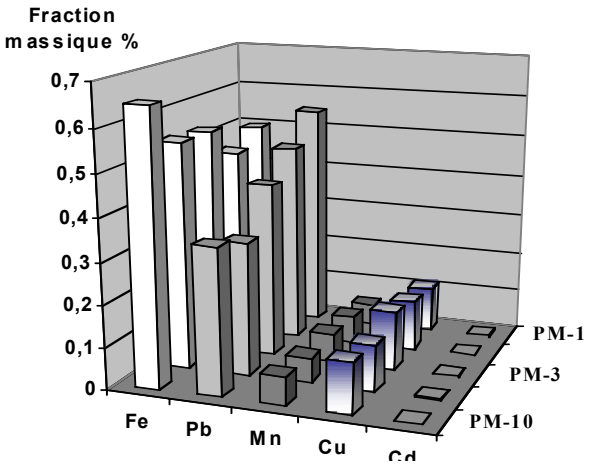
Tableau 2: Atmospherics levels of trace metals associated to the PM-i size fractions

PM-I	TENEURS MOYENNES EN METAUX LOURDS (NG/M^3)				
	FE	PB	MN	CU	CD
PM-1	**104,7**	**114,4**	**12,3**	**22,1**	**0,59**
PM-1,5	**120,1**	**126,5**	**19,3**	**31,3**	**0,86**
PM-3	**190,3**	**148,3**	**24,3**	**48,3**	**1,1**
PM-7	**383,2**	**187,1**	**36,1**	**62,3**	**1,2**
PM-10	**490,1**	**246,3**	**47,2**	**81,8**	**1,4**

On note par ailleurs que les métaux lourds se distribuent différemment sur les classes granulométriques. Le rapport Pb_{PM-1} / Pb_{PM-10} qui s'élève à 0,60 montre que 60 % du plomb de l'atmosphère a une granulométrie inférieur à 3 µm. Dans le cas du fer, 61 % se trouvent dans la fraction trachéobronchique (3 à 10 µm). Le cadmium et cuivre se comportent comme le plomb alors que le manganèse suit la distribution du fer.

Figure 4: Fractions massiques moyennes des métaux lourds dans les PM-i

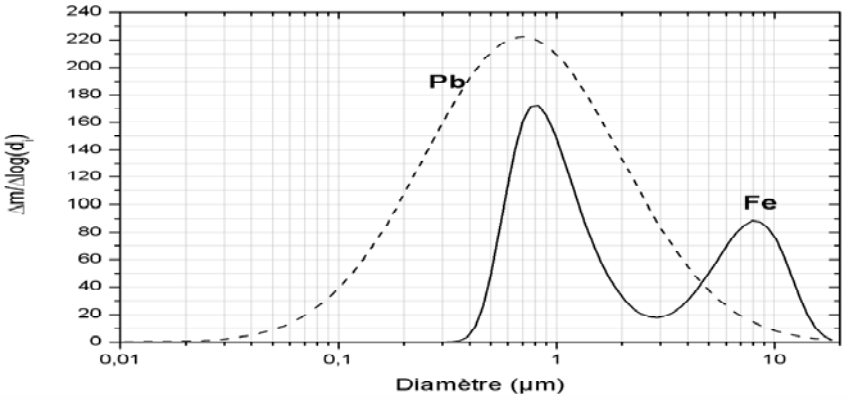
Figure 4: Mass fractions of trace metals in the PM-i measured in Algiers



Cette différence dans la taille et dans l'origine des particules métalliques se retrouve aussi dans les courbes de distribution (figure 5). Le plomb est régi par une distribution monomodale centrée sur 0,8 µm. Pour le fer, on détermine une distribution bimodale centrée sur 0,9 µm et 8,5 µm. Des résultats similaires sont évoqués dans la littérature (Lyons et coll. 1993).

Figure 5 : Courbes de distribution granulométrique des métaux lourds Fe et Pb

Figure 5: Modal size distributions of Fe and Pb measured in Algiers



Conclusion

L'étude a permis d'évaluer pour la première fois en Algérie les niveaux de pollution atteints en milieu urbain par les différentes classes granulométriques des particules fines. Les résultats montrent qu'en site urbain à forte densité de population, les teneurs atmosphériques en PM-10, PM-2,5 et PM-1 qui s'élèvent en moyenne à 69,2 ; 33 et 20 ,9 µg/m^3 respectivement, sont excessives et dépassent les normes en vigueur dans plusieurs pays. Ces particules sont d'autant plus nocives que plus de 50% des PM-10 sont des particules respirables. Ceci se traduit par un diamètre de la masse médiane de 2,6µm. L'exploitation des données montre que les PM-10 suivent une distribution bimodale et qu'il existe une étroite corrélation entre les particules très fines PM-1 et les particules alvéolaires PM-3 qui sont probablement de même origine.

L'étude de la répartition des métaux lourds par classe granulométrique et les courbes de distribution modale montrent clairement les différences dans la taille des particules métalliques, elles mêmes liées à la nature de la source émettrice (trafic routier ou écorce terrestre).

Il en résulte globalement qu'à Alger, la pollution par les particules fines est inquiétante de part son ampleur et de part ses caractéristiques physico-chimiques. L'ampleur de cette pollution résulte sans doute de la mauvaise combustion d'un parc automobile qui se diéselise de plus en plus mais qui demeure âgé, mal entretenu et où l'utilisation de l'essence non plombée est encore très faible.

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Transport routier et pollution de l'air dans Beyrouth Municipe (Liban)

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Résumé

A l'instar de la plupart des villes méditerranéennes, des interrogations se posent quant à la qualité de l'air de Beyrouth Municipe (Liban). Aucune étude sur l'évolution de la pollution de l'air dans ce milieu urbain n'a été menée jusque là. Les premiers résultats montrent que la principale source de pollution urbaine est le transport routier. Bien que ne disposant que de peu d'informations concernant ce secteur (flux, âge des véhicules,…), il a fallu déterminer le rôle du transport dans la répartition des polluants. Aussi, à partir des relevés de la teneur en NO_2, mesurée en 23 sites, d'un travail de terrain intensif et d'une enquête sur les transports routiers, il a été possible, grâce aux Systèmes d'Information Géographique et à l'exploitation de données cartographiques urbaines (hauteur du bâti, voirie, emprise des bâtiments, MNT de la ville,…), de déterminer les points les plus vulnérables à la pollution issue du flux automobile dans Beyrouth Municipe.

Mots-clefs : *Transport routier, pollution de l'air, Beyrouth Municipe, NO_2, SIG, points vulnérables.*

Abstract

Road transport and air pollution in the city of Beirut (Lebanon)

Like in most Mediterranean cities, the quality of the air of Beirut (Lebanon) gives rise to serious concern. Until now, no study of air pollution in this urban environment has been carried out. In June 2004, the Departments of Geography, Physics and Chemistry of Saint Joseph University, in partnership with the city of Beirut and in collaboration with AIRPARIF, launched a research project on air quality in Beirut. Since then, a fixed laboratory (installed in a reference site) has been continuously measuring the pollution content of the air.

Since November 2004, a background pollution measurement network, including 23 points distributed throughout the city of Beirut, has been equipped with passive tubes installed in PVC frames. This system supplies total values over 15 day periods of the following pollutants: SO_2, NO_2 and BTEX. The long-term goal is to map the distribution of the different pollutants measured in the Lebanese capital.

The first results show that transport pollution is the main source of urban pollution. Because no information was available about this sector (vehicle flows, vehicle age, etc...), and in order to determine the share of transport in the distribution of pollution, survey campaigns had to be organized, so we could characterize the "hot-spots" of Beirut. By collecting information and processing the urban cartographic data formulated in this study (building height, city DTM, etc...), and using a Geographic Information System, it was possible to identify the more vulnerable points to pollution and which are linked to transport and morphology of the city of Beirut.

Keywords: Road transport, air pollution, city of Beirut, NO_2, vulnerable points, GIS.

Introduction

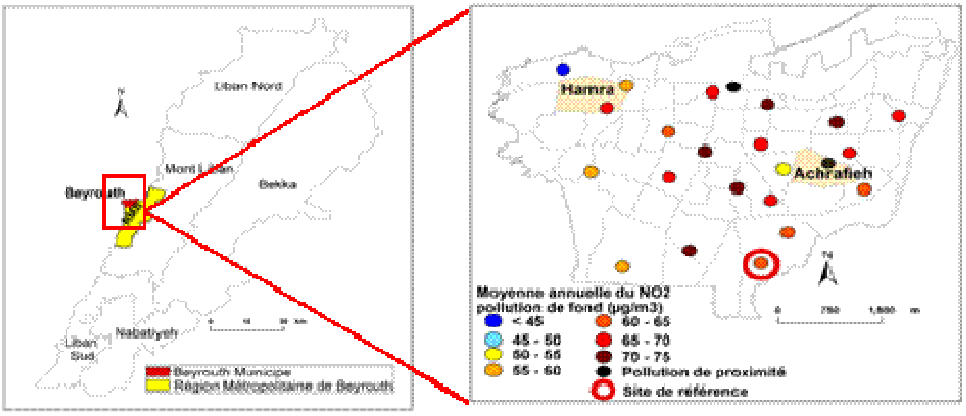
Beyrouth, capitale du Liban, connaîtrait à l'instar de la plupart des villes méditerranéennes, une dégradation de la qualité de son air (figure 1). A notre connaissance, aucune étude sur l'évolution de la pollution atmosphérique dans ce milieu urbain n'a été menée jusque-là. Des travaux ponctuels (Chaaban et al, 2001 ; Kaysi et al, 2000), effectués dans la ville et son agglomération et ne concernant que quelques types de polluants, ne peuvent montrer l'évolution de ce phénomène dans l'espace et dans le temps. Les résultats que nous avons obtenus, après une année d'observation en 2005 sur l'ensemble de la ville, montrent que le dioxyde d'azote est le polluant qui doit être incriminé dans la dégradation de la qualité de l'air de Beyrouth Municipe. Sa source principale étant le transport automobile, il nous a semblé pertinent, par conséquent, d'appréhender le rôle des transports dans l'émission de ce gaz.

La répartition du NO_2 dans Beyrouth Municipe

En 2004, l'Université Saint-Joseph, en partenariat avec la Municipalité de Beyrouth et en collaboration avec AIRPARIF, a mis en place un réseau de surveillance de la qualité de l'air dans la ville. Ce réseau, équipé d'échantillonneurs passifs, est composé de 21 sites de mesure de la pollution de fond et de 2 sites de mesure de la pollution de proximité, répartis sur l'ensemble du territoire municipal. Un camion-laboratoire implanté, dans un site de référence, mesure en continu la teneur de l'air en polluants (figure 1).

Figure 1 : Localisation de Beyrouth et moyenne annuelle du NO_2 en 2005.

Figure 1 : Localization of Beirut and annual mean for NO_2 for 2005.



Les résultats obtenus montrent que la teneur en SO_2 est négligeable sur l'ensemble de l'année, à l'inverse du NO_2 qui se démarque de manière très significative (figure 1). En effet, on relève une teneur moyenne annuelle en NO_2 de 67,5 µg/m^3, valeur élevée par rapport aux directives de l'Organisation Mondiale de la Santé, qui fixent la valeur moyenne annuelle à ne pas dépasser à 40 µg/m^3. Par ailleurs, l'ensemble de la ville est soumis à cette pollution : tous les sites de pollution de fond (à l'exception d'un seul) dépassent le seuil fixé. La capitale libanaise intra-muros étant essentiellement une ville de services avec quelques petites industries, il apparaît que le trafic routier est la première cause de cette forte teneur en dioxyde d'azote.

Les transports routiers dans Beyrouth Municipe

Dans un milieu urbain, les transports routiers sont responsables de la majeure partie du rejet total du NO_2. Par conséquent, mettre en place une politique de prévention en termes d'amélioration de la qualité de l'air, implique une bonne connaissance des flux routiers et de la pratique des transports des personnes. Or, au Liban, hormis quelques résultats partiels, publiés tout récemment, mais basés sur des relevés datant de 1998 (Atlas du Liban, en 2006), nous ne disposons pas de données actualisées sur la taille, la composition et l'âge du parc automobile libanais. Ceci serait dû au nombre élevé de fraudes sur les taxes (vignettes automobile) et de la mise hors service sans déclaration officielle de destruction d'un grand nombre de véhicules chaque année. De ce fait, un travail de terrain et d'enquête a été nécessaire, afin de combler ces lacunes.

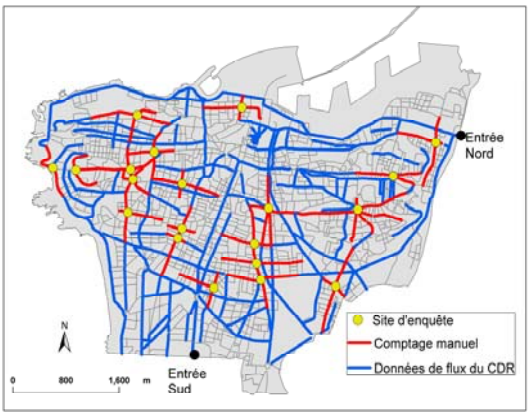
1. La méthodologie de recherche

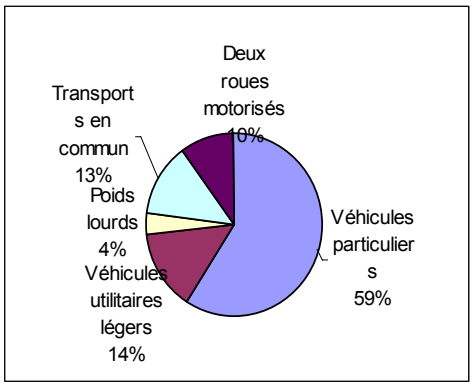
Une enquête et un dénombrement de véhicules en vue d'estimer des flux a été menée à Beyrouth sur un échantillon aléatoire de 20 points d'arrêt (feux rouges et points de congestion) (figure 2). Ce travail a consisté en la collecte des données suivantes :

- un comptage des flux horaires sur les axes routiers passant par les 20 points d'arrêt,
- une étude de la composition du trafic routier sur les différents axes,
- une enquête, menée auprès de 1000 individus (50 véhicules par point d'arrêt), a permis de mieux comprendre les pratiques des déplacements des conducteurs (âge du véhicule, nombre de passagers, lieu de résidence, destination, motif du déplacement, etc…).

Figure 2 : Sites d'enquête et de comptage et composition des flux routiers à Beyrouth.

Figure 2 : Survey and flow counting sites, and composition of the road flow in Beirut.





2. Le parc automobile : taille, composition et âge

Le service libanais des immatriculations a dénombré environ 1160000 véhicules, tous types confondus, soit pratiquement un véhicule pour quatre habitants. Les voitures particulières représentent 86 % de ce parc et, en 2005, leur nombre a augmenté de 8,2 % par rapport à 2004.

On ne peut pas estimer le nombre exact de véhicules circulant chaque jour dans la capitale, mais cette ville étant le pôle économique et administratif majeur du pays, un nombre considérable de véhicules converge vers elle. Néanmoins, grâce à l'enquête menée, nous pouvons avancer les chiffres suivants : Beyrouth compterait plus de 170000 voitures particulières, soit un nombre moyen de 1,7 par ménage résident. Cette valeur apparaît nettement supérieure à celle du pays. Cette catégorie constitue le pourcentage le plus élevé (59 %) par rapport aux autres moyens de transports (figure 2). Signalons également qu'un transport collectif est assuré par des véhicules de tourisme (taxis et taxis-service), en plus des bus et minibus.

L'âge des voitures joue sur la qualité et la quantité des émissions de polluants. Or, les résultats de l'enquête montrent que 28 % des véhicules individuels ont plus de 20 ans. Par ailleurs, pour des raisons de frais de douane et, surtout techniques et économiques, les pots catalytiques sont retirés lors de

l'achat des automobiles. Par conséquent, il s'avère que 74,4 % des voitures ne possèdent pas ce dispositif. En particulier, c'est le cas de 30 % des véhicules neufs, achetés depuis l'an 2000.

3. Les flux routiers

La répartition spatiale de la pollution dépend des flux routiers. Or, ce type d'information, essentielle à la compréhension de la relation transports/pollution, est inaccessible au Liban. Le seul document auquel nous avons pu avoir accès est une carte d'estimation des flux pour 2005, obtenue à partir d'une campagne de relevés datant de 2000 (CDR et Team International, 2005). Par conséquent, il a fallu mener un travail de terrain, comportant le comptage des véhicules sur un échantillon de tronçons de voies, pour compléter et vérifier ces données. Après comparaison des résultats, nous avons pu calculer un coefficient de correction qui nous a permis de corriger les chiffres CDR-Team International. Ceci nous a également permis de spatialiser l'information sur l'ensemble du réseau. Force est de constater que le trafic routier à Beyrouth est vraiment très important et que de nombreux axes se caractérisent par un flux supérieur à 1000 véhicules/heure, jusqu'à dépasser 4500 véhicules/heure.

4. Les déplacements à Beyrouth

D'après les résultats de l'enquête, il s'avère que 52 % des individus interrogés sont des résidents intra-muros, alors que les autres (48 %) proviennent de la banlieue et du reste du pays. Cela s'explique par le fait que les Libanais privilégient les déplacements à bord de leur propre véhicule, faute de transports en commun efficaces et bien organisés. La voiture individuelle est utilisée même sur les petites distances, puisque 5,4 % de la population la prennent pour se déplacer au sein de leur quartier. Cela est sans doute dû aux habitudes locales, les Libanais n'appréciant guère la marche à pied, dans un milieu urbain peu favorable à ce type d'exercice (topographie pentue, absence de trottoirs bien aménagés, routes encombrées par le stationnement anarchique…).

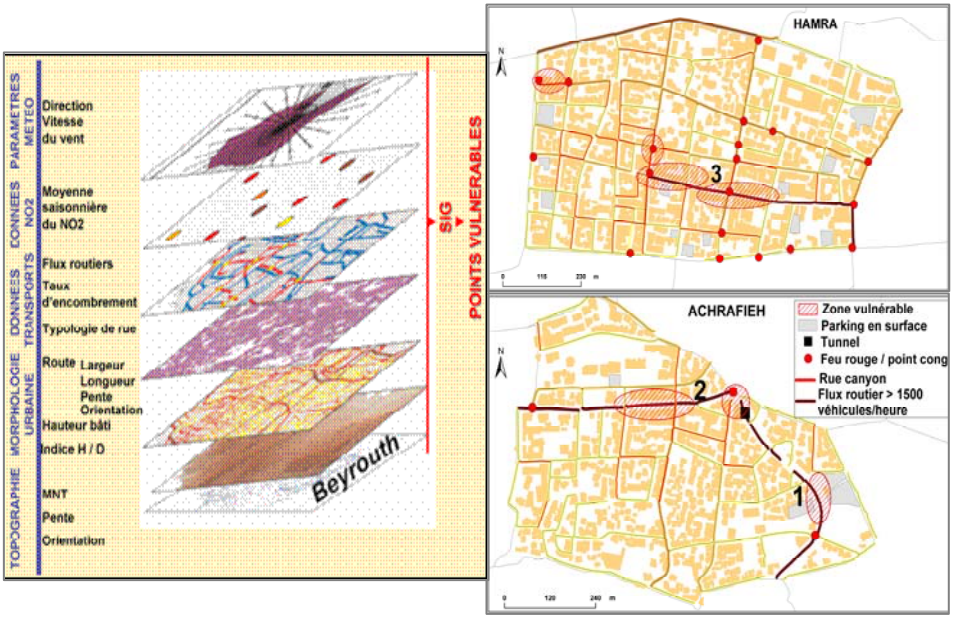
Le travail est le motif fondamental des déplacements, à raison de 67 % du total. Les destinations principales sont deux quartiers de la ville : Hamra (plus de 20 %) et Achrafieh (plus de 15 %) (figure 1).

Les points vulnérables : cas d'Achrafieh et Hamra

Compte tenu des flux, il a été intéressant de déterminer l'existence de points vulnérables à la pollution dans les deux quartiers mentionnés, ceux-ci montrant des valeurs très fortes pour les moyennes annuelles en NO_2 (figure 1). Ces taux élevés ne peuvent s'expliquer uniquement par le trafic. D'autres facteurs, tels que les conditions météorologiques, la topographie, le réseau routier, la morphologie urbaine… contribuent à l'augmentation de ces valeurs. Grâce au S.I.G., le croisement de différentes couches d'information concernant ces facteurs a permis de localiser les « hot-spots » (Longley *et al*, 2003) ou « points chauds » (figure 4).

Figure 4: Localisation des « points chauds » à l'aide des SIG.

Figure 4: Localization of "hot-spots" using the GIS.



5.Les facteurs contribuant à la formation des « points chauds »

5.1. Les rues-canyon

Figure 3: Rues-canyon dans les quartiers d'Achrafieh et de Hamra.

Figure 3 : Canyon Street in Achrafieh and Hamra.

Les rues-canyon constituent des zones favorisant l'accumulation de la pollution, notamment lors de forts flux automobiles, car leur configuration contribue à augmenter les phénomènes d'immission (Longley *et al*, 2003). Ceux-ci sont, de surcroît, mal et irrégulièrement dispersés de façon horizontale et verticale (Xie *et al*, 2003). La mise en évidence des rues-canyon se base sur le rapport H/D > 0,7 (H = hauteur moyenne des bâtiments, D = largeur moyenne de la route). Il apparaît que ce type de voie est bien plus fréquent dans le quartier de Hamra, que dans celui d'Achrafieh (figure 3).

5.2. Les autres facteurs

D'autres facteurs, comme l'influence de la topographie, la circulation atmosphérique, jouent également dans la formation des « points chauds ». Le drapage du réseau routier sur un Modèle Numérique de Terrain (obtenu à partir des courbes de niveau extraites d'un plan au 1/10000ème de Beyrouth) a permis de localiser les tronçons de rue en forte pente. Ceux-ci représentent un frein à une circulation automobile aisée, ce qui favorise l'augmentation des émissions polluantes à cause de la plus forte consommation de carburant. De plus, grâce au SIG, il a été possible de classer les orientations des rues par rapport aux vents dominants du SW. Dans notre démarche, toutes les voies à l'abri du vent ont été relevées comme zones favorisant la stagnation de la pollution.

L'occupation du sol en milieu urbain est aussi une donnée importante, notamment les grandes infrastructures liées aux transports routiers, car celles-ci représentent des sources de pollution ponctuelles. L'étude d'une image satellitaire QuickBird de 2005 et l'enquête sur le terrain ont permis de répertorier les grands parkings de surface, les points congestionnés, les tunnels, les stations de bus…

6. Les points chauds

Le croisement des différentes couches d'information mentionnées a montré l'existence de « hot-spots » dans les deux quartiers concernés, Hamra apparaissant comme étant bien plus vulnérable qu'Achrafieh. Il faut souligner que le tronçon le plus pollué à Hamra correspond à une rue commerciale très fréquentée (figure 4, n° 3). A Achrafieh, la zone la plus sensible se situe à proximité immédiate de l'un des plus grands hôpitaux de Beyrouth (figure 4, n° 1), alors qu'au Nord du quartier, le deuxième point chaud se trouve dans des rues résidentielles très denses, comprenant commerces et cafés en terrasse (figure 4, n° 2).

Conclusion

Le réseau de surveillance de la qualité de l'air mis en place et l'étude du trafic routier ont permis d'obtenir des éléments de connaissance sur la qualité de l'air dans la municipalité de Beyrouth. Il s'avère, jusque là, que la pollution en NO_2 est la plus marquée, parmi celles qui sont suivies. Une première approche des zones sensibles à cette pollution, utilisant les SIG, nous a également permis de localiser les « points chauds » dans deux quartiers. Dorénavant, il s'agit de mener une étude plus approfondie et plus spatialisée sur la dispersion du NO_2 à l'échelle de la rue, grâce au modèle STREET (MAIGNANT, 2002).

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Microanalysis of particular deposit on Conifer Needles: A new method for transports impact on ecosystem

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Abstract

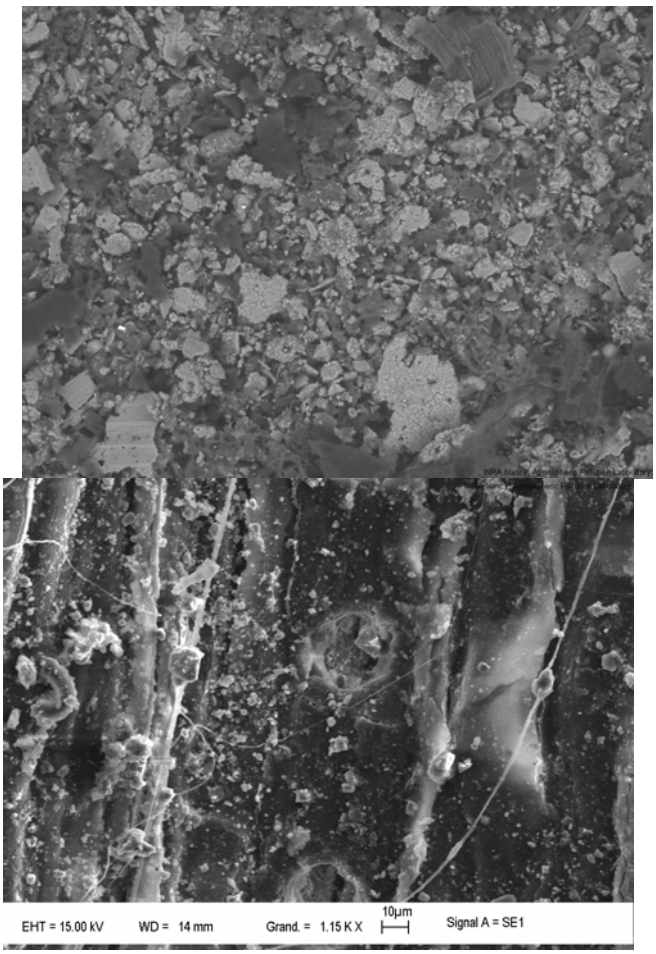
Extraction and microanalysis (EDS) of chemical composition of deposited particles on conifer needles has been tested in view to evaluate the spatial distribution of particulate emitted by traffic emissions in the Maurienne Valley (73, Savoie, France).

Introduction

Dealing with environmental pollution is one of the man's most urgent problems in the years to come. We must cope with a wide array of environmental pollutants including gases, particulates, agricultural chemicals in the atmosphere. Accumulation of toxic substances is causing serious changes in the structure and function of natural ecosystems and is a health hazard for human as well. Therefore in the last ten years, the increasing demand of information on air contaminants in surroundings of transport infrastructures (road and motorway, rail track, and airport) has led to the search of a new and efficient monitoring tool for identification and quantification of various pollutants. Most part of environmental pollution is a man-made problem and the motor vehicle is the most important source of atmospheric pollution. (Nriagu and Pacyna, 1988). Emitted with gases from natural and anthropogenic sources, airborne particulate matter is one of the most important constituent of the atmosphere. It usually consists of discrete particles with size ranging from molecular clusters of 0.005 µm to coarse particles of about 100 µm, which is usually called TSP (total suspended particulate matter). Airborne particulate matter is not a single pollutant, but rather a mixture of many subclasses of pollutants each containing a large number of chemical species. Particles can be transported on long distances according to winds and air circulation.

The cuticle is a complex interface protecting the epidermis of aerial organs of plants and is therefore exposed to numerous biotic interactions and to abiotic and anthropogenic airborne contaminants. The major components of the cuticle protecting aerial surfaces of vascular plant's, waxes, are embedded in the polymeric cutin matrix of the cuticle (intracuticular waxes) or deposited upon the surface of the cuticle (epicuticular waxes) (Eglinton and Hamilton, 1967; Baker, 1982; Holloway, 1982) during needles and leaves growth. Waxes prevent uncontrolled water loss from the leaf surface (Schönherr, 1976, 1982; Riederer and Schreiber, 1995) and reduce organic and inorganic substance diffusion from the leaf tissues.

Figure 1: On the left: Extracted particles collected onto a membrane surface by filtration under vacuum. On the right: Deposited particles on one-year conifer needle surface.



Among other properties, waxes of foliar organs and especially of conifer trees acts as an efficient collecting surface for air particles. Moreover, the use of conifer needles as bioaccumulator materiel is allowed by the long-life span of

them which make possible long-term studies, on several years. Free from plant metabolism, foliar particulate accumulation analysis is a particularly helpful way to quickly detect agents present in the air in tiny concentrations.

Sampling and preparation

During two years (2004-2005),, one and two years old needles were taken out from branches of adult conifer species (Norway spruce, Scots pine, Black pine, Arolla pine) every month (temporal study) on wild trees and planted saplings in order to investigate spatially the industrial and the road-traffic influence in the specific conditions of the Maurienne valley (Savoie, France). Samples were stored in paper bags at -5°C in cold chambers before analysis. Current year, one and two years old needles were oven-dried at 60°C for two weeks and samples of 0,5mg (Dry Weight) were randomly chosen.

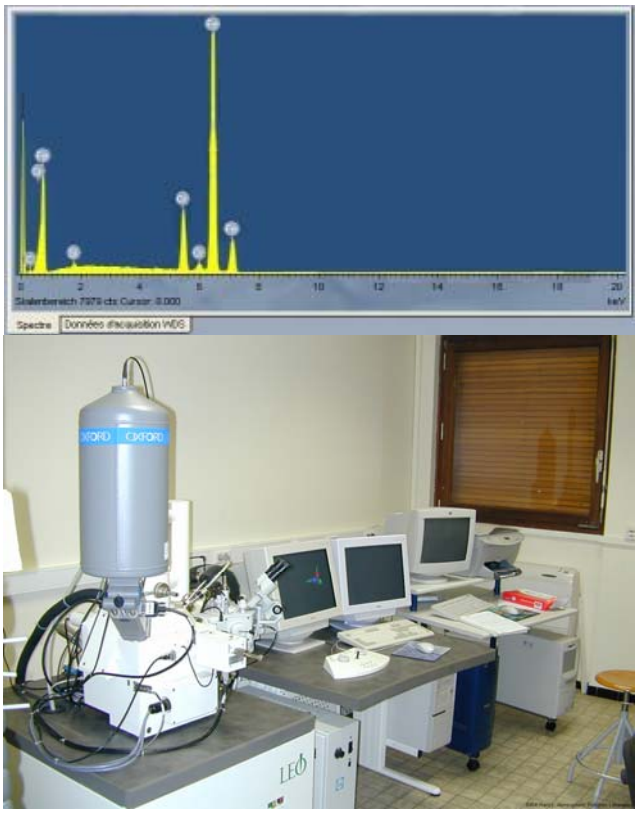
Extraction process

Extraction of particular deposit on conifer needle surface, was realised by soaking/shaking needle samples in organic solvent. Particles were collected onto a membrane surface by filtration under vacuum of the obtained suspension.

EDS/SEM analysis

The Scanning Electron Microscopy (SEM) is a well-known technique for observation of surface details which give information on both the size and the shape of needle-trapped particles. Elemental analysis of particles on the filter membrane was investigated with a variable pressure SEM (LEO 1450 VP) equipped with a X-ray microanalysis system (Energy Dispersive Spectrometer; EDS). This technique is relatively simple and fast and can also be used for direct observations on needles. Samples are introduced directly in the chamber, without conductive coating or further preparation. The EDS analysis system display the major elements constituting the deposit. Each membrane placed under the electron beam was analysed with the same working conditions: x200 magnification, 25kV acceleration voltage, 40 Pa variable pressure vacuum, 15mm focal length.

Figure 2: SEM LEO 1450 VP equipped with EDS system (INRA Nancy, France).



Conclusion

This method is an easy way for screening particles in natural ecosystems or agro-ecosystems located in the vicinity of pollution sources, giving information on the chemical composition, the level and the spatial distribution of particles emitted by both road traffic and factories. It can also help us to understand the mechanisms of dispersion and to evaluate the impact of pollutants on the vegetation and the ecosystems.

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Modeling air pollution concentration for urban highway underpasses: Iran experience

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Abstract

Highway vehicle emission constitutes of various environmental pollutants and is a major urban health concern. In tunnels and underpasses, higher air pollution concentrations can cause significant health effects. This paper presents an attempt to model vehicle-induced emissions and air quality in a heavily traveled underpass located in the Shiraz metropolitan area, Iran. In this underpass, during peak hours, air quality was often below standards due to many factors such as low traffic speed and flow, aged traffic fleet, unsatisfactory ventilation and inadequate vehicle maintenance. The study objective was to shed some light on air quality characteristics of the underpass and to suggest relevant mitigation measures. The study reported herein consisted of four stages. Firstly, confined and closed spaces air pollution modeling and theories were reviewed. Secondly, an air-sampling program was implemented and subsequently, the study database was developed. Thirdly, using the study database, different mathematical models, simulating air pollution field measurements, were developed and evaluated. Finally, deploying developed models and to insure proper underpass air quality, relevant mitigation measures and management schemes were proposed. Although this study was time and location specific, and the results were based on a rather limited field measurement, the same methodology can be applied to other confined spaces for addressing pertinent air quality issues.

Keys-words: *vehicle emission, mathematical modeling, air quality, confined spaces and developing countries.*

Introduction

Air quality is a dynamic and complex environmental phenomenon exhibiting large temporal and spatial variation. Air pollutants are emitted by a large variety

of anthropogenic and natural sources. Vehicle emission is an anthropogenic source with more significant adverse environmental impacts at urban areas. Indeed, urban growth is accompanied by increasing traffic and energy consumption, Rao and Rao (1990). Vehicle emission is variable and related to several factors including vehicle type and age, ambient air characteristics, altitude, operating cycle and driving pattern, Vaziri (1999). Inadequate ventilation of confined spaces of highway facilities during traffic congestion and peak volume periods often results in elevated air pollution concentrations due to vehicle emission. As a result, ambient air quality of highway infrastructures, such as in tunnels and underpasses are subject of significant air pollution risks and health hazards.

Several studies have focused on measuring, characterizing and modeling vehicular emission in tunnels and underpasses, for example Bellasio (1997), Chang and Rudy (1990), and El-Fadel and Hashisho (2000). These studies have suggested mathematical models with varying degree of complexity to simulate pollutant concentration inside confined spaces of highway facilities. The concentration of air pollutants at a given distance from underpass entrance was often found to depend to the distance from the entrance, underpass, air, ventilation, traffic and vehicle emission rate characteristics. Conservation of mass constitutes the basis of developing most of these models. Hypotheses should be made regarding air pollution emission and dispersion through time and space. These include assumptions regarding air pollution deposition, decay, chemical reactions, dynamics of air and vehicles. The mass balance across an underpass, with uniform and constant assumptions regarding cross section, airflow velocity, emission rate, vehicle flow rate, and no pollution deposition, decay, chemical reaction or removal, results in the simple model of Equation 1:

$$C_{o,p} = C_{i,p} + ((VF * ER) / (AV * UA)) * UL \quad (1)$$

Where $C_{o,p}$ is the air concentration of pollutant p as leaving the underpass in gram per cubic meter, $C_{i,p}$ is the air concentration of pollutant p as entering the underpass in gram per cubic meter, VF is the vehicle flow rate in vehicle per hour, ER is the vehicle emission rate in gram per meter, UL is the underpass length in meter, AV is the air flow velocity in meter per hour and UA is the underpass cross section area in square meter. With all the aforementioned assumptions regarding Equation 1, and in addition assuming that the underpass can be subdivided into infinitesimal elements and mass balance across each element, Equation 2 gives the air concentration of pollutant p at a distance X of its entrance:

$$C_{x,p} = C_{i,p} + ((VF * ER) / (AV * UA)) * X \quad (2)$$

Where $C_{x,p}$ is the concentration of pollutant p at the distance X of the underpass entrance in gram per cubic meter and X is in meter. Improved estimations can be obtained by introducing various correction factors into Equations 1 and 2 to account for non-uniformities. Furthermore, Equations 1

and 2 assume concentration uniformity along the other two underpass cross sectional dimensions of Y and Z. Another modeling approach is to use statistical methods to develop empirical relations for predicting concentration of air pollutants as functions of several explanatory or descriptive variables. These variables often are the distance from the entrance, underpass, air, ventilation, vehicle traffic and emission rate characteristics.

This paper presents a study of vehicle emissions and air quality in an urban underpass along a major traffic corridor in metropolitan Shiraz. Air pollution concentration at several points along the underpass was measured and analyzed. Mathematical and computer models were developed providing underpass air pollution estimates under various traffic and environmental conditions. This study was time and location specific, and the results were based on a rather limited field measurement, nevertheless, the same methodology can be applied to other confined spaces of transportation facilities for addressing pertinent air quality issues.

Study database

The study database consisted of relevant information in connection with air pollution concentration for an underpass in the Iranian central city of Shiraz. The city has one of the Iran's most agreeable climates with a calm and dry weather and moderate temperature. Shiraz is a historic city of more than one million population with a centrally located boulevard named Zand, being its major east-west urban travel corridor. The Zand underpass is located in central business district along the Zand boulevard. It has a rectangular cross section providing 4 traffic lanes in two directions and has been in service for more than 10 years. It is 625 meters long, 4.1 meters high and 15 meters wide. The underpass traffic is mainly consisted of automobile with average age of 10 years and more than 80 percent made in Iran. During working days of April 2000, at 26 points along the Zand underpass, traffic and air samplings were conducted using relevant instruments including video camera, air speed meter and portable air analyzer, Noll (1977). The sampling locations, X=1 to 26, were 25 meters apart adjacently and covered the underpass entrance and exit. The study database derived from the 36 samplings consisted of 34 variables as listed in Table 1. The results of database uni- variate analysis are also shown in Table 1. As the table shows, carbon monoxide concentration often exceeded the limiting ambient standard values.

Air pollution modeling

To develop an understanding of the basic relationships among variables, excluding variable NUM, a 33x33 correlation matrix of the database variables was investigated. The size of the correlation matrix prevented its display herein, nevertheless the matrix entries showed interesting results. The average significant correlation, at a 0.05 level, was 22 percent. This means that, on the average, each of the 33 variables was significantly correlated 22 percent with the other 32 variables. The 26 air pollution concentration variables of carbon

monoxide showed the highest percentages of significant correlations among themselves.

Table 1: Database variables and their statistical characteristics.

NO.	VARIABLE NAME	DEFINITION	DIMENSION	MIN	MAX	MEAN	STANDARD DEVIATION
1	**NUM**	**SAMPLE NUMBER**	**NONE**	**1**	**36**	**18.5**	**10.54**
2	**TPF**	**AUTOMOBILE VOLUME**	**VEH/HR**	**2670**	**3288**	**2937.8**	**162.39**
3	**TBF**	**BUS VOLUME**	**VEH/HR**	**42**	**90**	**66.34**	**12.67**
4	**TMF**	**MOTORCYCLE VOLUME**	**VEH/HR**	**228**	**336**	**274.68**	**28.02**
5	**TPS**	**AUTOMOBILE SPEED**	**KM/HR**	**44.38**	**50.18**	**47.20**	**1.81**
6	**TBS**	**BUS SPEED**	**KM/HR**	**36.28**	**45.14**	**42.12**	**2.31**
7	**TMS**	**MOTORCYCLE SPEED**	**KM/HR**	**36.72**	**48.60**	**43.85**	**3.34**
8	**ASP**	**AIR SPEED**	**KM/HR**	**5.1**	**7.2**	**5.93**	**0.62**
9-34	**COX, X=1 TO 26**	**CARBON MONOXIDE CONCENTRATION AT X**	**PPM**	**5**	**151**	**42.18**	**17.41**

To predict carbon monoxide concentrations at 25 locations of X= 2 to 26, using database information, 2 types of models were evaluated. Firstly, 25 models similar to Equation 2 with a correction factor were calibrated. Secondly to improve predictions, artificial neural network modeling was deployed.

The method of least squares is a technique that yields the best fitting polynomial model of a postulated form to a set of observed data. Firstly, using database information for 36 samples and simple linear regression analysis, the correction factors for Equation 2, were computed. Using past studies developed Iranian fleet emission models for vehicle types of automobile, bus and motorcycle, the average ER for Equation 2 was first determined, JICA (1997), Vaziri (1999). For example, Equation 3 was the model used for determining automobile emission.

$$ER = 0.0181 + 1.242/TPS \quad (3)$$

Where ER is the carbon monoxide emission in gram per meter and TPS is the automobile speed in kilometer per hour. Equation 4 represents the deployed model to calibrate correction factor, CR.

$$C_{x,p} - C_{i,p} = (((VF^* ER) / (AV^*UA)) * X)^*CR_{x,p} \quad (4)$$

Where the variables are defined similar to Equation 2. In calibrating Equation 4, simple linear regression passing through origin was deployed. Indeed, all the information for developing 25 models based on Equation 4 was available from the study database and Equation 3. The development of simple linear regression forced through origin led to 25 correction factors, $CR_{x,p}$, for predicting the carbon monoxide concentrations at 25 locations of X= 2 to 26. The 25 correction factors were often not significant at a 0.05 level, and had a range of 0.21 to 1.67 with a mean value of 0.82. The developed 25 simple linear regression models confirmed that the observed carbon monoxide dispersion in Zand underpass was more complex than Equation 4 and explained not sufficiently by the calibrated models.

To improve predictions, artificial neural network modeling was deployed. Artificial neural networks, ANNs, are powerful mathematical tools for modeling complex and sometimes intractable functions between system inputs and outputs. This is because of the fact that neural networks extract the essence of the relationship between system inputs and outputs through the data made available to them as training information. The key characteristics of an ANN include number of processing elements in each layer, number of layers, type of transfer function and learning rule, respectively. Variety of ANN architectures, such as, back error propagation, kohonen layer, competitive learning, adaline and madaline have been used in several past studies, Fausett (1994).

The back error propagation refers to the method by which the ANN is trained. A basic back propagation ANN consists of three layers, namely input layer, hidden layer and output layer, all interconnected with different weights. There are no standard criteria for determining the appropriate number of layers and processing elements. The back propagation ANN gets its name from how it handles error. In the training of back propagation networks, the error information is passed from the output layer to the input layer. Element connection weights are adjusted by comparing the desired outputs with actual outputs using a mathematical rule such as gradient descent method. The Delta rule is generally used as the training algorithm. The function most commonly used for the error is the sum of the square of the difference between the actual and the desired output layer elements' output.

To predict COX output variables, X = 2 to 26, among many available options, several ANNs were trained and tested. The selected ANNs would use 7 input variables of TPF, TBF, TMF, TPS, TBS, TMS and ASP as inputs to processing elements in the input layer. With 7 processing elements in the input layer, several one hidden layer and two hidden layer back propagation ANNs were trained and tested. Indeed, the actual architecture of any back propagation ANN is problem dependent. The selected ANNs, which had simpler architecture and smaller root mean square of error, RMSE, for the testing data,

were basic three layer networks. There were 3 processing elements in the hidden layer. In the output layer, the one processing element provided the output estimates. In this study, three types of transfer function namely, hyperbolic tangent, sigmoid, and sine were tried. For each transfer function, the training data were properly scaled. The sigmoid transfer function was selected due to its superiority in training convergence and testing results. The applied learning rule to the hidden and output layers was the cumulative delta learning rule, that accumulated the weight changes over several presentation of training examples and then applied them to the weights. The key parameters of the cumulative delta rule include learning coefficients, momentum and epoch.

After several trails, the epoch, momentum and learning coefficients of the hidden and output layers were set at 16, 0.5, 0.4, and 0.2 respectively. The momentum and learning coefficients were gradually reduced for higher number of training iterations for convergence to the preselected RMSE values. After more than 5000 iterations of randomly presenting 30 samples as ANNs' training data the trainings converged to the RMSE of 0.05 for standardized output. In this way 25 ANNs predicting COX's, X = 2 to 26, were trained and selected.

The trained back propagation ANNs were then tested with the remaining 6 samples. For the 6 testing data, the RMSE of the 25 trained ANNs and 25 simple linear regression models were compared. The testing data showed an average RMSE reduction of 80%, when ANNs' predictions were compared with the pertinent regression models. As the developed ANN models provided better predictions than the simple regression models of Equation 4, they were suggested for carbon monoxide prediction of the underpass.

Deploying developed ANN models for future traffic scenarios, carbon monoxide concentration for the underpass was predicted. To insure proper underpass air quality, relevant mitigation measures and management schemes were proposed, Faiz and Carbajo (1991). These covered tactical as well as strategical measures. The suggested key measures included installation of ventilation fans and through traffic control. Although this study was time and location specific, and the results were based on a rather limited field measurement, the same methodology can be applied to other confined spaces for addressing pertinent air quality issues.

Conclusion

This paper presents a study of vehicle emissions and air quality in an urban underpass along a major traffic corridor in metropolitan Shiraz. Carbon monoxide concentration at 26 points along the 625 meter underpass was measured and analyzed. Mathematical models were developed providing underpass carbon monoxide concentration estimates under various traffic and environmental conditions. In this study 25 simple linear regression models and 25 artificial neural network models were developed. The testing data showed an average RMSE reduction of 80%, when ANNs' predictions were compared with the pertinent regression models. Deploying developed ANN models for 25 locations along the underpass for future traffic and air scenarios, carbon monoxide concentration for the underpass was predicted. To insure proper

underpass air quality, relevant mitigation measures and management schemes were proposed. These covered tactical as well as strategical measures. The suggested key measures included installation of ventilation fans and through traffic control. This study was time and location specific, and the results were based on a rather limited field measurement, nevertheless, the same methodology can be applied to other confined spaces of transportation facilities for addressing pertinent air quality issues.

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Two-Scale Modeling of PM Dispersion in Large Urban Area

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Abstract

In the paper authors describe two-scale PM dispersion modeling in an urban area. CFD code StarCD was used to build up two models of the urban area. Combination of the regional model and the local scale model is used for the correct description of dispersion processes. The regional solution domain represents an area 12 × 12 km. The local solution domain represents an area of approximately 1 × 1 km. Traffic is considered as the primary source of airborne particles. The paper focuses on the modeling of deposition process of PM in an urban area and an accompanying process of re-suspension of once deposited particles that are lifted by traffic and dispersed into surroundings. Concentrations of PM10 are modeled and compared with results of measurements carried out in several locations of the solution domain.

Key-words*: deposition, re-suspension, CFD modeling, particulate matter, urban area*

Introduction

Many big cities are often heavily polluted by airborne particles released by road traffic. The highest concentrations of PM are generally present in inner parts of urban areas, especially at a close vicinity of major traffic paths. Many different parameters influence formation, transport and deposition of particles at these locations. Street particulate matter consists from complex mixture of motor vehicle exhaust particles, tire dust, brake lining wear dust, soil dust and other biological materials. Particles behavior is influenced by transportation in moving air, settling due to the gravitational acceleration, interaction with buildings walls, deposition on ground surface and re-suspension of once deposited particles that are lifted by a local air movement and dispersed into surroundings. Therefore, particles behavior is very complex process difficult for an accurate mathematical description. Appropriate simplifications must be used to involve the mentioned processes in numerical models.

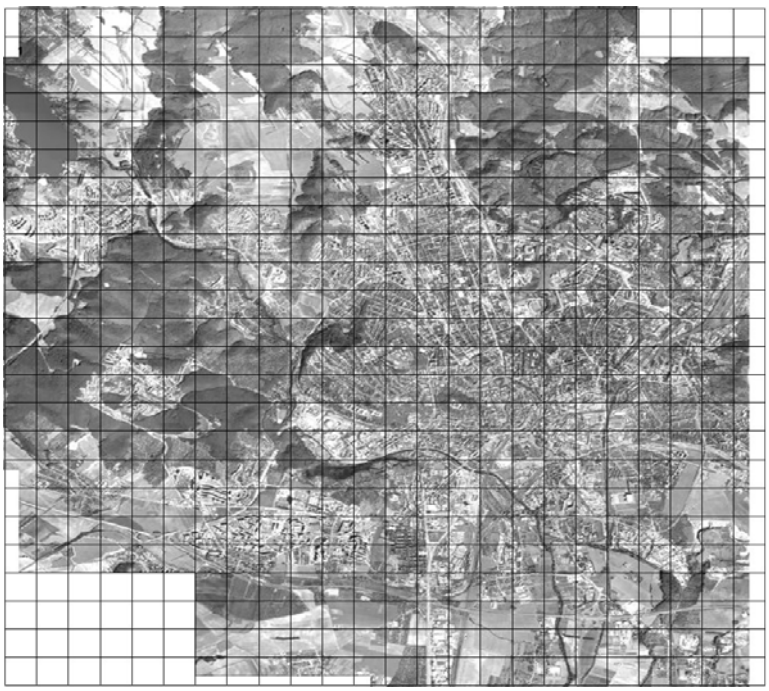
Particles spend a long time in urban areas and travel through long distances. Numerical models of large areas are necessary for correct

description of this transport. On the other side, small scale models are necessary for a detail prediction of PM concentrations in close vicinity of traffic paths. Dispersion of particles is directly connected with the geometry of urban areas and traffic conditions. An urban area is mostly heavily built-up area where buildings and other obstacles may significantly influence local concentrations. Moving vehicles enhance mixing processes in their surrounding. Small scale models based on the CFD technique represent a convenient tool capable to involve the above mentioned parameters with a better accuracy in comparison with regional models.

In this paper authors describe combination of the regional model and the local scale model used for the correct description of dispersion processes in the city of Brno. The regional model provides information on background concentration levels that serve as input parameters for the local scale model. The CFD code StarCD was used to build up both mentioned models. The paper focuses on the modeling of deposition process of PM in an urban area and an accompanying process of re-suspension of once deposited particles that are lifted by traffic and dispersed into surroundings. Actual size and density of particles are taken into account. PM10 particles are modeled and results of computational modeling are compared with results of measurements carried out in the solution domain.

Regional model description

Figure 1: The regional solution domain (12×12 km) divided in 576 square control regions.



The regional solution domain involves the city of Brno and a nearby surrounding, see fig. 1. The solution domain covers an area of 12×12 km. Due to large modeled area, it is impossible to accurately involve geometry of all objects. The parametrical roughness is used as a convenient substitution of ground cover geometry. The primary ground surface was build up in accordance with the actual terrain profile. The regional model ground plan was divided in 576 square control regions with the side length 500 m, see figure 1. A convenient parametrical roughness was assigned within these regions.

The ground cover was divided in seven groups that represent the most common ground covers in the studied area. Corresponding parametrical roughness values were derived from Stull R. (1990) for all considered ground covers. The table 1 shows the brief ground covers specifications and the corresponding parametrical roughness values.

Table 1: Ground covers specification and the corresponding parametrical roughness values.

Ground cover No.	Ground cover description	Equivalent roughness height [m]
1	calm water surface	0.001
2	field, meadow	0.2
3	forest	1
4	separate buildings up to 3 floors	0.4
5	continuing buildings rows up to 3 floors	0.7
6	separate buildings above 3 floors	1
7	continuing buildings rows above 3 floors	1.5

The primary ground surface was refined at terminal control volumes size with the top view dimensions 50×50 m. The 900m high air layer was modeled above the primary ground surface. This air layer was subdivided into 19 sub-layers. The lowest sub-layer height was 2.125m and the highest sub-layer height was set to 100m.

1. Traffic related PM sources

It is impossible to accurately quantify production of all actual PM sources. Therefore, an appropriate simplification of particles production description is convenient for a numerical solution of PM concentration field.

The primary exhaust emission factor is determined for car fleet composition – diesel engines to petrol engines = 1 to 3. The primary exhaust emission factor is calculated as

$$S_{pe}^{r} = 0.75 \times f_{PM10}^{B} + 0.25 \times f_{PM10}^{D}, \qquad (1)$$

where f_{PM10}^{B} is the PM10 emission factor of petrol engines and f_{PM10}^{D} is the PM10 emission factor of diesel engines derived for a horizontal road. The particular emission factor values were derived from software MEFA v.02 (Mobile Emission FActors) published by the Ministry of Environment of the Czech Republic. The primary exhaust emission factor value was calculated from (1) as 0.0179 g/km car.

Information about detail position of all important traffic paths involved in the solution domain and a corresponding traffic activity was derived from the Brno Transport Research Center database. Portions of traffic paths passing through individual control regions (500×500 m) were specified. A traffic activity (car km/day) at traffic paths portions was multiplied by the primary exhaust emission factor. The primary exhaust PM production rate is then obtained in the individual control regions.

A non-exhaust particle source related with traffic involves the primary and the secondary particles. The primary non-exhaust particles are released from cars, tires and road surfaces. The emission factors of non-exhaust particles released from cars and tires can be easily derived from different studies. Amount of the primary road surface particles is a function of a road surface material and an actual road state. Non-exhaust secondary particles are silt road particles drawn up from road surface. The re-suspension process intensity is fully dependant on an actual road silt load. The total PM10 emission factor is a sum of the exhaust particles emission factor and the non-exhaust emission factors. The average total PM emission factor of the regional model domain was derived from a previous study carried out in the studied area as 0.06265 g/km car.

The average total PM emission factor serves for the determination of the only particles source term prescribed in the numerical model. The source term was assigned at the air layer close to the ground surface, where major quantity of airborne particles is generated.

2. Deposition and re-suspension

Trajectories of coarse particles are influenced by advection, turbulent diffusion and sedimentation. The Brownian diffusion is considered for particles smaller than 1 μm. A deposition process was considered on surfaces covered by vegetation and on water surfaces. We assumed balance between the deposition rate and the re-suspension rate in control regions with majority of asphalt and concrete surfaces.

The particles deposition was modeled with inclusion of turbulent transport and particle settling (Csanady, 1973)

$$F = K\frac{dC}{dz} + v_S C, \qquad (2)$$

where v_s is the settling velocity of the particles, K is the eddy diffusivity for mass transfer of the species with concentration C and F is the downward mass flux.

The eddy diffusivity is correctly solved by CFD technique in fully turbulent flow. Wall functions substitute the accurate solution of eddy diffusivity in the surface boundary layers. Close to the surface, the eddy diffusivity is nearly zero. The Brownian diffusivity of the particles greater than 1μm is near zero too. The downdraft mass flux is then controlled by the settling velocity calculated as (Simpson at al., 2003)

$$v_S = \frac{D_p^2 \rho_p g C_C}{18\mu}, \qquad (3)$$

where D_p and ρ_p are respectively the particle diameter and density, μ is the air dynamic viscosity, g is the gravitational acceleration. C_c is the slip correction factor expressed as

$$C_C = 1 + \frac{2\lambda}{d_p}\left[1.257 + 0.4\exp(-\frac{1.1 d_p}{2\lambda})\right]. \qquad (4)$$

where, λ is the mean free path of gas molecules.

Steady calculation of specified situations was used in this study. Therefore, re-suspension due to changing wind conditions isn't considered.

3. Boundary conditions

The inlet/outlet boundary conditions are assigned on side walls of the regional model. The ground surface utilizes the wall boundary condition with appropriate parametrical roughness. The top of the domain uses condition of a wall with no friction. As a model of turbulence, *k-ε RNG* model was selected.

Local scale model description

The local solution domain represents a portion of the regional model, where actual buildings geometry is taken into account. The size of the local solution domain is 800×1000 m. Figure 3 shows the top view of this domain. It is convenient to locate the local solution domain in the central part of the regional model, where concentration fields are not influenced by boundary regions. In the local domain, the particles motion is primary driven by the actual air velocity field mostly influenced by wind conditions above buildings roofs. Moving cars significantly influence the air velocity field at the close vicinity of traffic paths.

Figure 3: The local solution domain in a central part of the city of Brno.

The traffic is taken into account for correct description of dispersion processes in the proximity of traffic paths. Moving vehicles drag the air in driving directions and enhance micro- and large-scale mixing processes in their surrounding. To simulate a moving vehicles drag force and an induced turbulence, an original model (Jicha M, at al. 2000) developed previously by the authors is used that takes into account traffic density, speed of cars and number of traffic lanes.

1. Local PM sources

The sources of the total PM emission are set as line sources located tightly above road surface in the middle of traffic paths. In the numerical solution, the particulate matter was substituted by the passive scalar. Physical parameters of the passive scalar are assumed the same as for the ambient air. The main advantage of this approach consists in simple and fast calculation. The primary exhaust emission factor of the local model S_{pe}^{l} was calculated as in the equation (1), but with consideration of the road inclination. The local total PM10 emission factor was obtained from previous studies carried out in the center of the city of Brno as 0.04045 g/km car. The value of the local total emission factor is lower in comparison with the regional total emission factor. This results from a better quality of road surfaces and more frequent road cleaning in inner parts of the city.

2. Deposition and re-suspension

The simplification used in this study assumes equivalence between the particles deposition rate on smooth dry surfaces and the particles re-suspension rate from these surfaces. Stable deposition is assumed only on surfaces covered by vegetation. The vegetation covers 20% of the ground

surface in the local solution domain. 30% of particles generated by traffic are absorbed by this vegetation.

3. Boundary conditions

Meteorological conditions are set in the local model using the wind velocity layer boundary configuration. This boundary configuration prescribes specified wind speed and wind direction at a horizontal layer of the air. The air layer is led at height corresponding to the position of measurement. The pressure boundary conditions were prescribed on all side walls of the solution domain. The slip wall boundary condition is set on the top of the domain. As a model of turbulence, *k-ε RNG* model is used.

Results and discussion

In calculations, we presume coarse spherical particles with diameter 10 μm. Density of the particles is set to 340 kg/m^3 according to experiments carried out by Coppale A. (2005). The results of calculations are presented for north wind direction and wind velocity 2 m/s representing the predominant wind conditions at the solved area. The figure 2 shows the predicted PM10 concentration field obtained from the regional model. Only particles generated by traffic were taken into account. The PM10 concentration field was predicted for the daily average traffic rate. The figure 2 shows higher PM10 concentrations along roads with the highest traffic rate. At the bottom of the figure, the interstate highway passes around the city. Intensive traffic on this highway causes significantly high PM10 concentrations along this traffic path.

The PM10 concentration 5 μg/m^3 was obtained from the prediction at the position of the local solution domain. In-situ measurements were carried out during peak traffic hours and it is necessary to regard the actual traffic activity for a following comparison of the prediction and the measurements. The actual traffic activity was assessed as 1.8× the daily average traffic activity. The new predicted local solution domain concentration is now 8.5 μg/m^3. The regional background PM10 concentration was derived from a measurement outside of the urban area as 15μg/m^3. The north part of the city of Brno is without any intensive local sources of particles. This part of the city serves as residential areas without industry. In case of the north wind direction, influence of local sources wasn't considered.

The total predicted PM10 concentration is calculated as sum of the predicted concentration and the regional background concentration. The result of this calculation is 23.5 μg/m^3 at the position of the local solution domain. From measurement, we obtained the PM10 local background concentration value 45 μg/m^3. The result of calculation represents 52,2% of the concentration value obtained from measurements. The result shows that the predicted concentration values underestimate the measured concentration values. The difference is probably due to an intensive re-suspension of soil particles. This process is not taken into account in the numerical models due to difficult description of its source term.

Figure 2: Predicted PM10 concentration fields [μg/m^3] at height 3 m above the ground surface,north wind direction, wind velocity 2 m/s.

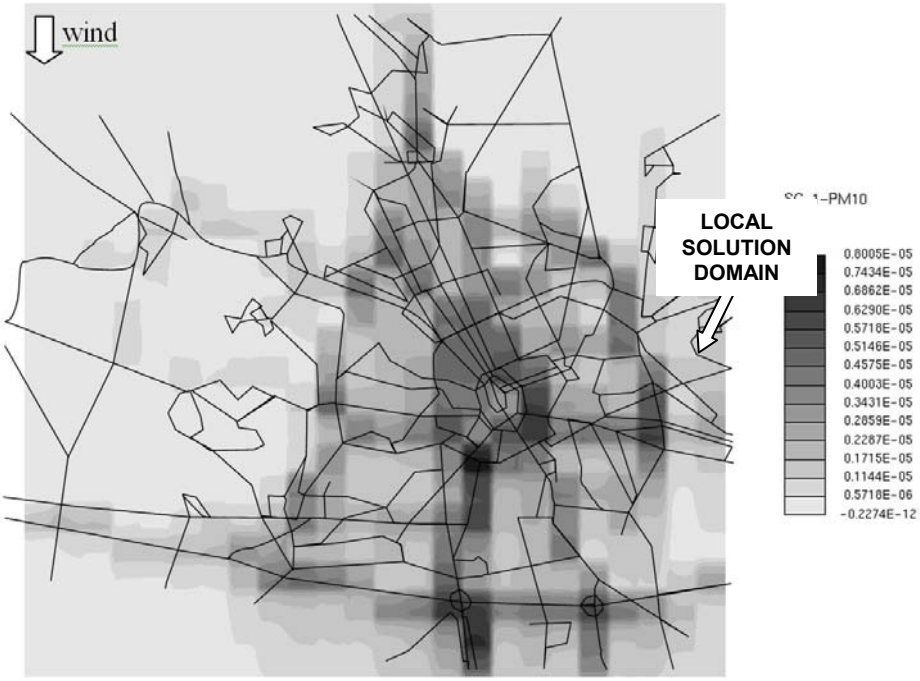
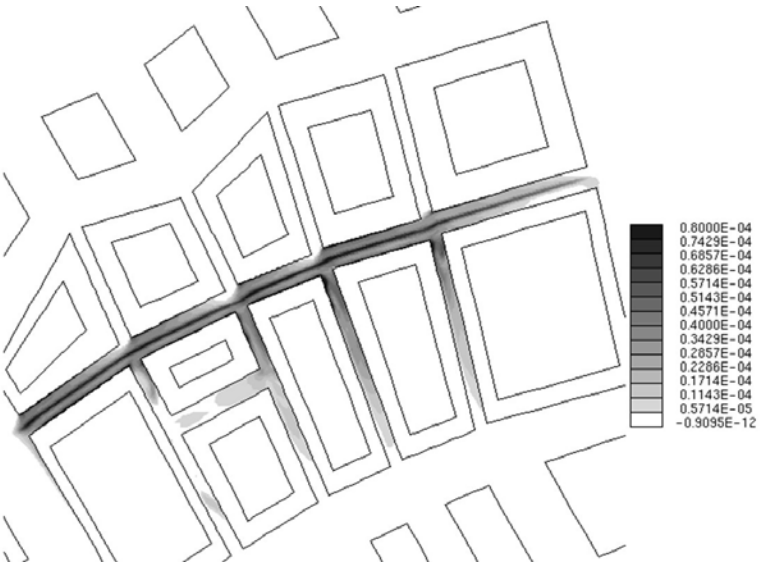


Figure 4: The predicted PM10 concentration field [μg/m^3] at height of 1.5 m above the road surface, north wind direction, wind velocity 2 m/s.



The local solution numerical model provides much closer vales of predictions and measurements. The predicted concentrations were compared

with measured concentrations at nine receptor points located in the main street canyon and its close surrounding.

For the north wind direction, the local background PM10 concentration was assumed 45 $\mu g/m^3$. The predicted concentration contribution from traffic is 27.5 $\mu g/m^3$. Then, the total predicted PM10 concentration is 72.5 $\mu g/m^3$. The corresponding concentration obtained from measurement is 83 $\mu g/m^3$. At this case, the result of calculation represents 87.4% of the concentration value obtained from the measurement. The local numerical model underestimates the total PM10 concentrations as well. But the inaccuracy of the regional model is lower in comparison with the regional model due to better mathematical description of transport processes in the smaller solution domain.

Conclusion

In this paper authors introduce a two-scale modeling of PM dispersion in large urban areas. The CFD code StarCD was used as an appropriate engineering tool for building up of two models. The city of Brno was used as the studied area. The regional model covered an area of 144 km^2. The actual geometry of the terrain profile was respected in the numerical model. Influence of buildings and other obstacles was substituted using a ground surface parametrical roughness. The regional domain was divided into 576 control regions. These regions were used for an assignment of PM emission related with traffic. Wind conditions were prescribed using the wind velocity profile on side walls of the numerical model. Particles PM10 were substituted by the passive scalar approach.

The local model covered area of 1 km^2. Detail buildings geometry was taken into account. Also influence of moving cars was taken into account. The source of PM was prescribed at the middle of traffic paths slightly above a road surface. A stable deposition was considered only on surfaces covered by vegetation. The wind velocity layer was used for correct assignment of meteorological conditions.

The predicted PM10 concentration fields were compared with the results of measurement. The both tested numerical models underestimate the terminal PM10 concentration values. The predicted results represent 52,2% and 87.4% of the PM10 concentration value obtained from the regional model and the local scale model, respectively. The difference is probably due to an intensive re-suspension of soil particles. This process is not taken into account in the presented numerical models due to a difficult description of its source term.

Acknowledgments

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Aerosol Modelling at the local scale

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Abstract

Nowadays, a special attention is paid to the aerosol number distribution as it might be more related to health and radiative impact than the mass distribution. Simulations have been performed on a winter episode over Paris with the Modal Aerosol Model MAM and the CTM (Chemistry Transport Model) Polair3D, both developed by CEREA. A strong nucleation event appears, controlled in particular by the sulphuric acid emission. However, the rapid growth of nuclei observed in several measurement studies is not reproduced by the model. Actually, the Kelvin effect is too strong for such nanoparticles and prevents condensation to occur substantially. The condensation of the sulphuric acid, which has an extremely low volatility, cannot explain on his own this growth. Heterogeneous chemical reactions between organic vapors and nuclei are supposed to be responsible for the crossing of the Kelvin effect barrier.

Keys-words*: aerosol modelling, local scale, condensation, nucleation, coagulation, secondary organic aerosol.*

Résumé

Une attention particulière est portée de nos jours à la distribution en nombre d'aérosols qui pourrait être plus corrélée aux impacts sanitaires et radiatifs des particules que la distribution en masse. A l'aide du modèle modal d'aérosols MAM et du code CTM (Chemistry Transport Model) Polair3D, tous deuw développés au CEREA, des simulations en bords de route ont été menées sur un épisode hivernal sur Paris. Un fort épisode de nucléation apparait piloté en particulier par l'émission d'acide sulfurique. La rapide croissance des particules nucléées mise en évidence par différentes campagnes de mesures n'est pas reproduite par le modèle. L'effet Kelvin est en effet trop fort sur ces nanoparticules pour autoriser une condensation suffisante. La condensation de l'acide sulfurique, extrêmement peu volatile, ne peut pas expliquer à elle seule cette croissance. L'hypothèse la plus probable pour le franchissement de cette barrière est l'apparition de réactions hétérogènes entre vapeurs organiques et particules nucléées.

Mots clefs : *simulation aérosol, échelle locale, condensation, nucléation, coagulation, aérosols organiques secondaires.*

Introduction

Particle emissions are regulated on the basis of particulate matter mass. However more attention is paid nowadays to the aerosol number distribution as it might be more related to health and radiative effects than aerosol mass distribution. In particular, a large amount of ultrafine particles are formed near traffic linked sources which contribute only a little to the mass distribution.

Nevertheless, the formation and rapid growth of these ultrafine particles is not yet well understood. In this paper, we try to reproduce this evolution, focusing on the number distribution and on the evolution of particle diameters, with the MAM (Modal Aerosol Model, see Sartelet et al., 2006) linked to the CTM (Chemistry Transport Model) Polair3D (see Boutahar et al., 2004), developed at CEREA.

Presentation of the model

Polair3D is a three dimensional Chemical Transport Model (CTM). The chemical mechanism RACM (Regional Atmospheric Chemistry Mechanism) is used, updated to take into account the formation of semi-volatile organic species.

In MAM, the aerosol distribution evolves under advection, diffusion, Brownian coagulation, condensation/evaporation of gases onto particles, nucleation of new particles and emissions. MAM can deal with four modes (three in the fine range the first of them exclusively dedicated to nucleation and one in the coarse range), called respectively mode I, J, K and C, described by a lognormal distribution. Each mode is made of sulfate, nitrate, ammonium, chloride, sodium, eight organic lumped species, primary organic aerosol (POA), mineral dust, carbon and water. The thermodynamic model ISORROPIA (see Nenes et al., 1999) is used for inorganic species and SORGAM (see Schell et al., 2001) is used for the partitioning of organics between gas and condensed phases. Mass transfer can be computed by assuming thermodynamic equilibrium or dynamically as done here. The expression of the condensation flux of species s onto a particle of diameter d_p is given by:

$$I_s(d_p) = AA_s(d_p).\left(C_{bulk_s} - C_{K_s}(d_p).C_{eqi_s}(d_p)\right) \qquad \text{Eq 1}$$

where AA_s is the condensation kernel coefficient ($m^3.s^{-1}$), C_{bulk_s} is the concentration of species s in the gas phase ($\mu g.m^{-3}$), C_{eqi_s} is the equilibrium gas concentration of species s ($\mu g.m^{-3}$) given by the thermodynamic model and C_{K_s} is an adimensional coefficient accounting for the Kelvin effect (based on the curvature of liquid droplets). The Kelvin effect is very strong for ultrafine particles (namely the nuclei around 1 nm) and constitutes a strong barrier to condensation (except from sulphuric acid condensation because its equilibrium gas concentration is almost 0). It decreases exponentionally as particle diameter increases.

For nucleation, the parametrization of Napari (Napari et al. 2002) for the ternary mixture $H_2SO_4 - H_2O - NH_3$ is used.

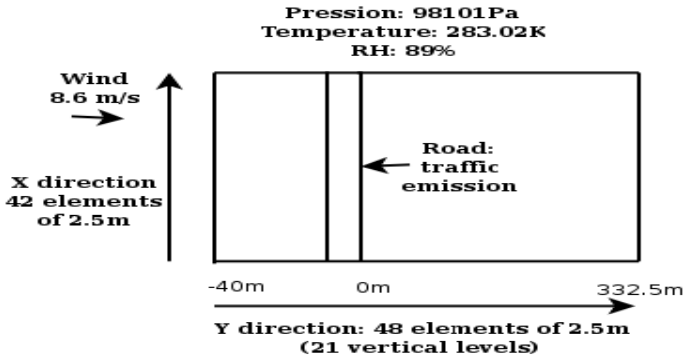
Transfer between modes is done with a mode merging scheme inspired from the one described by Binkowski et al. (2003). However, in the special scope of the local scale, it has been slightly modified. Because we want the mean diameter of mode I to keep close to the nucleation diameter, the Mode I is merged into mode J for diameters greater than a threshold diameter taken equal to 2nm. Mode J can grow freely. However if mode J and mode K become close, mode J is merged into mode K with a threshold diameter chosen as the intersection diameter of the two distributions.

Purpose and case study

Several measurement campaigns have put in evidence high nucleation events close to a source linked to traffic. The formation of the acid sulphuric in the atmosphere through oxidation of SO_2 emission by traffic is too slow to explain such nucleation events. In fact, sulphuric acid seems to be formed directly in the exhaust fume release system of vehicles where oxidation reactions are catalyzed. In consequence, sulphur emissions have to be partitioned between sulphur dioxide and acid sulphuric. The corresponding ratio is not known precisely yet but a common value is 5% of sulphur material emitted as acid sulphuric.

The ultrafine particles have been shown to undergo a rapid growth. This phenomenom is not yet well understood but several hypothesis might explain it. In general, models have difficulties to reproduce it. In order to investigate the qualitative formation and evolution of an aerosol distribution close to traffic sources, we simulate the evolution of the aerosol distribution near a road in Paris. Meteorological data and background concentrations of gases and aerosols have been extracted from a continental simulation over Europe led over 10 days in January 2001 with the simulation system Polyphemus (containing Polair3D, http://www.enpc.fr/cerea/polyphemus/). Background aerosol distribution is supposed to be close to thermodynamical equilibrium which guaranties it to have little direct impact on the aerosol distribution growth. Aerosol background is allocated to mode K and C with initial number median diameters of 100 nm and 300 nm. Mode I (exclusively dedicated to nucleation) and mode J (susceptible to welcome nuclei which have grown through condensation) are initially empty. January the fourth is chosen for simulations led in the scope of this paper. This day corresponds to a low pollution event (less than $12 \mu g.m^{-3}$ of PM) with a quite high wind speed ($8.6 m.s^{-1}$). The simulation domain and the main meteorological data are described in figure 1.

Figure 10: Simulation domain and main meteorological data.



Emissions of gases and aerosol come from the speciation done by CITEPA and integrated emissions from COPPERT3. They are based on equivalence with CO_2 emission. The CO_2 emission flux is put to $87500 \mu g.s^{-1}.m^{-1}$ and expressed by lineic meter of road. Among emitted species, we can notice XYL, OLT, OLI and TOL (which are precursors of anthropogenic semi-volatile organic species), sulphuric acid, ammonia and soot. Soot particles are emitted as elemental carbon with a diameter of 100 nanometers.

For all the simulations presented in this paper, the mass transfer through condensation process is evaluated dynamically. Boundary conditions are kept constant in time and equal to background concentrations. Emissions and meteorological conditions are also supposed to remain the same. Deposition is not taken into account nor resuspension of particles. After 3000 iterations with a time step of 0.05s, processes involved have equilibrated and simulations do not evolve anymore.

To evaluate the relative importance of nucleation, condensation and coagulation, a reference simulation with a sulphuric acid emission ratio of 5% of the sulphur dioxide emission is compared to an acid sulphuric emission ratio of 2%, another one with 8%, another one without coagulation and another one without condensation.

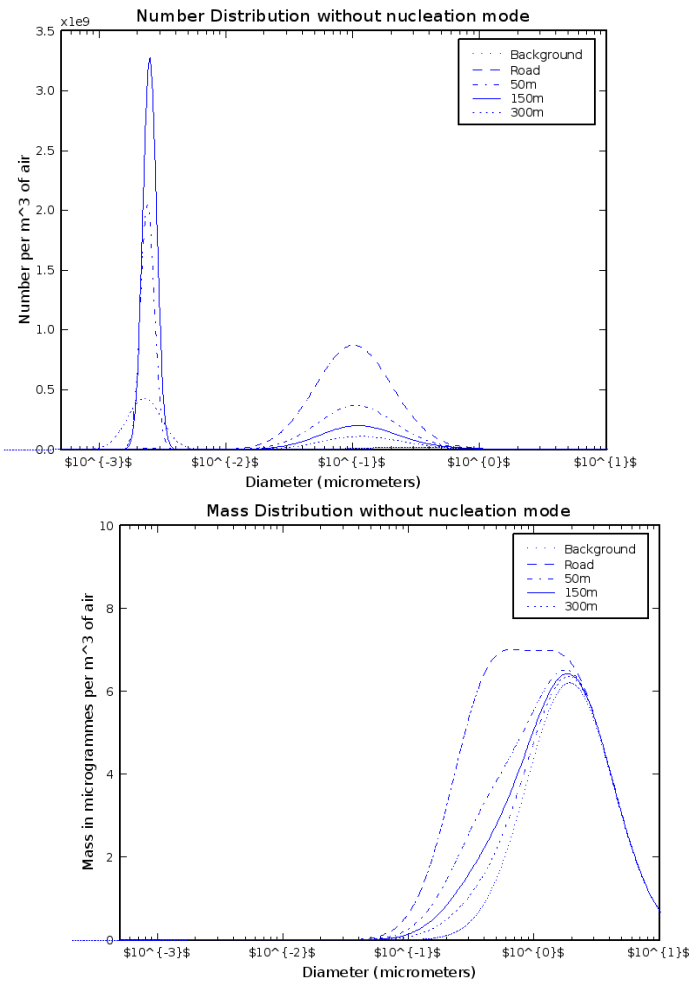
Results and discussion

First of all, the chemistry mechanism has revealed to have little impact on evolution of the aerosol distribution at such a local scale.

Figure 2 presents the aerosol number distribution (on the left side) and the aerosol mass distribution (on the right side) at different distances from road. The nucleation mode is not shown on those figures. Actually this mode does not contribute significally to the mass distribution, although it strongly dominates the number distribution. However, because measurement techniques do not allow to measure particles whith diameters less than 3 nanometers, and in order to focus on the rest of the distribution, mode I is not plotted here. The augmentation of mass is at most of 60% in the domain mainly due to soot emission in mode K. This corresponds in fact to an augmentation of at most

$7\mu g.m^{-3}$. This value agrees fairly well with Rosenbohm et al. (2005) who have measured a difference between aerosol mass concentration on the two sides of a motorway of $5\mu g.m^{-3}$ which corresponds in this case to 15-20% of increase. With increasing distance from road, the aerosol mass distribution tends back to the background distribution.

Figure 2:The aerosol number distribution on the left side and the mass distribution on the right side. Mass increase is mainly due to soot emission, whereas number augmentation by several orders of magnitude (background number concentration is 4.3 $10^7 \#.m^{-3}$) is due to the nucleation event.

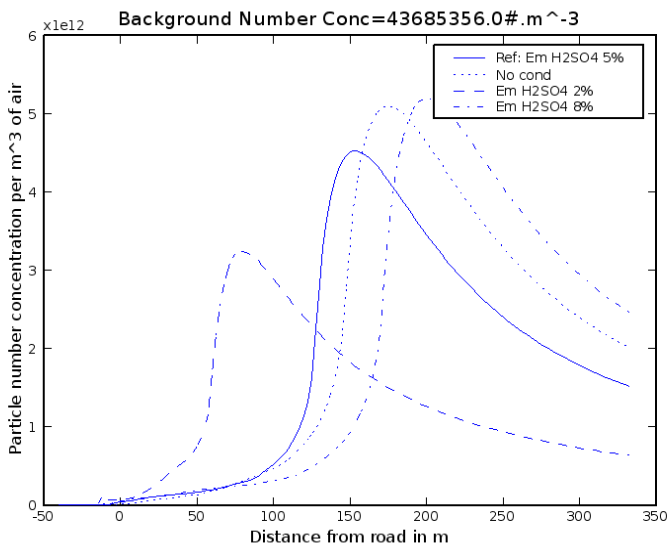


The aerosol number distribution is dominated by mode J (as nucleation mode is not plotted here). The distribution obtained is bimodal as it is reported in Rosenbohm et al. (2005) and Zhu et al. (2004) by measuring aerosol distribution close to a motorway (near Heidelberg) and close to a major highway in Los Angeles respectively. In mode J, we find fresh new nuclei which have

grown a little through condensation and have been transfered to mode J through the mode merging algorithm. Three observations can be done on the number distribution:

- Particle number concentration has increased five orders of magnitude from 4.3 $10^{7}\#.m^{-3}$ to approximately 4.6 $10^{12}\#.m^{-3}$ due to the high nucleation event (see Figure 3). Rosenbohm et al. (2005) have measured an increase of 3.5 $10^{10}\#.m^{-3}$ of the number concentration between the two sides of a motorway. To explain this difference, we can notice that the background concentrations were higher in this study, that we probably count here particles which cannot be measured by actual measurement techniques and the strong dependance of the nucleation flux to nucleating species concentrations, temperature and relative humidity.

Figure 3: Evolution of the total number concentration with distance from road. Results obtained without condensation and with two different ratios of sulphuric acid emission factor are compared to the reference simulation.



- The growth of fresh new nuclei is not reproduced. The critical size for sulphuric acid-ammonia-water nucleation is about 1nm. For such particles, the Kelvin effect is very strong and prevent condensation to occur apart from that of sulphuric acid which saturation pressure is almost 0. As sulphuric acid has a very low volatility, it may either condense onto existing particles or nucleate with ammonia and water. Nevertheless, it cannot explain on his own the growth of fresh new nuclei. Organic species are supposed to be involved in this original growth through heterogeneous chemical reactions as mentioned in Zhang and Wexler (2002). As explained in Jang et al. (2002), those

reactions might be acid-catalyzed and sulfuric and nitric acid are principal candidates for such a catalyst role.

- The nucleation event does not occur just next to the road but at about 150 meters from it. Contrary to what happens for soot directly emitted on the road and whose concentration diminishes rapidly with increasing distance from the road through dilution, the maximum number concentration is found at 150 meters from the road. This is probably due to the high dilution situation and characteristic time step of the nucleation process. One of the key parameter of nucleation is of course the sulphuric acid emission ratio. The sensitivity to this parameter is investigated below.

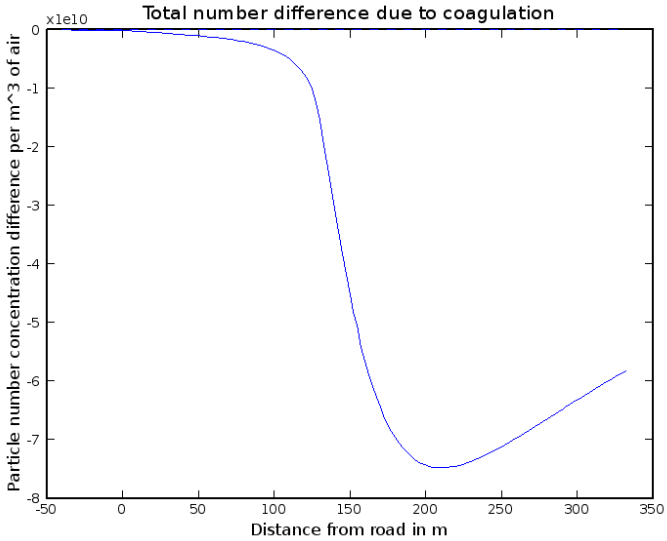
1. Emission of sulphuric acid

The reference sulphuric acid emission factor used in this paper correponds to 5% of sulphur dioxide emission. To investigate sensitivity to this parameter we have tested respectively 2 and 8% as factors. The results are compiled in Figure 3. An increase of the sulphuric acid emission ratio from 2 to 8% leads to an increase at maximum of 65% of the total aerosol number concentration. Moreover, the peak has been shifted from a distance of 80 meters from the road to more than 200 meters probably because it takes more time to nucleate more particles. The curve without condensation illustrates the competition between condensation and nucleation. As sulphuric acid can either condense or nucleate, neglecting condensation leads to an over estimation of nucleation.

2. Coagulation

On Figure 4, the difference between the number concentration obtained on the reference simulation and on the simulation without coagulation is plotted as a function of distance from the road. The impact of coagulation is more important when the number concentration is high (around 150 meters from the road here). The sink corresponds to nucleation mode particles. However, the number of particles depleted from mode I through the coagulation process is 2 orders of magnitude lower than total particle concentration here. Coagulation impact on total aerosol number concentration is quite low in this case of high dilution. The coagulation sink may be more significant in confined environments such as a street-canyon or a tunnel for example and in case of high number concentration.

Figure 4: Coagulation particle sink with distance from road. Coagulation is more efficient to deplete particle number in case of high concentration. As dilution is strong here, coagulation impact remains low.



3. Secondary organic aerosol (SOA)

The organic matter seems to be involved in further growth of the aerosol distribution once the Kelvin effect barrier is crossed (see Zhang et al., 2004). However, the chemical mechanism used in the simulations does not form rapidly enough semi-volatile organic species (namely CVOLE1 which represents the alkene class) from emitted precursors (namely OLT and OLI) to allow a possible condensation of SOA. New generation exhaust fume release system has revealed to have a high oxidation power. So, one may considere that oxidation reactions involved in the formation of semi-volatile organic compounds may be catalyzed in the release system of vehicles. This will lead to consider a direct emission of the semi-volatile organic compounds whose precursors are emitted.

Conclusion and perspectives

Traffic influenced aerosol distribution has been simulated near a road in Paris area during a high dilution winter day. The aerosol mass distribution is mainly influenced by direct soot emission. However, in proportion the aerosol number concentration is sharply more impacted by traffic emission through sulphuric acid-ammonia-water nucleation. Coagulation has revealed to be of little influence on the aerosol distribution for such a high dilution event. Nevertheless, it might be a substancial sink for fresh new nuclei in case of high number concentration and for more confined environment. The model is able to reproduce sulphuric acid competition between condensing onto existing particles or nucleating with ammonia and water.

The rapid original growth of fresh new nuclei observed in several measurement studies has not been reproduced by the model. Sulphate condensation is not sufficient to explain the original growth of fresh new nuclei and Kelvin effect is a strong barrier for condensation of other species on such nanoparticles. Heterogeneous chemical reactions between organic vapors and nuclei are supposed to be involved in this original growth. Next step of this work is to succeed in simulating the crossing of the Kelvin effect barrier. For further growth of the aerosol distribution, SOA condensation might play an important role. As new generation release systems of vehicles seem to have a high oxidant power, we wonder if anthropogenic semi-volatile organic compounds should not be considered directly as an emission as it is done for sulphuric acid. It is plan to apply this aerosol model within the CFD (Computational Fluid Dynamical) model Mercure_Saturne, developped at CEREA, in complex and more confined domains such as street-canyons.

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Évaluation de l'impact sur la qualité de l'air des mesures de réduction des émissions du trafic routier

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Résumé

Lors d'un programme INTERREG III, l'ASPA[3], le LUBW[4] et le LHA[5] ont créé une plate-forme commune de modélisation de la qualité de l'air dans la vallée du Rhin supérieur.

Le système est alimenté par des cadastres transfrontaliers des émissions pour des situations 2000 et 2020, cette dernière se basant sur la Directive sur les Plafonds d'Emissions Nationaux de 2001, l' «étude plurimodale des transports» du Groupe Expert Transport de la Conférence du Rhin Supérieur et l'EMEP. Les différentes situations sont étudiées avec ou sans mesures d'urgence.

L'évolution des émissions entre 2000 et 2020 montre une diminution pour les principaux indicateurs de pollution routière, de même pour l'application de mesures d'urgence.

Les concentrations modélisées se trouvent également orientées à la baisse, prononcée pour le dioxyde d'azote, sensible pour l'ozone qui dépend davantage des imports extérieurs. Les mesures d'urgence pour réduire les concentrations en ozone doivent concerner une aire géographique large.

Mots clés : *émissions, simulation, exposition, scénarios, modélisation, concentrations*

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Abstract

Objectives

The ASPA is in charge with air quality measurements, study and forecasts in Alsace. In the frame of a European INTERREG III program, it is working together with the networks of Baden Württemberg (LUBW) and Basel (LHA) towards a "common air quality assessment and information system in the Upper Rhine Valley". The current and last step of the project is the set up of a common modelling platform, which will complete the bilingual website[6] presenting daily data of the networks. Further, the platform allows the simulation of emission reduction scenarios and the impact assessment of traffic emission reduction measures coming from European and national regulations or set up by territorial collectivities.

Method

The platform for deterministic air quality forecasts and simulations designed by ACRI-ST is based on CHIMERE[7] chemistry-transport (IPSL[8]) and MM5[9] meteorological (NCAR[10]) models. Chemical boundary conditions are issued from European forecasts (PREVAIR/INERIS[11]) and meteorological boundary conditions come from global forecasts (GFS/NCEP[12]). The system has been calibrated and validated thanks to a comparison of models outputs with 3 dimension data of a big meteorological and chemical measurement campaign that took place in the Upper Rhine Valley in June. Moreover the system is used automatically to produce daily air quality forecasts and analyses: an automatic comparison with the fix measurement network data provides regular statistics (like mean bias, root mean square error, correlation) on the system ability to reproduce or forecast real pollutant concentrations.

The emission cadaster used as input in the modelling platform was elaborated in the frame of the second part of INTERREG III. Several software were developed to collect the Upper Rhine Valley primary data. For traffic emissions the tool CIRCUL'AIR was designed : the inputs are primary data from the DDE (Departemental Equipment Head Office) and the output is a linear sources emissions database. The tool EMISS'AIR computes a communal and annual emission inventory by integrating primary data into a common database (surfacic, linear and punctual sources, about 40 pollutants, 10 sectors and 50 subsectors, different fuels according to NAPFUE).

Last but not least, the MANAG'AIR tool computes thanks to GIS a kilometric and hourly emission cadaster. Miscing data on the sides of the domain are completed with EMEP data. The detailed land use categories are provided by the Corin Land Cover. Very detailed speciations of PM and non methane VOC worked out by the CITEPA and the IER are used (Pregger 2004 and Samba 2004). MANAG'AIR finally introduces an emission temporal distribution for each

[6] http://www.atmo-rhinsuperieur.net/
[7] http://euler.lmd.polytechnique.fr/chimere/
[8] Institut Pierre Simon Laplace IPSL de l'Ecole Polytechnique de Paris
[9] http://www.mmm.ucar.edu/mm5/mm5-home.html
[10] National Center for Atmospheric Research
[11] Institut National de l'environnement industriel et des risques
[12] National Center for Environmental Prediction

sector, under-sector and day type (week, Saturday or Sunday). The tool output is an emission cadaster with the desired spatial and temporal resolutions, used as input in CHIMERE. The MANAG'AIR tool allows the preparation of emission scenarios, by cutting or reducing activity of chosen sectors.

The CHIMERE model is fed up with this emission cadaster which contains anthropic emissions of each pollutant for each grid cell and time step of the simulation (biogenic emissions depend on meteorology are calculated separately). These input chemical components are transported and transformed by the chemie-transport model into pollutants concentrations. The ability of the model to reproduce reality with emissions is known, in this exercise CAFE scenarios are applied to emissions as input to the model which calculates new output concentrations.

Results :

First CHIMERE was fed up with the emissions of the « basis scenario 2000 ». Then « emergency measures » of the French circular of the 18th June 2004 are applied to this basis scenario. Evolution scenario for the year 2020 are also applied : these are based on the NEC Directive of the 23 October 2001, on the plurimodal study on traffic in the Upper Rhine Valley piloted by the Regional Equipment Head Office of Alsace in 2003 for the Expert Group on Air Quality of the Upper Rhine Conference, and on the EMEP.

Evolution of emissions between 2000 and 2020 shows an important reduction of emissions for the main traffic emissions indicators. The application of emergency measures like alternated traffic over big agglomerations have a visible impact.

A decrease of the concentrations also appears, with an important decrease for NO_2 and lower decrease for ozone since ozone is more dependant on the boundary concentrations. This means that emergency measures towards traffic emissions reduction have to be applied on a larger scale than the valley (regional scale) in order to be efficient.

Conclusion

The modelling system set up in the frame of the INTERREG III program is able to assess the efficiency of emission reduction measures in the Upper Rhine Valley, giving deterministic information for the improvement of air quality.

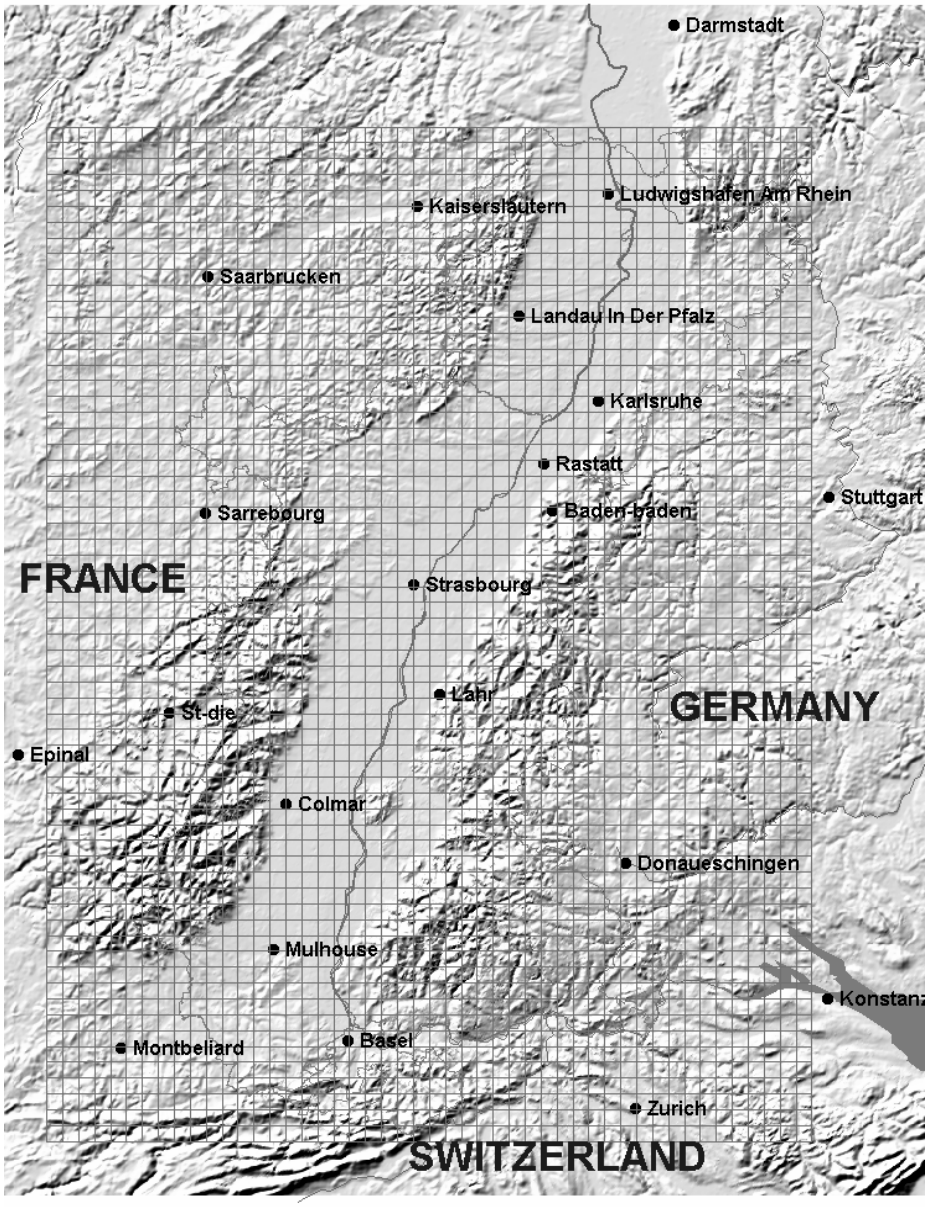
Key words : *emissions, simulation, exposition, scenarios, modelisation, concentrations*

Introduction

L'Eurorégion du Rhin Supérieur est un vaste espace trinational structuré par le Rhin, qui totalise plus de 4,7 millions d'habitants depuis Karlsruhe jusqu'à Bâle en passant par Strasbourg et Mulhouse. Dans le cadre d'un programme INTERREG III, l'ASPA, le LUBW[4] et le LHA ont mis en place une plate-forme commune d'information sur la qualité de l'air à l'échelle de la vallée du Rhin supérieur. Un site internet bilingue d'information sur la qualité de l'air en direct a été mis en place. Ce site est complété par des prévisions quotidiennes et cartographiées de qualité de l'air alimentées par une plate-forme commune de

modélisation. Le système de modélisation permet également d'évaluer l'impact de mesures de réduction des émissions du trafic routier réglementaires ou mises en œuvre par les Collectivités Territoriales.

Figure 11 : Domaine transfrontalier de modélisation chimie-transport (mailles de 4x4km, 48 mailles en longitude, 68 mailles en latitude) – Chemie-transport transboundary modelisation grid (4x4km cells, 48cells in longitude, 68cells in latitude)



Méthodes : mise en place d'une plate-forme commune d'émissions et de modélisation des immissions dans le Fossé Rhénan

1. Les outils de préparation des émissions

La plate-forme transfrontalière de modélisation de la qualité de l'air est alimentée par un cadastre transfrontalier d'émissions élaboré dans le cadre du programme INTERREG III. Au préalable et afin de réaliser l'inventaire communal et annuel transfrontalier, des outils informatiques ont été développés.

L'outil CIRCUL'AIR est spécialement dédié aux émissions du trafic routier : les entrées de cette macro sont des comptages routiers fournis par les services de l'équipement, le parc routier fourni par le CITEPA (types de véhicules, normes), des données topologiques et des données météorologiques pour le calcul des émissions à froid. Le résultat est une base de données d'émissions linéaires de trafic.

Les données primaires concernant l'ensemble des émissions sont ensuite intégrées dans une base de donnée d'émissions linéaires, ponctuelles et surfaciques développée par l'ASPA et nommée EMISS'AIR (40 polluants, 10 secteurs ou activités, 50 sous-secteurs et plusieurs combustibles selon la nomenclature européenne NAPFUE).

L'outil MANAG'AIR permet de convertir l'inventaire annuel communal en un cadastre de résolutions temporelle et géographique données (SIG). Sur les bords du domaine les données sont complétées avec le cadastre EMEP afin d'aboutir à un domaine rectangulaire adapté aux grilles de modélisation. L'occupation du sol utilisée pour répartir les émissions est la Corin Land Cover. Des profils verticaux sont introduits pour chaque mois, chaque jour type (jour ouvré, samedi et veille de fête, dimanche et jour férié), et chaque heure. L'outil introduit des spéciations détaillées des PM et des COVNM (Pregger 2004 et Sambat 2004).

2. La plate-forme de modélisation

Le choix s'est porté vers une plate-forme de modélisation construite par ACRI-ST et constituée des modèles MM5 pour la simulation de la météorologie (NCAR) et CHIMERE pour la simulation de la qualité de l'air (IPSL). Les conditions aux limites météorologiques sont issues du Global Forecast System du NCEP. En prévision les conditions aux limites du modèle de chimie transport sont fournies par le système PREVAIR de l'INERIS.

Les performances de la plate-forme de modélisation ont été évaluées en mode prévision durant l'année 2005 et en mode simulation en coopération avec l'Ecole Polytechnique de Lausanne EPFL avec l'étude approfondie d'épisodes de pollution durant lesquelles une campagne de mesures intensive a eu lieu.

3. Les scénarios 2020 et «mesures d'urgence»

Les déplacements internes au Rhin Supérieur sont au nombre de plus de 3,7 millions par jour. L'automobile constitue le mode de transport essentiel de la mobilité régionale (parties française et allemande du Rhin Supérieur).

Pour sa partie transport, le scénario 2020 appliqué dans le cadre d'INTERREG III est issu de l'étude plurimodale des transports « les déplacements dans le Rhin supérieur en 2020 » commandée par le Groupe Expert Transport de la Conférence du Rhin Supérieur. Ce scénario inclut un abaissement des coûts de transport en général, l'usage de la télématique pour le transport routier de marchandises et le fret ferroviaire, un cadencement à la demi-heure de l'Euro-Rhin et du Regio-S-Bahn et la réalisation de projets routiers et ferroviaires. Les données de trafic de la Direction Régionale de l'Equipement (DRE) et le parc 2020 de l'ADEME ont été utilisées pour calculer les émissions routières en Alsace. Pour l'Allemagne, les NO_x, le SO2, les COVNM et le NH3 sont calculés à partir des données 2000 et les émissions de CO et de particules proviennent de facteurs EMEP. Pour les évaporations de COVNM en Allemagne, la remise en suspension des particules et le CH4, les émissions 2000 sont multipliées par le rapport 2020/2000 de l'Alsace. Pour la Suisse, les émissions sont calculées à partir des facteurs EMEP que multiplient les émissions 2000.

Pour sa partie transport, le scénario « mesures d'urgence » appliqué dans le cadre d'INTERREG III est issu de la circulaire du 18 juin 2004 du Ministère français chargé de l'Environnement relative aux procédures d'information et de recommandation et d'alerte et aux mesures d'urgence. Concernant le trafic routier, ces mesures d'urgence se traduisent par une réduction évaluée entre 40 et 80% des émissions de NO_x, CO, COVNM, PM sur les principales agglomérations.

Résultats : impact de scénario d'émissions du trafic sur les émissions et les immissions dans le Fossé Rhénan

1. Impacts de l'application des scénarios sur les émissions

L'évolution des émissions entre 2000 et 2020 fait apparaître une diminution importante des rejets de PM10 issus du trafic routier. De même, l'application de mesures d'urgence comme la circulation alternée sur les principales agglomérations peut avoir un impact notable sur les émissions.

2. Impacts de l'application des scénarios sur les immissions

Les simulations des scénarios sont actuellement mises en œuvre. On peut déjà conclure que les concentrations se trouvent également orientées à la baisse, prononcée pour le dioxyde d'azote, moins sensible pour l'ozone qui dépend plus des imports de pollution extérieure dans la vallée. La mise en

œuvre de mesures d'urgence pour réduire les rejets du trafic routier et donc les concentrations en ozone doit concerner une aire géographique large (régionale voire plus) pour être efficace.

Conclusion

Les outils développés permettent d'évaluer l'efficacité des mesures de réduction de la pollution proposées dans la vallée du Rhin supérieur. Ils apportent des éléments techniques indis-pensables à l'évaluation des coûts-bénéfices des politiques d'amélioration de la qualité de l'air à l'échelle transfrontalière. Par ailleurs, la plate-forme de modélisation transfrontalière est également utilisée pour alimenter la plate-forme URBAN'AIR de prévision à l'échelle urbaine de Strasbourg.

Remerciements

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Assessing the exposure to traffic $PM_{2.5}$ in urban neighbourhoods

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Abstract

Staring from traffic microsimulation modelling and emissions for a disaggregated vehicle fleet $PM_{2.5}$ concentrations were modelled with a very high geographical and time resolution while taking into account the land use and building heights along the streets of the modelled area. With this information we calculated exposure using the concentration at the residential address to give an estimate of the impact of exposure to $PM_{2.5}$. Based on the detailed dispersion results for $PM_{2.5}$ concentrations at street and sub-street level we discuss the implications and caveats of combining these data with results from existing epidemiological studies for the purpose of health impact assessment.

Keys-words*: $PM_{2.5}$; exposure; impact assessment; mobility plans*

Introduction

Increasingly, people live and work in densely populated urban environments, and it is now evident that transport within cities causes multiple stresses and risks to the health of inhabitants and commuters. More and more city authorities are tackling the mobility problems driven by the need to increase safety and reduce congestion, but mostly without knowing the exact impact of different measures on either noise or air quality. The Belgian Mobilee-project quantified the effects of traffic plans in urban areas on the perceived safety of the area (the quality of life), on exposure to noise and on exposure to air pollution.

Objectives

In this paper we present and discuss the $PM_{2.5}$ exposure and health impact results of model simulation runs for Ghentbrugge, a suburb of Ghent, Belgium. We compare results for the base year 2003 with three different traffic scenarios for the year 2010.

Methods

We used detailed traffic modelling results and emissions for a disaggregated vehicle fleet, and modelled concentrations of $PM_{2.5}$ with a very high geographical resolution (25 m) and taking into account the land use and building heights along the streets of the modelled area. The dispersion model calculates the contribution of local transport to the background concentrations, and the contribution of transport inside and outside a certain street to the concentrations in that street. A novel approach was used based on the coupling of the street canyon model OSPM and the Gaussian model IFDM. OSPM calculates the contribution of the traffic emissions inside a particular street canyon, whereas IFDM computes the background contributions, including the concentration levels caused by the surrounding streets. Both models are interacting and have been integrated into an advanced computer program. These models have been described elsewhere (see Int Panis, 2003 ; and Mensink, 2005). With this information we calculate the daily average exposure using the concentration at the residential address, and give an estimate of the impact of the exposure to $PM_{2.5}$ based on concentrations at the residential address. This procedure has been followed for the base year 2003, and for 3 different mobility scenarios in 2010:

- a business as usual scenario, BAU, in which only current legislation (euro standards) with respect to vehicle emissions is implemented;
- a first mobility plan scenario, SCENARIO1, adding local traffic measures, speed limits and changes in infrastructure to the BAU scenario.
- A second mobility plan scenario, SCENARIO2, in which a local industrial site is redeveloped, attracting more traffic to that zone in comparison with SCENARIO1.

The exposure assessment uses a GIS based approach, where traffic-related concentration-increments derived from the dispersion model are intersected with population data. Exposure to traffic-related pollutants was calculated with a population map of the study area including the residential population as well as temporary ‘residents’ in schools, hospitals and the redeveloped industrial sites in the local area. Residential population data for different age groups were disaggregated to street level. Per street segment of the same street the age distribution was kept constant. Then the residential population was multiplied with the contribution of local transport to the background concentrations to calculate the population-weighted exposure to $PM_{2.5}$.

The approach for health impact assessment is based on methods applied in ExternE (see also Int Panis, 2004), and is similar to impact studies on air pollution as performed by several other organisations (like WHO, see also WHO, 2002; Künzli, 2000). Based on background morbidity or mortality data for the population that is being studied, and using concentration response functions from epidemiological literature, the attributable fraction of the population that is related to the air pollution concentration is calculated. For morbidity we have modelled two indicators:

The relative increase in respiratory hospital admissions due to the traffic related concentrations of $PM_{2.5}$. We use the epidemiological results from the APHEA2 study (Atkinson, 2001). In the original study the relative risk is associated with PM_{10}, whereas we apply this risk to the traffic related $PM_{2.5}$ fraction of PM_{10}. This is an assumption and more research will certainly improve our estimates, but the relative change of the morbidity impact when going from 2003 to 2010 is less affected by this assumption.

The relative increase of the prevalence of lower respiratory symptoms (in this case acute bronchitis) in children, based on studies in Switzerland (Braun-Fahrlander et al., 1997). We use these series of Swiss studies because of the follow-up studies that show that small decreases in air pollution improve health, adding to the causality and credibility of this morbidity impact in an health impact assessment (Bayer-Oglesby et al., 2005).

Both endpoints have been linked to traffic as well (WHO, 2005).

For mortality impacts an identical approach is proposed by Künzli (2000). It now is more acceptable to use a life expectancy analysis to calculate the years of life lost due to chronic exposure. Within ExternE life table calculations have been applied to calculate the impact of changes in air pollution on a current living population. A value of 65 Years of life lost (YOLL) per 1 µg/m³ $PM_{2.5}$ increase per year and per 100000 people (aged 30 or more) is proposed. This is consistent with calculations of Leksell and Rabl (2001), who find an average value of 52 to 64 YOLL per µg/m³ per year and per 100000 people for European countries and the US

Results

First the population weighted exposure in the area of Ghentbrugge for the current situation (2003), BAU (2010) and the two scenarios (2010) is calculated with the concentrations from an IFDM calculation, without taking street canyons into account. In Figure 12 it is shown that exposure shifts to lower concentrations in 2010 compared to 2003. The effect of the local mobility plans on exposure is much smaller than the general trend towards lower emissions that is driven by European legislation. Exposure to $PM_{2.5}$ is expected to be marginally smaller in some areas by 2010 when the local mobility plan (SCENARIO1) is implemented (e.g.Figure 12), compared to BAU. Nevertheless there are also locations (notable the vicinity of two former industrial sites that will be redeveloped, in SCENARIO2) where exposure shows an increase compared to the BAU-scenario. In any case the absolute value of these changes is small compared to the total concentration (attributable to local traffic).

Figure 12: Histogram of the number of people exposed to 24h average PM2.5 traffic related concentrations (IFDM results). The exposure is aggregated in 1 µg/m³ categories.

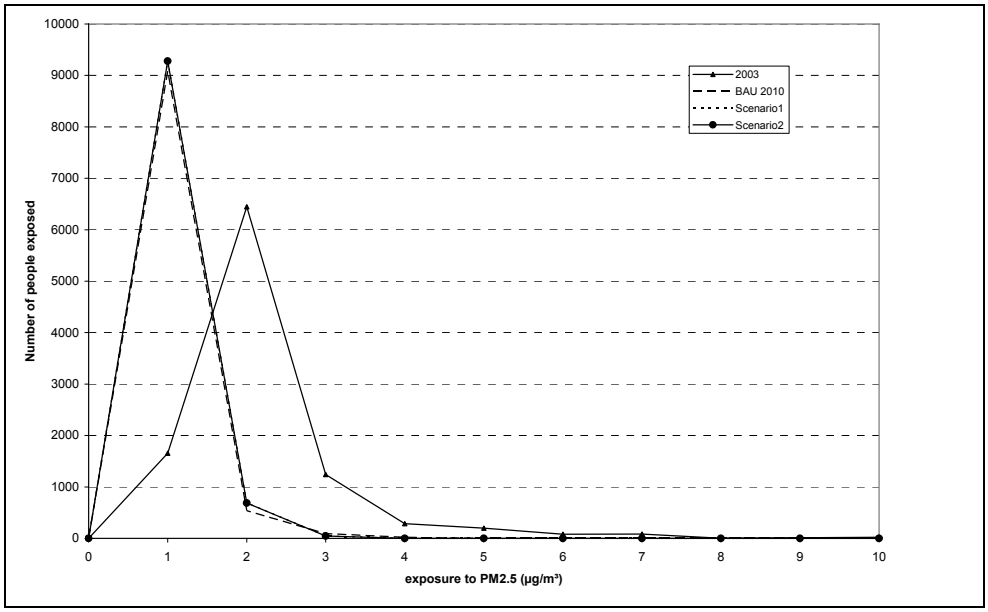
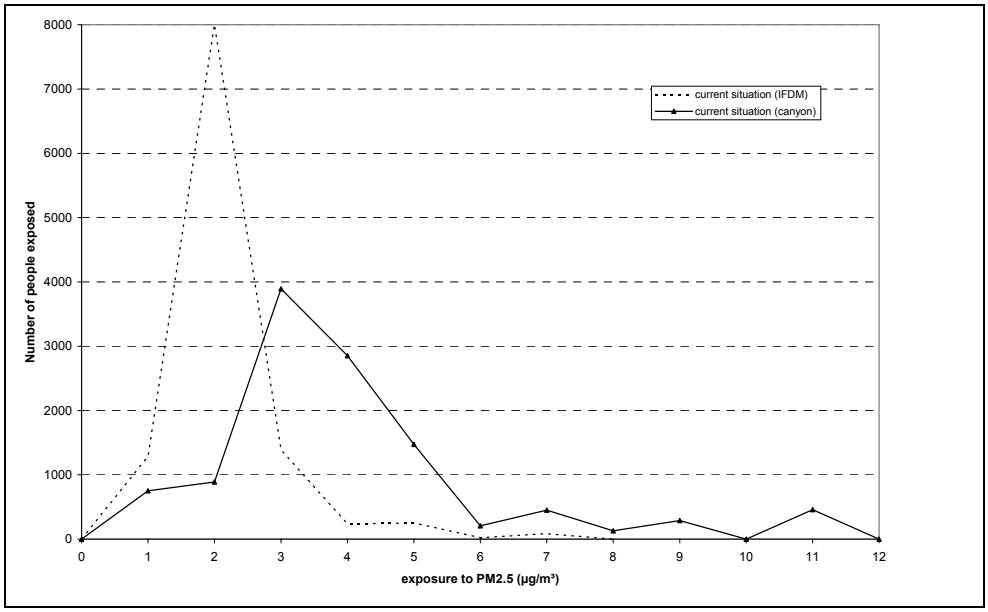
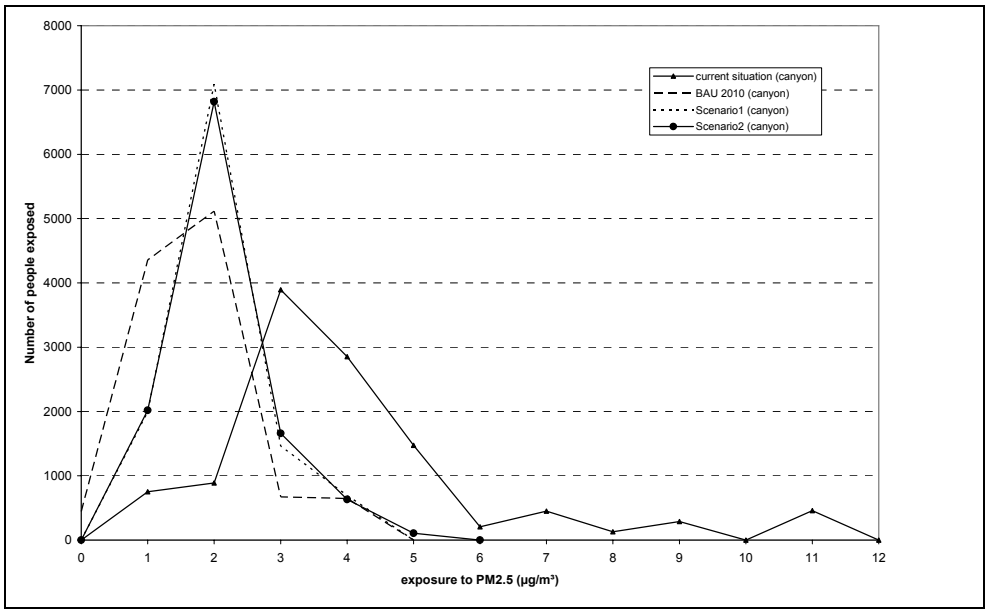


Figure 13 : Histogram of the number of people exposed to 24h average PM2.5 traffic related concentrations (IFDM compared to IFDM-OSPM street canyon results). The exposure is aggregated in 1 µg/m³ categories.



Second, the influence of taking street canyons into account when modelling exposure is shown in Figure 13. Exposure shifts to higher concentrations, which is to be expected, and which is more likely to be the real exposure to traffic related air pollution, whereas the Gaussian (IFDM) concentrations and results reflect more an urban background situation. Now, both the SCENARIO1 and SCENARIO2 result in a higher exposure on the local population in the street canyons. Population weighted exposure is then about 20% higher than in the BAU scenario. On the other hand exposure in the BAU scenario in 2010 will still be about 60% lower than the exposure in 2003 in the street canyons. Redevelopment of the industrial site (SCENARIO2) does not change the exposure compared to SCENARIO1 (Figure 14).

Figure 14 : Histogram of the number of people exposed to 24h average PM2.5 concentrations (IFDM OSPM street canyon results). The exposure is aggregated in 1 µg/m³ categories.



Exposure of people in traffic is not included in the scenarios. Due to the small area studied the time spent in traffic is very small compared to other activities in the area. Using average speeds, assumed occupancy in cars, and length of streets in the area, it is calculated that the average exposure inside cars would add an extra 7% to the overall population-weighted exposure in the study area. It should be noted however that we did not take into account the effect of tailing behind other vehicles.

Impacts on health have been calculated with the concentrations from the Gaussian IFDM model. We assume these concentrations match with the exposure indicators (ambient air concentrations in central-site monitors) in the original epidemiological studies. We conclude that on average the current situation contributes to premature mortality in such a way that 10 years of life are lost, each year, in the exposed population of about 9500 people in the local area that has been taken into account (Table 1). This is significantly higher than

in 2010. But in 2010 differences in air quality and exposure in the two scenarios considered are not significant. The same applies to the other impact categories considered. For elderly as for children the impact on respiratory health decreases significantly in 2010. No additional health impact is to be expected from the local mobility plan.

Table 10 : Health impact assessment of the different scenarios (95% confidence interval).

	population at risk	current situation (2003)	BAU (2010)	SCENARIO1 (2010)	SCENARIO2 (2010)	Unit
Mortality	total	10.7 (7.2-14.1)	3.7 (2.5-4.9)	4.3 (2.9-5.7)	4.4 (3.0-5.8)	YOLL
Morbidity :						
Respiratory effects	+65	0.17 (0.1-0.23)	0.06 (0.04-0.08)	0.07 (0.04-0.09)	0.07 (0.04-0.09	% increase in hospitalisation
Lower respiratory symptoms	children	6.2 (0-16.4)	2.1 (0-5.6)	2.5 (0-6.5)	2.5 (0-6.7)	% increase in prevalence

Discussion

We were able to demonstrate with a very detailed exposure model for a suburban area that implementing EU emission legislation for transport will result in significantly lower exposures and impacts to $PM_{2.5}$. The exposure model also demonstrates the effect of street canyons on exposure, shifting the average daily population weighted exposure to higher concentrations. In both modelling results, either based on IFDM or on street canyon concentrations, the effect of the local mobility plans is much smaller than the effect of cleaner cars in 2010 compared to 2003.

In past air pollution impact studies, results from very large time series or cohort studies were used to estimate the effect on public health from air pollution, either on a supra-national or national scale (Künzli, 2000) or on a city-wide scale. In those studies ambient air pollution concentrations, measured by central site monitoring stations, were used as the suitable indicator of exposure. This is the current practice and has been applied e.g. in ExternE for the calculation of external costs of transport (Int Panis, 2004). When using a detailed exposure indicator, either measured through personal monitoring or through modelling, the use of the concentration-response functions based on central-site monitoring are likely to give wrong answers. The WHO (2005) also noted that the direct evidence is still too inconsistent to derive well-based concentration–response functions, which are needed to quantify precisely the adverse effects of transport-related air pollution. In general however it is assumed that this kind of exposure misclassification will underestimate the real effect of air pollution. New evidence suggests that a detailed exposure assessment based on concentrations at doorstep increases the mortality risk in the ACS cohort study (Jerrett, 2005).

We have worked on a very local scale, a suburb of the city of Ghent, with about 9500 inhabitants. We have detailed the exposure up to a resolution of 25 m, and have distinguished between segments of streets, allocating sometimes

only a few dozen of inhabitants to a concentration. There is then an ethical and methodological problem to the straightforward application of the classical concentration-response functions. For the sake of simplicity we develop our arguments for mortality impacts of air pollution.

Ethical: Applying classical exposure response to these segments will result in a false perception of real risk. Assume that the impact assessment will estimate that 1 premature mortality will occur in a certain street or area. Since air pollution effects are typically multi-causal effects, the explicitation of such an early death and subsequently the first death in this area due to any cause that can be related to air pollution will cause unnecessary and unwanted public concern.

Methodological: Epidemiological studies on air pollution and mortality derive a risk on a population level. In case of premature mortality the risk is expressed in terms of survival probability and loss of life expectancy. On a population level the effect is known on average, but it is impossible to detect whether a lot of people loose a little bit of life expectancy, or a small number looses a lot of life expectancy. Extrapolating this result to a very small number of people (a few dozens) is only plausible when the first assumption would be the correct one. It is however more likely that the second assumption is correct, and that on the level of the street there is not a homogenous distribution of people that will loose a lot of life expectancy. In other words in some streets the real impact might be zero, although we would calculate a non-zero impact.

It is clear that still more research is needed to introduce more specific exposure variables and a higher geographical resolution in epidemiology as well as in health impact assessments. It is obvious that transport-specific impacts of air pollution should be available to assess the benefits of policy measures. The efficiency of policies and the costs depend on tackling the correct issues and making the right choice of suspect sources and pollutants. Also from a societal point of view it is desirable to allocate the scarce public resources such that the highest public health protection is achieved with the lowest cost. It is a matter of defining the necessary and detailed concentration-response functions for traffic-related air pollutants in order to use exposure and impact models like the one presented here at its highest resolution.

Acknowledgments

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Assessment of Air Pollution in Alpine Valleys

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Abstract

The Alpine environment as a sensitive region is heavily influenced by major traffic routes. Within the project ALPNAP (Monitoring and Minimisation of Traffic-Induced Noise and Air Pollution along Major Alpine Transport Routes) the integration of advanced scientific methods of monitoring, simulating and assessing the air quality distribution and noise propagation is a key aspect for the impact analysis on human health. A methodology for measurement strategies and model simulations will be demonstrated for the Brenner traverse. First results of a field measurement campaign give detailed insights of the complexity of the wind systems and the distribution of air pollutants in the Inn valley.

Key words: *air pollution, measurements, modelling, traffic, alpine valleys.*

Résumé

Le milieu alpin est une région sensible fortement influencée par le trafic routier. Au sein du projet ALPNAP (Contrôler et réduire les nuisances environnementales le long des axes de communication alpins), l´intégration de méthodes scientifiques pointues de mesures, de simulations numériques et d´estimation de la variation spatiale de la qualité de l´air et de la propagation du bruit est un aspect essentiel pour l´analyse d´impact sur la santé humaine. Une méthode de stratégies de mesures et de modélisations numériques est testée pour la traversée du Brenner. Les premiers résultats de la campagne de mesures éclairent la complexité des vents et de la répartition de la pollution atmosphérique dans la vallée de l´Inn.

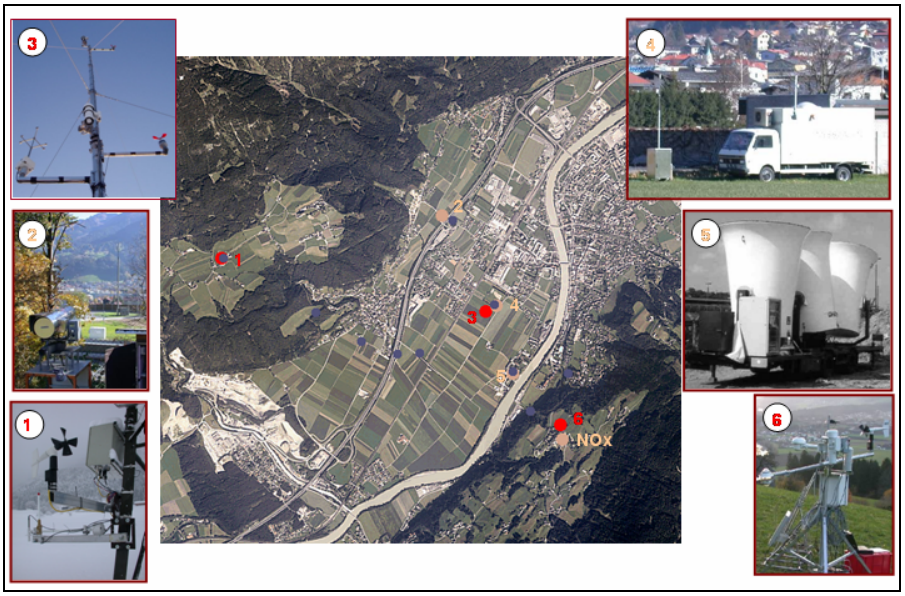
Mots clefs : *pollution atmosphérique, mesure, modélisation, trafic routier, vallée alpine*

Introduction

Road traffic emissions combined with unfavourable meteorological conditions like calm winds and low inversion layers have severe impacts on the natural environment as well as on the socio-economic development of regions in the vicinity of major Alpine traffic routes. Increasing amounts of heavy duty vehicles and passenger cars force the increase of traffic emissions, which continually violate the EU air quality thresholds of e.g. PM_{10} and/or NO_2 not only in this region.

Figure 1: Target area Schwaz / Vomp and instrumentation. Note the river Inn and the A12 highway (closer to the northern slopes). Images of the measurement devices clockwise from bottom left: (1) AWS on power pylon, (2) DOAS receiver/emitter unit, (3) 10 m AWS, (4) measurement van with PM_{10} device, (5) SODAR and (6) AWS. At location 5 a ceilometer was set up additionally. Tiny circles denote NO_2 passive sampler locations.

Figure 1: Région d'investigation et de mesures à Schwaz/Vomp dans la vallée d'Inn (Austriche). L'autoroute A12 (à gauche de la vallée) et le fleuve Inn (à droite) sont visibles clairement. Les images représentent des instruments représentés sur la carte des cercles rouges (dans le sens des aiguilles d'une montre): (1) station météorologique automatisée (SMA) placée sur un pylône électrique, (2) DOAS, unité d'émetteur/récepteur, (3) SMA à un mât de 10 m, (4) camion avec appareil de mesure de PM10, (5) SODAR, (6) SMA de surface. À l´endroit du SODAR une ceilometre a aussi été installée. Les cercles indiquent les positions des récepteurs passifs.



ALPNAP is an ongoing European Union research project focussing on corresponding effects along several major transit routes across the European Alps. Assisting regional authorities with appropriate output, a unique

cooperation of scientists within the Alpine region was set up to better assess and predict the spatial and temporal distribution of air pollution and noise propagation close to major Alpine traverses.

In a first step a measurement campaign in the lower Inn-valley was designed to determine cross-valley air pollution and meteorological information as well as vertical profiles to determine flow regimes (valley, slope winds), mixing layer height, stability in the boundary layer and emission sources at specific locations. Covering the major part of the winter season, this data will be used for enhanced analysis as well as for the set-up and validation of corresponding models merging the wealth of different remote sensing and in-situ measurements. In a second step air quality simulations will be carried out, in order to receive detailed 3D information of the distribution of air quality parameters.

Methodology

1. Measurements

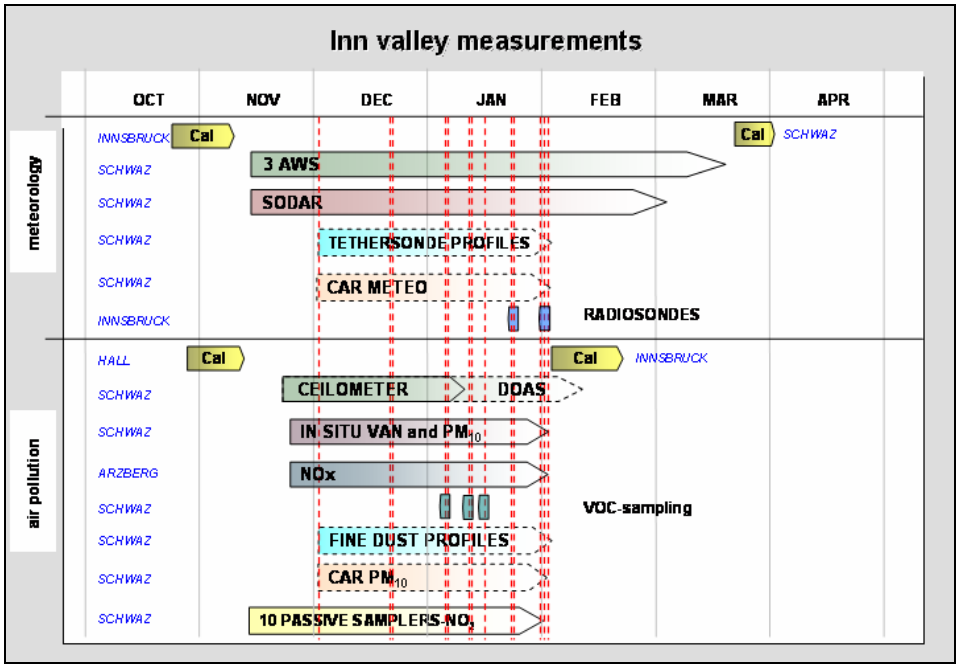
In the frame work of ALPNAP, a field campaign in the Inn valley was performed between November 2005 and January 2006. This was based on existing background and it focussed on air pollution (AP) and noise strain in the lower Inn valley. The target area was centred on Schwaz / Vomp (47°20' N / 11° 41 E / 540 m a.s.l.), where exceedances of nitrogen dioxide and PM_{10} are frequently recorded. From the viewpoint of air pollution induced by inner Alpine traffic, the most important goals for the field campaign are to study the spatial variation and distribution within a cross-section along the northern and southern slopes. Furthermore to determine the dependence of the observed air pollution patterns on meteorological parameters like wind, stability and mixing height, and to evaluate the spatial representativity of routine networks in the area as a function of distance to the main sources and height. Another goal will be to evaluate the best use of an existing slope temperature profile for mixing height and stability analyses and finally to use the field data for the set-up and validation of analysis and modelling intercomparison studies.

There exists a certain routine measurement network in the area including e.g. AP monitoring stations of regional and national authorities or slope temperatures. Based on this, a two-way approach was taken during the field phase. Permanent AP and meteorological instrumentation including a SODAR (vertical profiles of wind, turbulence and backscatter), a ceilometer (vertical profiles of optical backscatter intensity), an open-path DOAS (Differential Optical Absorption Spectroscopy, a long-path AP information in different directions), three automated weather stations (AWS) and 10 passive samplers for NO_2 provide a consistent climatology of the temporal development throughout the winter. The location of the instruments as well as images of the devices is shown in Figure 1. During high air pollution episodes additional measurements were performed. These include profiling with a tethered balloon to determine the vertical structure of dust particles, temperature, humidity and wind, mobile car traverses yielding PM_{10} and meteorological information and

sampling of volatile organic compounds (VOCs) at selected spots. The operation periods of the different measurement instruments are given in Figure 2.

Figure 2: Operation periods of the different measurement instruments. Cal denotes calibration phase. The red dotted lines represent additional measurements, where tethersonde profiles, car traverses and VOC sampling were performed.

Figure 2: Périodes d'opération des instruments de mesure. "Cal" indique les phases de calibration. Les lignes rouges hachurées montrent des mesures supplémentaires effectuées durant des périodes de pollution atmosphérique élevée utilisant une sonde captive, des traverses d'automobiles et des récepteur des COV.



2. Modelling

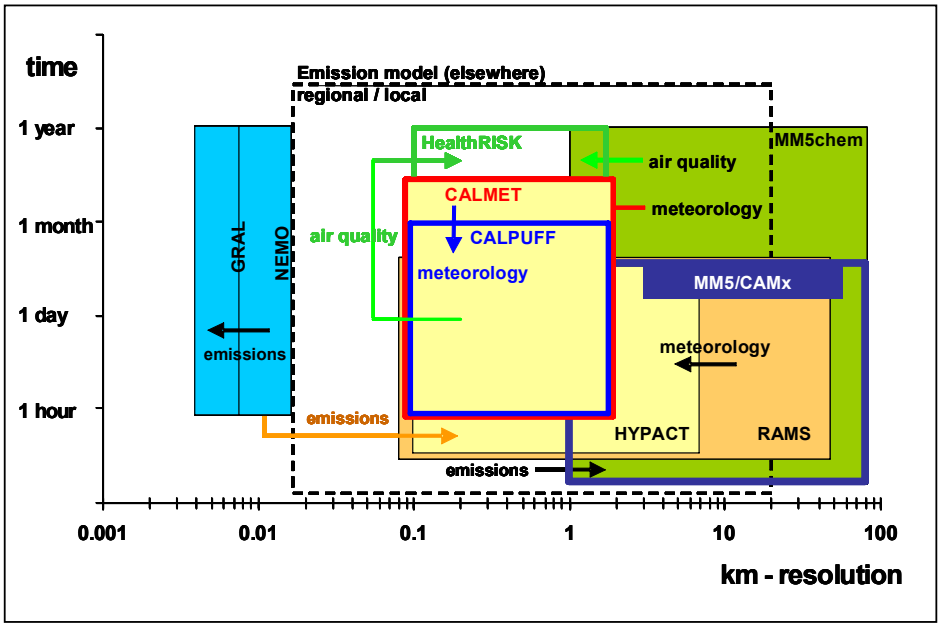
Additional to air quality measurements also the simulation of the horizontal and vertical distribution of air pollutants on a high temporal and spatial resolution is a key aspect. In this study it should be demonstrated how to utilize advanced methods to simulate the concentrations of airborne pollutants such as NO, NO_2, different VOCs, and PM as a function of the emissions within such a complex topography. Furthermore the evaluation of the consequences of specific emission reduction measures (e.g. traffic ban on certain vehicles as a function of time of day and year, future development of traffic) will be considered.

Therefore a model hierarchy from the micro- to mesoscale has to be set up to calculate traffic emissions, to simulate meteorological and air pollution

parameters for assessing the health impact in an Alpine environment. In Figure 3 the hierarchy of the models starting from traffic emission model NEMO/GRAL to the online coupled mesoscale Chemistry-Transport-Model MCCM with a spatial resolution of less than 100 m and up to 100 km, respectively, is shown. The temporal resolution varies between hours and more than 1 year for the calculation of annual mean thresholds.

Figure 3: Model chain and modelling tools used by the ALPNAP project partners and their possible spatial and temporal field of application.

Figure 3: La chaîne des modèles numériques utilisés par les membres du projet ALPNAP indiquant leur champs d'application possibles aux échelles spatiales et temporelles.



The model chain comprises models used as forecast tools within a region of couples of kilometres up to mesoscale models which will simulate annual means of NO_2, O_3 and PM_{10} according to the European air quality directives for the whole Brenner traverse from Rosenheim/Germany to Verona/Italy in a resolution of up to 2 km.

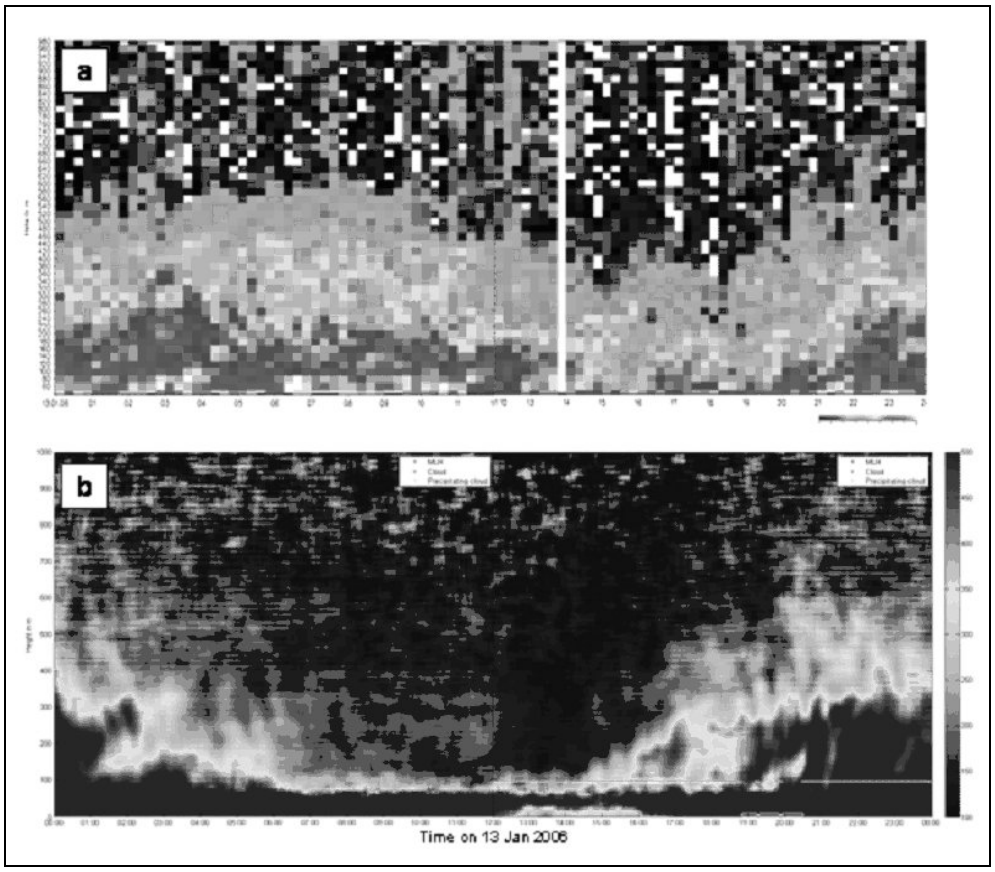
Results

The NO concentrations are clearly dominated by the traffic volume and therefore are the highest at the highway (DOAS, 570 m a.s.l.) followed by the valley floor in 800 m distance to the highway (Schwaz, 540 m a.s.l.) and at the southern slope (Arzberg, 720 m a.s.l.). The exceedance at the valley floor as compared to the slope station is basically related to a stable layering of the valley atmosphere during nearly all the time. Outstanding high pollution episodes were found during: 20 – 24 December 2005, 09 – 22 January and 25

January – 02 February 2006, when the detailed structure of the valley atmosphere was captured by the additional intensive measurements periods.

Figure 4: Temporal development of vertical structures on 13 Jan 2006 0000 to 2400 CET as measured by a Sodar and Ceilometer at location 5 in Figure 1. (a) Acoustic backscatter intensity from SODAR indicating thermal structure (medium grey near the surface indicates stable stratification). (b) Optical backscatter intensity from LD 40 ceilometer basically indicating aerosol concentration (from black (low) to dark grey (high)).

Figure 4: Développement temporelle de la structure aérienne verticale le 13 janvier 2006 de 00h00 à 24h00 heures mesuré par (a) SODAR (l'échelle des gris indique la structure thermale, le gris moyen près de la surface indique la stratification stabile) et (b) ceilometre (l'échelle des gris indique la concentration d'aérosol de noir (moindre) à gris moyen (très élevée)) à la position no. 5 dans la Figure 1.



Moreover, the data indicate that the ratio of concentrations near the highway to the background is systematically higher for NO_2 (more than factor 2) than for NO, which cannot be explained up to now. On a local scale the data allow e.g. to demonstrate the impact of nearby construction work imposing on the CO, NO and NO_x measurements. As a well known feature on the other hand, a

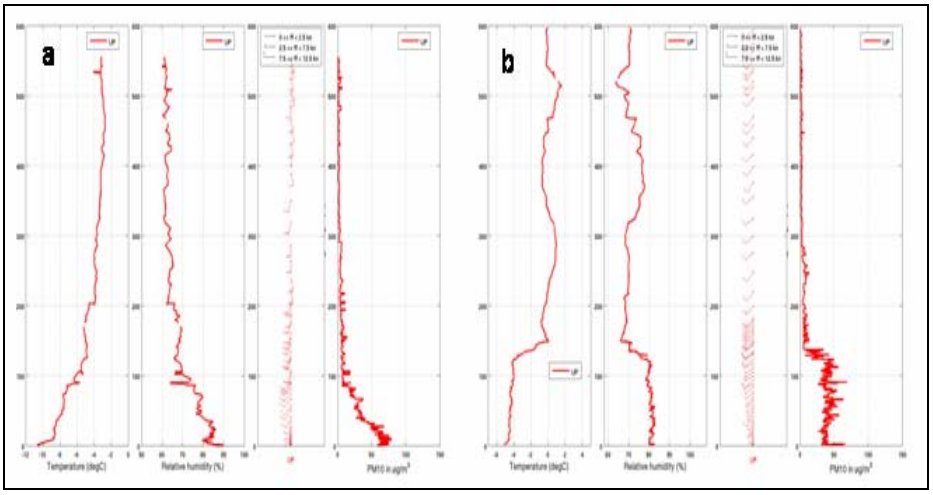
dominant “new year” peak in PM_{10} concentration from the night of 31 December 2005 up to the night at 01 January 2006 was found.

A short example shows the evolution of the polluted boundary layer on 13 January 2006. The acoustic remote sensing with a SODAR detects the vertical stratification (Figure 4a) and vertical wind profiles. The optical backscatter from a ceilometer is an indication of the aerosol density (Figure 4b). An inversion in the lowest 100 m (purple and whitish colours) persists until midday, when radiation leads to a short break-up in the early afternoon before reforming after sun-set. The ceilometer reveals, that the polluted layer is restricted to about 80 m a.g.l. before noon, when the intensity decreases from the bottom while still present below the sharp inversion layer.

A more detailed picture at a given time can be seen from the tethersonde ascents depicted in Figure 5. The left graph shows the vertical structure around 1030 CET. The beginning of the marked inversion around 90 m a.g.l. marks the top of the polluted layer, with PM_{10} values gradually decreasing with height from 70 µg/m^3 to background values close to zero. Two hours later radiation has heated up the surface layer a bit, leaving an even more pronounced inversion higher up at 140 m a.g.l. Consequently the dust particles where vertically redistributed leading to more uniform values of around 50 µg/m^3. Hence the surface impact is exposure is reduced due to a deeper and more uniformly distributed aerosol layer.

Figure 5: Tethersonde ascents on 13 Jan 2006 at (a) 1007 – 1042 CET, (b) 1154 – 1234 CET The four panels shows temperature in degC, relative humidity in %, wind vanes and PM_{10} in µg/m^3.

Figure 5: Ascension de ballon captif le 13 janvier 2006 (a) à 10h07-10h42 heures et (b) à 11h54-12h34 heures. Les quatre tableaux montrent la température (°C), l’humidité relative (%), la direction et la magnitude du vent et la concentration PM_{10} (µg/m³).



Conclusions

A methodology for the assessment of the air quality within Alpine valleys was introduced. Both measurements and modelling simulations are necessary tools to describe the distribution of air pollutants in such an inhomogeneous surrounding for further human health impact analysis.

In a first review a brief description of the air quality situation within the cross section of the Inn-valley near Innsbruck was summarized. First results of the measurements show the dominating influence of traffic emissions to the overall air quality situation within the valley. The measurements give also a detailed insight into the vertical distribution within such a complex surrounding.

Model simulations will help to understand the complex flow regimes in alpine valleys as well as the horizontal and vertical distribution of chemical parameters. Detailed measurements like in this study can only reflect very scarcely the 3D information of high resolution simulations. Therefore a validation process will be initiated taking these measurements into account in order to set up the models in a most accurate way to get a full set of meteorological and chemical parameters for detailed studies on impact analysis.

Further information about the ongoing work can be obtained at the ALPNAP web site http://www.alpnap.org/

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Unexpectedly low decrease of NO_2 air pollution – Correlation with ozone concentration and altered exhaust emissions

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Abstract

An analysis of air pollution data of nitrogen oxides and ozone over the last 16 years was performed for the German federal states of Baden-Württemberg and Bavaria, covering more than 60 air quality monitoring stations. These stations were clustered into four groups according to their distance to road traffic.

At highly traffic-influenced sites the total nitrogen oxides (NOx) and also nitrogen monoxide (NO) show a distinct decrease, in accordance with the reduction of NOx emissions of vehicles, whereas nitrogen dioxide (NO_2) concentrations reveal only a modest decline or even a slight increase at some sites. This is an obvious discrepancy to the calculated development of NOx emissions.

The ratio NO_2/NOx exhibits a pronounced increase at urban monitoring sites. Ozone concentrations in cities show a comparable increase in the mean, probably because of reduced degradation reactions.

One explanation for these divergent trends is based on the photochemical balance between NO, NO_2 and ozone. Another, and probably important, reason seems to be a large increase of direct NO_2 exhaust emissions as a result of the growing number of modern private diesel cars equipped with oxidation catalysts, producing high NO_2/NOx ratios by the oxidation of NO. The database concerning reliable NO_2 (not NOx) emission data of modern cars and exhaust treatment equipment is yet insufficient.

From the NO_2 and ozone concentration trends over 16 years it is concluded that the EU air quality limits of NO_2, valid from 2010, may then be exceeded at locations with a heavy traffic burden.

***Keys-words**: Air pollution trend, traffic-related pollution, nitrogen oxides, nitrogen dioxide, diesel passenger cars, oxidation catalyst, exhaust after treatment.*

Résumé

Une analyse des moyennes annuelles en oxydes d'azote et en ozone fut effectuée pour la période de 1990 à 2005 pour les stations de mesure de la qualité de l'air de Bade-Wurtemberg et de la Bavière. Tandis que le niveau de pollution atmosphérique de NOx et de NO a diminué distinctement, en conformité avec le développement des émissions de NOx, seulement une petite diminution, partiellement aussi une augmentation, s'est manifestée aux concentrations de NO_2 près de rues très fréquentées. Une explication pour cet effet est vue dans l'équilibre photochimique entre NO, NO_2 et ozone. Une autre raison est la composition changée du gaz résiduel des voitures diesel. Les voitures particuliers modernes diesel sont équipées avec un pot catalytique d'oxydation qui transforme NO en NO_2, de sorte qu'une partie importante de l'oxyde d'azote est directement émis comme NO_2. Par conséquent, un dépassement des valeurs limites pour NO_2 en 2010 sera vraisemblable à proximité de rues très fréquentées.

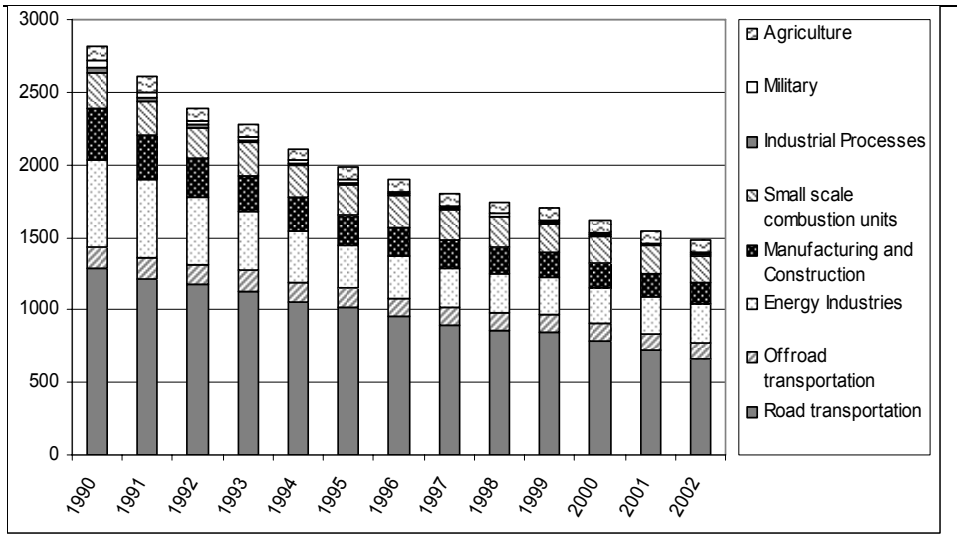
***Mots-clefs :** qualité de l'air, oxyde d'azote, dioxyde d'azote, équilibre photochimique.*

Introduction

The development of NO_2 air concentrations at highly traffic-influenced sites is contrary to the decreasing trend of nitrogen oxide (NOx) emissions. A trend analysis of air concentration data from monitoring sites in Baden-Württemberg and Bavaria was performed to identify the reasons.

Figure 1: Development of NOx emissions in Germany, in kt NO_2/a (Source: Umweltbundesamt, 2004)

Figure 1: Evolution des émissions d'oxyde d'azote en Allemagne, en kt NO_2/a



Development of nitrogen oxide emissions

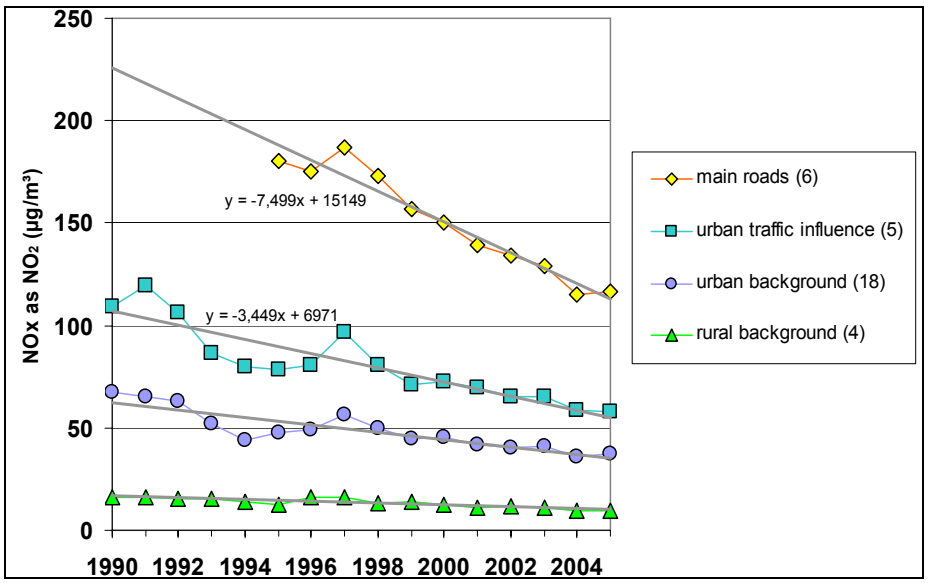
Road traffic is the main source of nitrogen oxide (NOx) emissions. In 2000, road transport accounted for 48% of the total NOx emissions in Germany (Umweltbundesamt, 2004) and for 51% in Baden-Württemberg (UMEG, 2004). Between 1990 and 2002, total NOx as well as traffic NOx emissions showed a continuous decrease of about 47-48% (figure 1).

Development of nitrogen oxide and ozone air concentrations

Based on the calculated decrease of NOx emissions, a corresponding decrease in NOx air concentrations should obviously be expected. For the trend analysis, the monitoring sites were classified into four groups according to their distance from road traffic. The results for Baden-Württemberg are presented below; the analysis of data for monitoring sites in Bavaria yielded similar results (shown in Rabl & Scholz (2005)).

Figure 2: Development of NOx air concentrations in Baden-Württemberg 1990-2005
(annual means, calculated as NO_2; number of monitoring sites in parentheses)

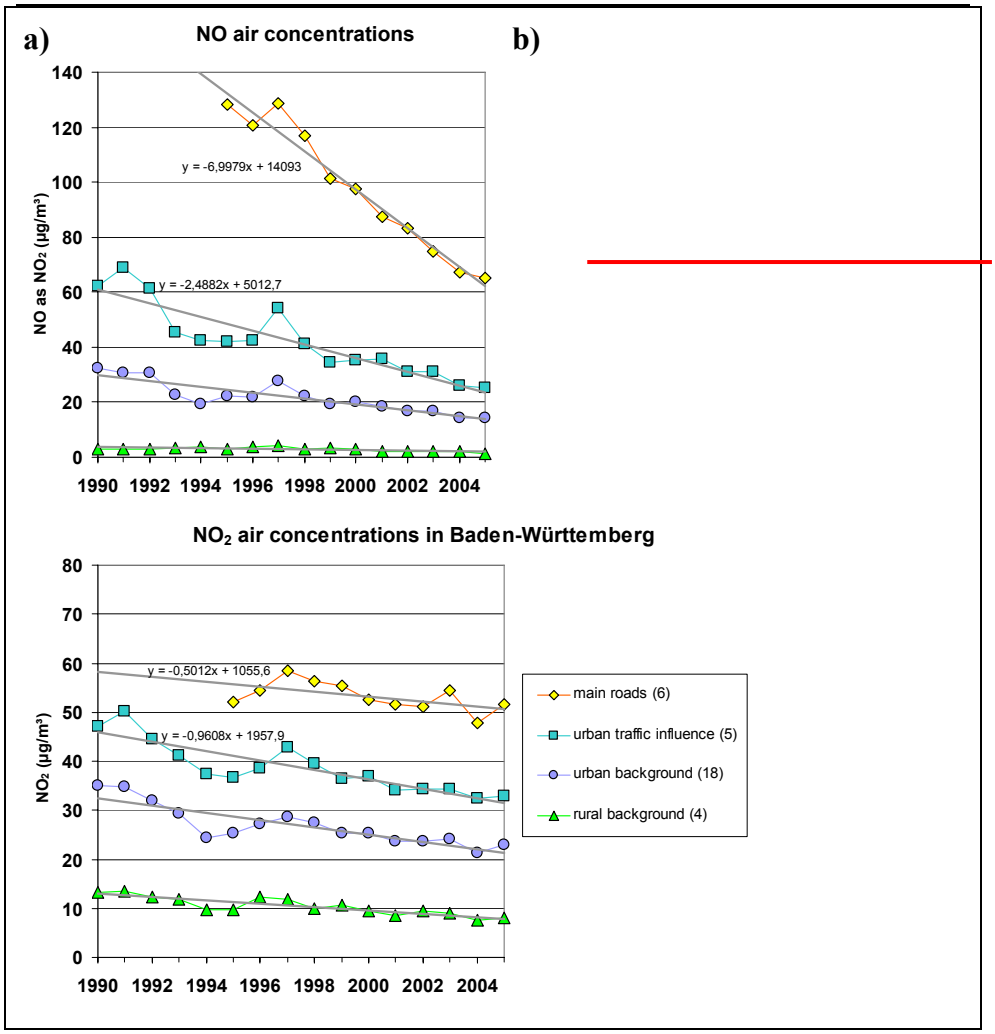
Figure 2: Evolution des niveaux d'oxyde d'azote (NOx) à Baden-Württemberg de 1990 à 2005 (moyennes annuelles, calculé comme NO_2; nombre de stations en parenthèses)



NOx air concentrations show a distinct decrease which is most pronounced in main roads and at urban sites with traffic influence (figure 2). The observed decrease in these groups is by a factor of 53% and 51% respectively between 1990 and 2005, in good correspondence with the calculated emission trend. The graph of the development over time is reasonably fitted by a linear approximation.

Figure 3a, b): Development of a) NO and b) NO_2 air concentrations in Baden-Württemberg 1990-2005 (annual means, number of monitoring sites in parentheses)

Figure 3: Evolution des niveaux a) de NO et b) de NO_2 à Baden-Württemberg de 1990 à 2005 (moyennes annuelles, nombre de stations en parenthèses)



NO air concentrations exhibit an even steeper downward trend at main roads and urban sites than the NOx concentrations. Only in the rural background NO remains essentially unaltered at a very low level (figure 3a).

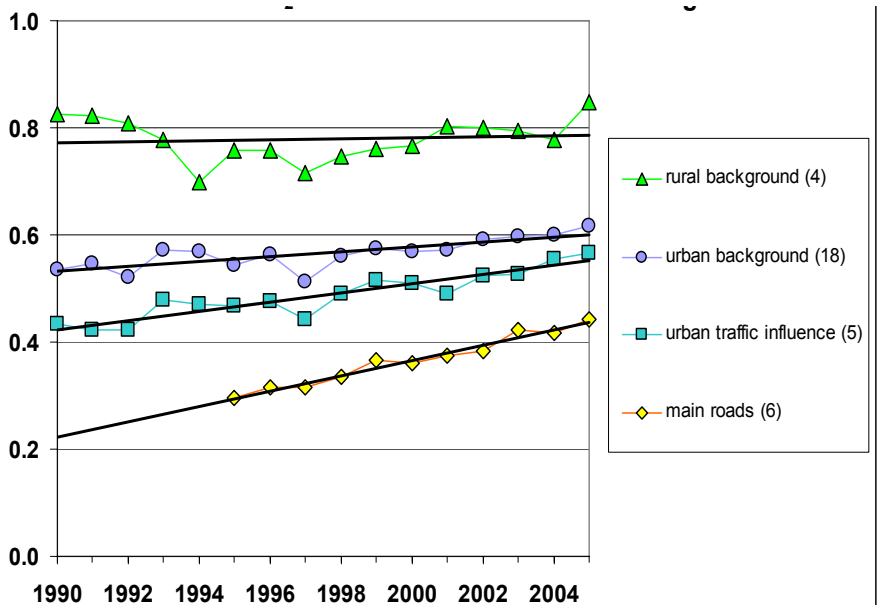
In contrast, NO_2 air concentrations do not exhibit a corresponding decrease (figure 3b): In urban areas the downward trend is more moderate than that one of NOx and NO (-33% to -37%), whereas in direct vicinity of highly frequented streets almost stagnation is observed, in some cases even an increase of NO_2 concentrations.

This trend of NO_2 concentrations will turn into a problem for the air quality situation in many cities during the next years. As can be seen from figure 3b, the NO_2 annual mean concentrations at main roads are considerably above the EU air quality limit of 40 µg/m³ valid from 2010. Even a further considerable reduction of motor vehicle NOx emissions would only have a perceptible effect several years later.

Nitrogen oxides are emitted from combustion processes mainly as NO and subsequently oxidized to NO_2, usually in the atmosphere. Therefore the ratio NO_2/NOx increases with increasing distance from the emission source. The analysis of the measured NO_2/NOx ratios shows pronounced increases at the urban and traffic influenced monitoring sites (figure 4). At main roads, in 1990 about 25% of the NOx consisted of NO_2 (Rabl & Scholz, 2005), whereas in 2005 the proportion of NO_2 was increased to more than 40%.

Figure 4: Development of the NO_2/NOx ratio in Baden-Württemberg 1990-2005
(annual means, number of monitoring sites in parentheses)

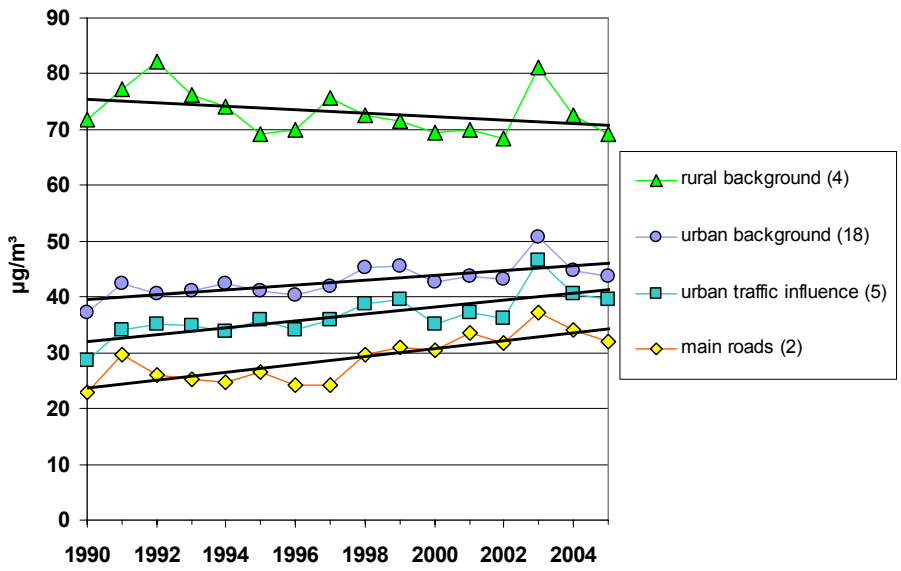
Figure 4: Evolution de la relation NO_2/NOx à Baden-Württemberg de 1990 à 2005 (moyennes annuelles, nombre de stations en parenthèses)



A similar picture is obtained from the analysis of the ozone trend (figure 5). For the site type "rural background", a slow decrease with annual variations is observed, whereas in the cities - at a lower level - a distinct increase in the annual mean is recorded, suggesting a gradual adjustment of the urban and the rural situation.

Figure 5: Development of ozone concentrations in Baden-Württemberg 1990-2005
(annual means, number of monitoring sites in parentheses)

Figure 5: Evolution des concentrations d'ozone à Baden-Württemberg de 1990 à 2005
(moyennes annuelles, nombre de stations en parenthèses)



The increase of the ozone annual mean values in cities is not interpreted as an enhanced formation, but as a reduced degradation of ozone due to reduced emissions of primary pollutants, mainly NO.

First explanation: Photochemical balance

The parallelism in the development over time of the NO_2/NOx-ratio and ozone points to a photochemical correlation between nitrogen oxides and ozone. A simple approach is the well-known photo-stationary equilibrium:

$$NO_2 + O_2 \rightleftharpoons NO + O_3$$

According to the law of mass action the following relation results:

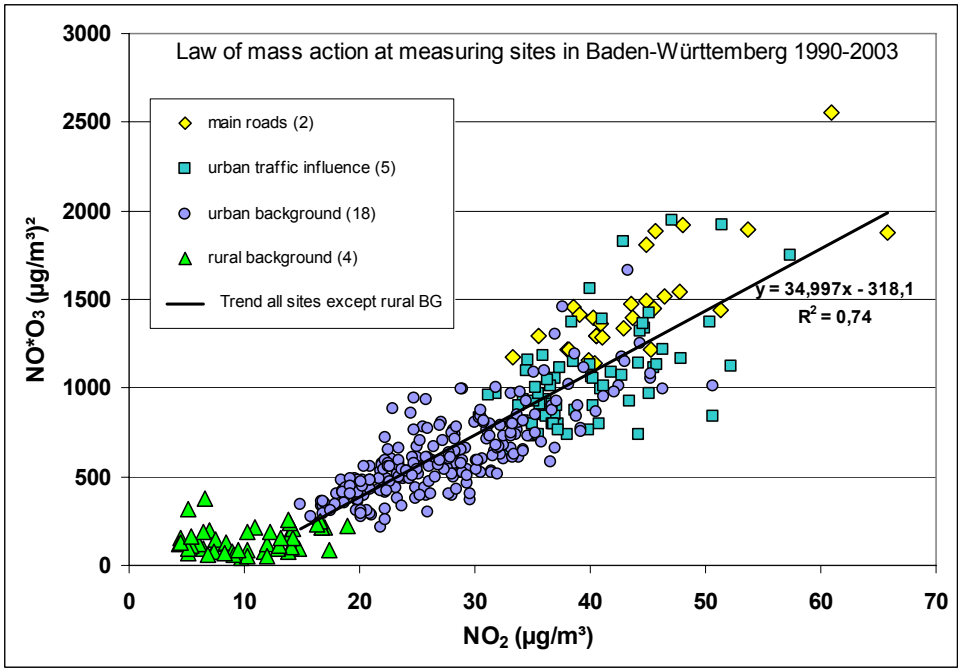
$$k = \frac{[NO] \cdot [O_3]}{[NO_2]} \qquad \text{with } k = \text{constant of equilibrium.}$$

Figure 6 shows that this explanation applies quite well. The product [NO] · $[O_3]$ is plotted against the corresponding NO_2-concentration for the air quality monitoring sites of Baden-Württemberg between 1990 and 2003. Each point in the graph represents the mean values of one site and one year. A satisfying linear correlation is obtained for urban and main road sites (with $k \approx 35$). The deviation in rural background is probably caused by the measuring inaccuracy of low NO-/NO_2-concentrations. This result underlines the photochemical balance between NO, NO_2 and ozone, which is observed with annual mean values, but also with daytime values (shown in Rabl & Scholz (2005)).

Figure 6: Relationship between NO, NO_2 and ozone according to the law of mass action

at air quality monitoring sites in Baden-Württemberg 1990-2003 (annual means).

Figure 6: Equilibre photochimique entre NO, NO_2 et ozone aux stations de qualité de l'air à Baden-Württemberg de 1990 à 2003 (moyennes annuelles).



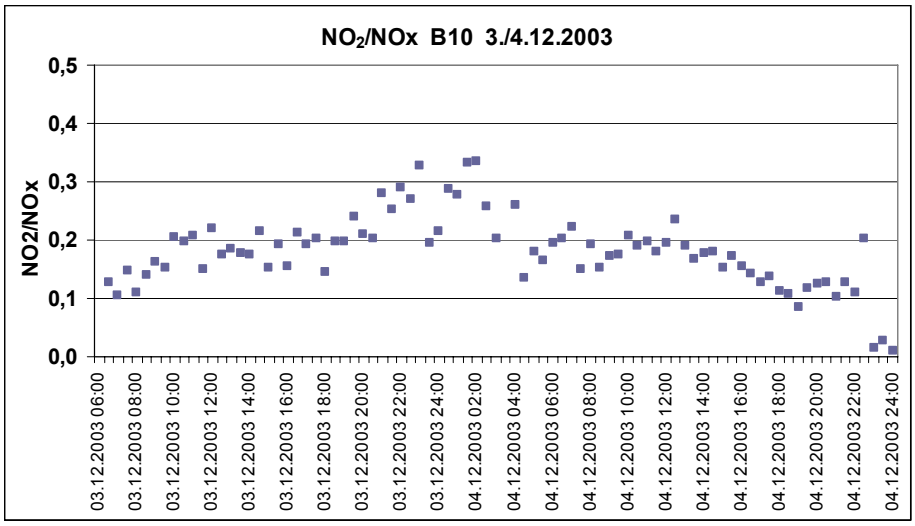
The importance of this relationship for the situation in the cities is that the three components are tightly coupled and changes in one component affect the others. The increased ozone concentrations due to reduced NO emissions represent an elevated oxidative potential in the atmosphere, resulting in a constant or even enhanced formation of NO_2 according to the product $[NO] \cdot [O_3]$.

Second explanation: Changes in diesel vehicle exhaust emissions

The NO_2/NOx-ratio in the exhaust emission of diesel cars has also changed over the last years. Modern diesel cars, which have been significantly increasing in number for several years, are equipped with an oxidation catalytic converter in order to keep within the emission limits for HC and CO. As a side reaction, these catalytic converters oxidize NO to NO_2, with the result that a considerable part of the vehicle's NOx emission is emitted directly as NO_2. This oxidation of NO to NO_2 will probably be performed by any noble metal catalyzed exhaust treatment device, as well as by catalytically active particle filters. Unfortunately, up to now the database concerning reliable NO_2 (not NOx) emission data of modern cars and exhaust treatment equipment is insufficient.

Figure 7: NO_2/NOx-ratio for the concentration difference between opposing measuring sites on the national road "B 10" in Karlsruhe (details see text)

Figure 7: Relation NO_2/NOx pour la différence de concentrations de deux stations de mesure opposé à la route nationale "B 10" à Karlsruhe (détails en texte)



An experimental proof for the changed NO_2/NOx-ratio in the exhaust emission can be deduced from the results of a measuring campaign with two measuring sites positioned at the same location on opposite sides of the highly frequented national road "B 10" in Karlsruhe. The winter situation presented in figure 7 is characterized by: a) wind in constant windward-leeward-direction, perpendicular to the road, with an average wind speed of 1-3 m/s, b) a very low ozone concentration of 1 µg/m³ on average at both sides. Under these conditions, the concentration differences between the two measuring sites represent the contribution directly produced by the road traffic. From the NO-

and NO_2-differences a NO_2/NOx-ratio of about 0.2 – 0.3 is obtained, which means that about 20% of the NOx is directly emitted as NO_2 during the daytime (with a high proportion of trucks) and about 30% of the NOx is emitted as NO_2 at night (mainly cars). This is far more than the proportion of 5% which has been assumed for a long time as the direct NO_2 emission of vehicles.

Conclusion

The changes in diesel vehicle exhaust emissions seem to be the main reason for the slow decrease or even increase of NO_2 concentrations at highly traffic-influenced sites. Since diesel powered cars are still increasing in number, and NOx, but not NO_2-emissions are regulated, it is very probable that in 2010 the EU limit values for NO_2 will be exceeded at locations with heavy traffic burden. Only a further reduction of motor vehicle NOx emissions or a separate limitation of NO_2 emissions will be effective in reducing the NO_2 air concentrations.

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Application of the ISHTAR Suite for the assessment of the environmental policies in 7 European cities

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Abstract

The ISHTAR Suite is an innovative software for the simulation of the effects of transport policies on the urban environment, population health and artistic heritage. Starting from the effects of the measure on citizens behaviour, the calculation path goes through the modelling of transport, vehicles safety and emissions of pollutants and noise, pollutants dispersion and noise propagation, exposure of population, health effects assessment, monuments degradation, up to the comparison of the alternative scenarios in terms of cost-benefit or multi criteria analysis. The ISHTAR Suite was tested in the seven cities involved in the FP5 ISHTAR Project: Athens, Bologna, Brussels, Graz, Grenoble, Paris and Rome. The main results of these studies are here described. The case studies include new road infrastructure analysis in central Graz, Bologna Province and Attiki region, traffic banning measures in metropolitan Brussels area, Paris and central Rome, and measures in favour of public transport in Grenoble.

***Keys-words**: integrated software, case studies, assessment, demonstration.*

Introduction

Worldwide cities face common challenges concerning their quality of life: degradation of the urban environment, significant risks for citizens health, traffic congestion causing stress and economic inefficiency, progressive damage of the artistic and monumental heritage. Additional difficulties derive from the lack of integrated tools that allow cities to make balanced decisions on a wide range of issues. In this context the European Commission co-funded from 2001 to 2005 the ISHTAR (Integrated Software for Health, Transport efficiency and Artistic heritage Recovery) Project (Negrenti and Zaini (2002)). The Project aimed at building an Integrated Suite of software models for assessing the impacts of various types of urban policies and actions on the quality of life of citizens, and in particular on traffic congestion, air quality, citizens health and conservation of cultural heritage.

Objectives

The ISHTAR Project had four main scientific and technological objectives:

- The integration of a large number of software tools and the creation of specific modules for the simulation of key processes such as transport and its direct impacts on the urban environment.
- The achievement of a high spatial and temporal flexibility, for maximizing the possibilities of application from local short-term actions to widespread long-term policies.
- Development of specific modelling areas such as policies effects on citizens behaviour, the integrated 24 hours simulation of traffic emissions, noise and safety, the microscopic analysis of air pollution effects on health and monuments.
- The application of the tool to the analysis of measures tested or planned in the seven involved cities: Athens, Bologna, Brussels, Graz, Grenoble, Paris and Rome.

The results of the applications

While it was at the outset of the ISHTAR project the intention to ideally apply the whole ISHTAR suite to all of the case studies, it turned out during the course of the project that the majority of the case studies covered the application of single modules of the suite. The performed case studies can be described as follows in the next sections.

1. Athens and Attiki region new motorway

In the Attica region there are more than 2.000.000 vehicles running on the network and more than 5.500.000 person trips (all purposes) every day. The application for the ISHTAR suite case study dealt with the new roadway

construction, the so-called “Attiki Odos”. This new toll highway was assessed in terms of traffic, toll strategy and pricing, environmental conditions in the highway and all of its accesses. During the case study ISHTAR suite modules for traffic, emissions, air pollution and noise have been applied. With the operation of the highway (after case study analysis) 250.000 vehicles travel in Attica Road at an average of 15 km per trip, meaning (250.000 vehicles x 15 km) 3.750.000 vehicle-km daily. This highway is becoming very popular for the Athenians, and the traffic is increasing every month, reaching, on certain days and hours, congestion levels.

In the cases where the noise caused by the traffic was proven to be above the limits for the surrounding settlements, noise barriers have been installed along the motorway achieving the prevention of the dispersion of sound towards residential and other sensitive areas (schools, hospitals, etc.). The analysis of air pollution and noise impacts indicated that this motorway has not caused negative side effects to the environment. Now, people once opposed to such an enormous project within Athens city’s bounds were re-assured and relieved since no great health impacts were about to be imposed on their lives. Special notice was also shown to the accident factor; the report on this analysis indicated that accidents have been reduced within the region of Attica.

ISHTAR project provided various benefits to a) the Ministry of Planning, Environment & Public Works, b) “Attica Road” realisation, and c) the citizens of Athens (especially those living in areas adjacent to the highway), with the analytical structure of the models and the results, by explaining in clear manner the highway’s operation and its impacts.

2. Bologna province : the Imola case

The Bologna Province case study concerns an Environmental Impact Assessment of a new infrastructure for the City of Imola. The goal of the simulation was to estimate the impact on air quality of a new urban road. Different infrastructural scenarios have been considered aiming at supporting the decision-making process to choose among the alternatives which are likely to have less significant effects on the environment. The ISHTAR modules used to carry out the case study have been the Direct Impacts Module (TEE2004), the pollutants dispersion module ARIA IMPACT and the noise propagation module SOUNDPLAN.

The scenarios were built up with reference both to direct interventions of traffic management (new paths, roadway adjustment, intersection regulation) and to indirect interventions (public transport services, etc.). The air concentration of NOx, CO and PM10 from road emissions have been modelled. These pollutants were chosen because they are the most critical ones for the Province of Bologna. The simulation of some of the different scenarios offered the opportunity to test the suite as an integrated tool for supporting decision-makers in adopting environment-conscious actions.

The Province of Bologna case study tested the three core tools of the suite integrated in the first prototype of the ISHTAR Suite. The case study was also run by the Province but with the tools not integrated, and the results were

obviously similar, showing a clear advantage for the so called 'Definitive Project' vs. the postulated alternatives. This case study was not a 'before-after' study but a pure planning exercise. This test has been very useful for the identification of bugs and necessary development and improvements of the integration software.

3. Brussels Capital Region banning policies

After having observed for years the strong relationship between road traffic intensity and air pollutant concentrations, the Brussels Capital Region (BCR) decided to prepare a set of traffic banning measures and related accompanying measures to be implemented when air pollution forecasts exceed specific thresholds. Various scenarios describing traffic banning measures were investigated and the benefits for reductions in congestion time and improvements in emissions described. During the case study, ISHTAR suite modules for traffic have been applied. Brussels acted as demo location for the new traffic module VISOPULIS by PTV (D).

The aims of the case study were the following:

- Analyse the pollutants concentrations records available for the Brussels area;
- Design crisis scenarios with different severity degrees: these include the possibility of banning some vehicles categories in the Brussels Region with the definition of a banned area;
- Forecast the behaviour of travellers facing the scenarios, through preliminary surveys;
- Design accompanying measures such as parking provision, intensified public transport etc.;
- Estimate traffic impacts by means of traffic models;
- Estimate noise and pollutants emissions in the Brussels area through the ISHTAR models.

The ultimate objective was to test the feasibility and the efficiency of a Car Free Day in Brussels. Car free days were supposed to be part of a global ozone plan for the Brussels Capital region. To model the impact of banning measures, a survey has been performed to persons travelling by car as driver at some strategic places in Brussels. This survey has allowed forecasting required crisis car parks and modal choice. New trips matrix for transport models could then be built. The main results in terms of transport were:

- 33 % of trips cancellation;
- 51 % of modal shift (the regional public transport company & pedestrian mode);
- 11% of measure infringement.

As a result, on average, noise was reduced by ten decibels; while the highest level of NOx emissions recorded at the city's busiest traffic intersection was eight times lower than for a normal weekday. Car free days appear to be efficient to reduce pollutant concentrations like NOx, CO and particles but are

useless for decreasing ozone levels in short-term. The main conclusions were the following:

- The most efficient scenario was the scenario banning all EURO 3 not conformable vehicles.
- The Diesel banning scenario got a very significant impact in terms of PM10 emissions reduction. The reduction, in comparison with the Reference scenario, is about 80%;
- The fleet evolution has at least as much impact as the traffic reduction in itself.

As a consequence, weekdays car free days can be organised punctually according to environmental conditions, by providing travellers valid transportation alternatives.

4. City of Graz new tunnel

In the city of Graz the historically grown road network lacked in a certain region in a good connection between two major roads. This unsatisfactory situation led to an increased traffic load in residential areas between these two roads. In order to improve that situation a new connection was built in the form of a 'cut and cover' tunnel. As one of the portals of this tunnel is situated very close to residential buildings the concern about local environmental impacts was very high. Therefore an environmental impact study was commissioned to prove the effects of this project were in accordance with the noise and air quality standards. The main reason for this measure was the improvement of the situation within the residential area concerning : a) reducing the risk potential related to accidents, b) reducing noise pollution, c) Improving the traffic situation concerning the connection of the main roads

Within the framework of ISHTAR suite demonstration, the traffic emission and the dispersion modules have been applied. In addition a detailed inter-comparison between different emission and dispersion tools has been performed (comparative assessment). The main transport objective of the 'measure' was to calm down the traffic in a residential quarter and to improve the traffic connection between two parts of the city. Hence the impact on the traffic is restricted to a small part of the total street network. The impact on overall air quality is negligible – except at the kerb side locations. The only remarkable influence is expected to be on the noise side. The modules used were the emission module TEE and the dispersion model ARIA IMPACT. In addition the emission module was checked against the Austrian standard emission calculation tool (Handbook of Emission Factors) and the dispersion tool against the GRAL model. The inter-comparison between the emission tools proved that with TEE software reliable emission estimates are to be expected. However, in order to achieve these good results it is necessary to adjust the fleet composition to the local situation and this implies some manpower and a good knowledge about the local fleet distribution.

When considering the dispersion tools it has to be mentioned that the ISHTAR dispersion module (ARIA IMPACT) is neither designed to handle

emissions from tunnel portals nor to consider complex terrain (buildings, noise barriers, etc.). Nevertheless, although knowing of these limitations the dispersion module was applied with some adjustments (e.g. the portal emissions were treated as volume sources whose size was defined by the emission rate and a maximum concentration). In addition ARIA IMPACT was tested against measurement results from field experiments. The overall effect of the measure on air quality is not very high. There are no major changes at a first glance. Only if looking at direct differences the local effects can be depicted. The main effects of the measure on the noise pollution can be reported as follows:

- In the central part of the residential area a strong noise reduction was achieved.
- At the boundaries of the study area no remarkable changes were achieved.
- The accompanying measures at the main arterial road lead to a very strong decrease in noise pollution. The traffic increase at that location due to the implementation of the measure does not counteract the benefits gained due to the noise barriers. The changes in traffic in the 'before and after' case is not reflected in the noise measurements. The situation behaves stable.

The positive effect of this measure was proven by noise and air quality measurements. Even in zones with a traffic increase an improvement in noise pollution could be achieved as noise barriers were included into the measure. The module ARIA IMPACT was able to show the general trend. The trend on the small scale (portal regions) was confirmed by application of more detailed models.

5. City of Grenoble measures for enhanced Public Transport

Set at the crossing of three alpine valleys, Grenoble (150 000 inhabitants) is the major city of the Grenoble urban area (470 000 inhabitants). This location means that the city has a high density of population on a small surface and that many urban streets have heavy traffic; the population is exposed to noise and air pollution linked with this traffic. The case study is intended to monitor the effects of the installation of reserved lanes for public transportation and new traffics lights on boulevards with heavy traffic in Grenoble centre (60 000 vehicles/day).

The objectives of these measures were:

- to test the possibility of reducing the number of lanes dedicated to car traffic (from 6 to 4),
- to improve the average speed of public transport,
- to reduce car speeds, and monitor the impact on traffic flow.

Within the ISHTAR work the measure should have been assessed in terms of traffic, air pollution and noise. The objective of this ISHTAR case study was to compare the results of the simulations done with the modules of the ISHTAR suite to the measurements done before the measures implementation in 1999

and after in 2000. The implementation of the measures (reserved lanes and improved traffic lights) led overall to a small reduction in emissions (~ 3% for CO, NOx and VOC). However it can not be expected that the small changes in emissions in a restricted area can have a significant impact on air quality.

The monitoring programme concerned noise measurements at one locations and air quality at two locations. Referring to noise pollution a reduction of 2 dB(a) is reported for one part of the domain while in a second part no changes could be found. Referring to air quality a reduction of some 8% in NOx and up to 40% (!) in PM for short term and 2% in long term were found. The short term (14 days) reduction was definitely biased by the different general meteorological conditions between the monitored period in 1999 and 2000. The long term values (6 months) are much more reliable.

Within this study the following ISHTAR modules were used: 1) the full ISHTAR interface as a module manager, 2) the ISHTAR GIS module, 3) the emission module TEE, 4) the dispersion tool ARIA IMPACT. However, as only single modules of the ISHTAR suite have been applied at least the general trend of the changes due to the action could be followed in the emission calculation as well as in the monitoring values.

6. City of Paris ‘Car Free Day’

Every September 22nd, the City of Paris takes part in a car free day called “En Ville Sans Ma Voiture" (EVSMV). In 2002 and 2003, the experiment was implemented in the historical centre of Paris (area concerned: 3 x 2 km). Between 7 a.m. and 7 p.m., this central area was only accessible to public transport, taxis, “green” vehicles (LPG and electric cars) and professional users. The temporal and spatial scale of the experiment focuses the assessment on the short-term road-side air quality impact. The background pollutant concentration, which is a regional parameter with strong weather dependence, sets the context.

Airparif's experience prior to ISHTAR has shown that the modelling tools must take into account detailed road geometry and traffic characteristics, in particular fleet composition and traffic congestion. The objective of the ISHTAR case study was to test the enhancements to the modelling tools contained in the ISHTAR suite. The traffic and pollution dispersion modules were applied during the case study. The ISHTAR project has given us the opportunity to make a first assessment of traffic simulation in congestion with a new tool called VISUPOLIS by PTV (D). This software uses hourly origin-destination matrices which keep the total traffic volume, but allows better modelling of congestion by allowing to distribute demand over time at peak hours.

We also tested a new dispersion model (Aria IMPACT). Globally, an evaluation of Car Free Day 2003 impact on Air Quality in the central area could be estimated as ~ 60 % decrease for the roadside pollution. On the boulevards where the enhanced traffic model points to increased congestion, a further examination of roadside pollution with detailed consideration of fleet composition and road geometry will hopefully be possible in the near future.

7. City of Rome traffic banning policy

The city of Rome has established various strategies to tackle traffic problems implementing a framework to rebalance the modal split towards public transport and promote alternative means of transport. An access restriction for non-catalysed vehicles has been implemented within the “Rail Ring”. The “Rail Ring” area, which surrounds the historic centre, is densely populated with a high concentration of activities making it one of the key areas in the city for measures to lower emissions caused by road vehicles. A simulation of the ISHTAR suite was prepared to test the input-output connections among different software modules of the suite, data exchange with external software, modelling factors, and clarity of output comprehension. The suite run the simulated case study with the traffic, emission, dispersion (air and noise), exposure and health effects modules. The case study of Rome can be considered as the most comprehensive ISHTAR suite application so far and was managed directly at ENEA.

The cited measures had as their main effect a change in the fleet composition and no significant effects were expected and measured on traffic flows. The analysis carried on is based on a comparison between two simulated scenarios: 1) Do nothing scenario, and 2) Actual scenario (based on the traffic limitation measures described above).

Pollutants modelled both by the Emission and Dispersion modules were CO and PM10. CO was also considered by the exposure module and PM10 by the Health effects module. Pollutant concentrations data of a day, the 12th of November 2001, have been calculated for CO and PM10 within the semi-central area named ‘HEAVEN area’. Traffic data from O/D matrices were elaborated by a software external to the ISHTAR suite. A simulation of the ISHTAR suite was operated through the use of several software parts of the suite, in particular, as no effects were expected in terms of traffic flows, the Suite Entry Point was the ‘direct impacts model’ TEE-2004. The PM10 dispersion modelling output were used to generate an exposure and health effects assessment. The simulation gave a small difference between the two scenarios in terms of health impacts of the tested policy. The low difference between the scenarios, and between the scenarios and the background, can be explained with the small dimensions of the area under analysis, that is strongly affected by the surroundings that include sources that have not been modelled.

Conclusion

This work summarises the main outcomes of the application of the ISHTAR suite to the seven case studies included in the ISHTAR Project, concluded in 2005. These applications gave several positive indications on the performance of single tools and of the whole integrated software, but also put into evidence areas of improvement as it regards models refinement and user friendliness. Due to size limitations no figures could be here included. These will be a

relevant part of the Poster for the Reims conference and of the Publishable Final Report to be distributed to 1000 worldwide potential users.

Acknowledgments

The authors wish to thank all the colleagues having cooperated directly or indirectly in the ISHTAR Project, and working for the 19 partner organisations or the various subcontractors supporting them (see www.ishtar-fp5-eu.com).

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Numerical and experimental study of the traffic induced pollutants' dispersion in a cross road

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Abstract

The computational fluid dynamics software, Fluent 6.1 is applied to determine dispersions of emissions from vehicles traversing streets. The field measurement campaign has been fulfilled in a cross road in the central area of the Timisoara city. All data concerning traffic counting, meteorological parameters, and carbon monoxide concentrations were obtained from medium term continuous on-line monitoring trials. The gaseous concentrations of CO were measured both with ROMT techniques and a classical point source measurement instrument, working in accordance to EU legislation. For comparison, measured concentrations were normalized by the background wind speed and an estimation of the traffic emissions, based on traffic flows.

Keys-words*: Traffic induced pollution, Exhaust plume, Pollutant dispersion, CFD-analyze, ROMT – remote optical measurement technique.*

Introduction

The architecture of city spaces with a mixture of geometry composed from buildings, streets and parks will cause a complex flow, which can give rise to irregular distribution of pollutants. Many studies have been carried out on the flow regimes by field measurements, physical modelling and numerical simulations (Armaly (1983), Oke (1988), Lee (1994), Meroney (1996), Rafailidis (1997), Miller (1998), Chua (2005)). Most previous studies have only considered the complex physical processes occurring within a single canyon or have analyzed these through two-dimensional vertical cross-sections. More recently, studies have been extended to more buildings or three-dimensional analyses have been carried out. These provide more realistic information on the dispersion of pollutants over an urban area. The present paper proposes a methodology for such realistic calculations. Real layout of buildings and real dimensions of building structures were used. The FLUENT (CFD) technique will then be employed to study the dispersion of pollutants from the realistic urban

area. For illustration purposes, a central area in Timisoara will be chosen for our studies on the three-dimensional characteristics of pollutant dispersion for various wind directions and wind speeds.

Objectives

The first aim of the work is to study numerically the dispersion characteristics of motor vehicles exhaust plume near to a cross road, under different meteorological conditions, in an idealized and simplified environment. The comparative experimental research is accomplished in that area and refers to the CO species, although the air quality monitoring was accomplished on more pollutants, in accordance to the EU standards, active also in Romania. The second aim focuses on depicting the reason of the sequential anti-correlation of the experimental measurement of the CO concentration.

Computational techniques and data

The geometrical pre-processor Gambit 2.0 is used in this study. Realistic information on the layouts and heights of building was employed. In the centre of the domain is placed the cross road between Bv. Mihai Viteazu and Bv. Pârvan (see Fig. 1.a). For different zones of the numerical domain (see Fig. 1.b) specific properties for roughness were applied. The traffic is commanded with traffic lights with four stages and every street is divided in three traffic lines. Meteorological data used for numerical modelling (wind speed and direction) was selected according with the city meteorological station for long term monitoring. For the input data of CO pollutant, different emission factors were adopted according to the specific zone. At the stationary zone for the traffic light was considered an average speed of vehicles of 2 km/h, average between the moment of zero speed and the period when the vehicles go away at the green lights. For the zone where the vehicles run away from the cross roads, was considered and adopted an emission factor according to Corinair for an average speed of vehicles of 25 km/h. The traffic structure was give from local authorities according to the vehicles register database of the city.

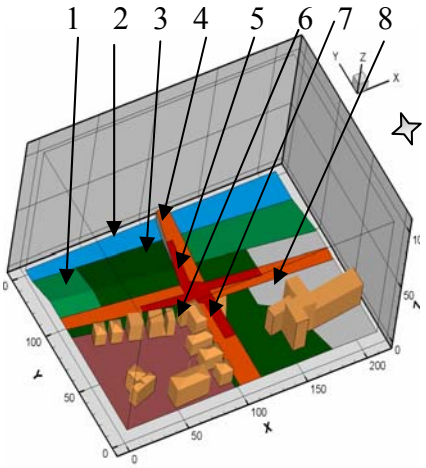
The CFD code FLUENT 6.1 is used for simulating the wind flow and pollutant simulations for four wind directions and two wind speeds (1.5 and 3 ms^{-1}). The atmospheric stability conditions are neutral for the analyzed episode. For the external flow simulations, a hybrid mesh of about 1 million cells is utilized (see Fig.2.a). This model spans a geometric region of 200 x 150 x 100 m, surrounding the area of interest, containing a typical mesh size of 0.5 m. In the present stage, the fluid under consideration is a mixture of ambient gas and pollutant substance in thermodynamic equilibrium, (i.e. substances, sharing the same pressure and temperature). The fluid dynamics is described by the mixture mass, momentum and energy conservation equations. The pollutant substance mass conservation law is fulfilled by its mass transport equation. In order to maintain the computation time and storage in realistic levels, turbulence closure modelling is based on the gradient transport hypothesis and involves application of the eddy viscosity/diffusivity concept**.** Fig 2.b present a 3-

dimensional solution for South-West wind. FLUENT(***2005) is used as modelling code and TECPLOT 10 (***2005) is used for visualization.

Fig. 1: a) View of the investigated area; b) Numerical modelling of investigated area and the main elements of the domain. 1 – park short vegetation; 2 – Bega channel; 3 – Park higher vegetation; 4 – Bridge over Bega channel, 5 –Pollutant input area calculate for a speed of 2 km/h; 6 – buildings with real geometry; 7 – pollutant input area calculate for a speed of 25 km/h; 8 – parking area.

Fig. 1 : a) Vue de la région sélectée, b) Modélisation numérique de la région et les principaux éléments du domaine. 1 – végétation réduite du parque, 2- le Bega cannelle, 3–végétation plus élevée, 4 – points sur le cannelle, 5– polluants input zone, calculée a un vent de 2 Km/h, 6 - édifices a géométrie réale, 7 – polluant input area calculée a un vent de 25 Km/h, 8 zone de garage –parcage.

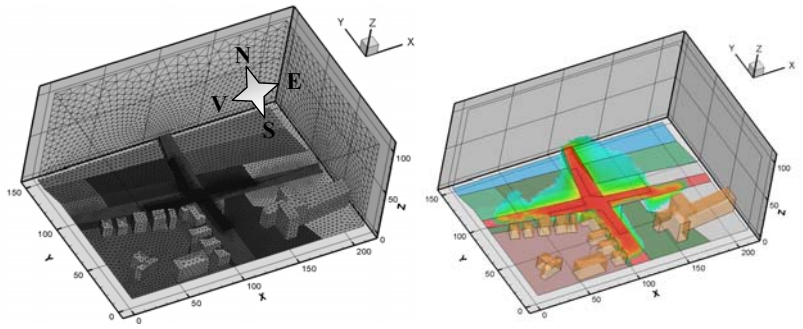
a)



b)

Fig. 2: a) Geometry of the mesh for simulated domain. b) 3D dispersion of the pollutant in the investigated domain for a S-W wind with wind speed of 3 m s^{-1}

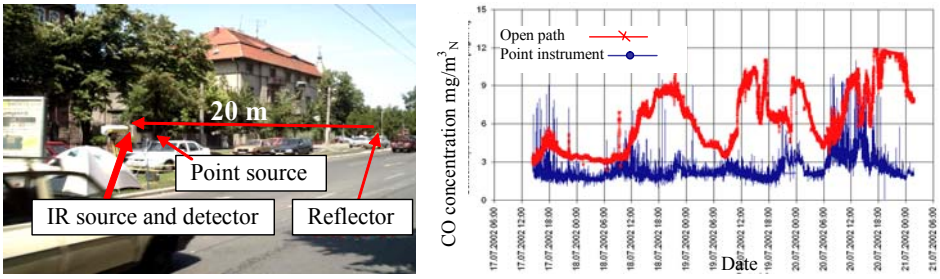
Fig. 2 : a) Géométrie du domaine de la simulation. B) 3D dispersion des polluants dans la région, a un vent de SV de 3 m/s.



a) b)

Fig. 3 : a) Position of the monitoring instrument. b) Time dependence of the CO concentrations recorded for a 6 seconds interval,

Fig. 3: a) Position de l'instrument, b) dépendance du temps des CO concentrations mesurées a un intervalle de 6 seconds.



a) b)

Monitoring campaign

Between 17th and 26th July 2002 the CO-concentrations were measured simultaneously using two different specialized instruments: a HORIBA device which furnishes the local pollution level and a SIEMENS open path instrument delivering spatial average values of CO-concentration on a distance of 10-50m (typically). The open path instrument delivered by the Siemens Environmental Systems is an IR-DOAS apparatus which can be configured to measure several pollutant gases, among them CO. The measuring system consists of a monitor (source of infrared radiation and detection unit) and a reflector. The beam emitted by the source and reflected back to the monitor is filtered at a specific wavelength specific to the gas of interest. The detector compares the filtered

and the unfiltered reflected radiation in order to measure the concentration of the target gas. A comparative study shows that the IR-DOAS principle is better suited for AQ monitoring on large areas than a non-disperse in infra red device which measures the pollution level in a certain point. The data acquisition system with 16 analogue channels, consisting of a special hardware and a PC, was able to register in real time, and simultaneously, the inputs from the: (i) Meteorological sensors: temperature, wind rose and speed, air humidity, solar radiation, atmospheric pressure, (ii) Traffic counters VEK M4C-E with 4 coupling loops, (iii) Air quality monitors: SO_2, NO, NO_2, NO_X, with special concern paid to parallel CO monitoring, using a ND IR analyzer and an IR DOAS instrument (optical paths 20 m). The emplacement of the instrument is indicated in Fig. 3.a. In Fig. 3.b the representative experimental results are given.

Results and discussion

In the graphics (see Fig. 5), the open path of the instrument is represented with double arrow and the position of the device which furnishes the local pollution level is represented with a point. All the graphics present the concentration distribution in a horizontal plan, located at 1.5 m from the ground level.

In order to study the influence of the wind speed values, the situations presented in Fig. 5.a and Fig. 5.b were simulated. Here, one may observe that the effects of a small wind speed of 0.5 m $s^{-}1$ (Fig. 5.b) generate a blocking of the pollutant in the centre of the crossroad; this means a bad performance of the dispersion process and that the pollutants cannot be easily dispersed away.

Fig. 5.a, c, d, e, f, present the situation when the wind direction is changed. Thus, one concludes that the contours of the pollutant cloud is different, but in all causes the higher concentration of the pollutant is recorded in the centre of the cross road, and, generally, the dispersion of the noxes depends on the free spaces of the domain and on the wind direction.

The computational comparative analyze presented by Fig. 4, concerning the values recorded along the open path and in the position of the source point, demonstrates that, although the detected principle of the instruments is the same (NDIR), the recorded values may be different, because of variable concentration of the pollutant along the open path. Only in the peculiar position where the point instrument is located the concentration detected should be the same. The explanation is due to the fact that the optical instrument averages the infinite number of values from investigated points along the path, the effect of one single point value might then be considered as mostly insignificant.

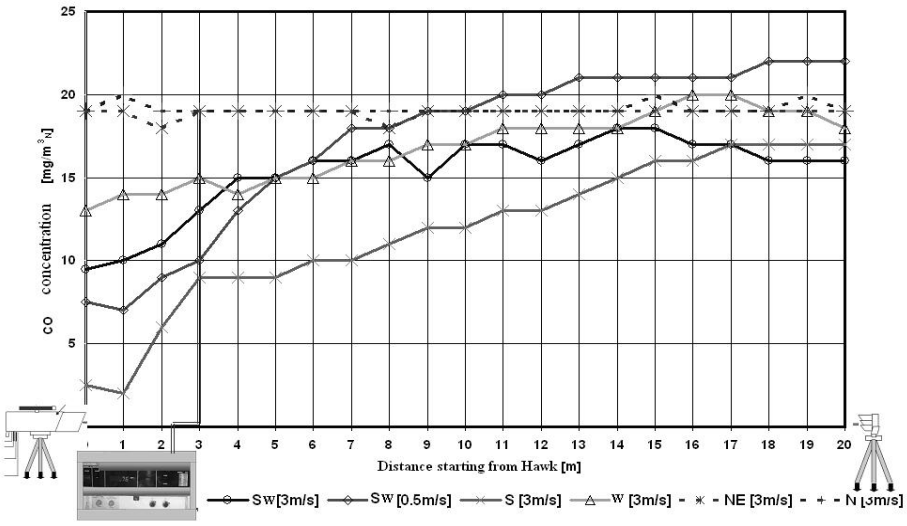
The best correlation of the recorded values of both instruments is installed for the episode when wind is blowing from North - West and North. Then the pollutant noxes are transported from the center of the crossroad along to the open path of the optical instrument, and also to the point source's input of the classical instrument.

When the wind is blowing from South, the instruments recorded the most uncorrelated series of results because at the input of the classical instrument a relatively clean air is present, but the open path instrument recorded values also from the vicinity of the crossroad and thus, additional impact of the central concentration is active.

Fig. 3.b presents series of the recorded values for carbon monoxide with the instruments during the measurement campaign from May 2002. One can observed that the optical instrument is more sensible because it averages the scanned values along the open path (20 meters distance), and the influence of the local effect is avoided.

Fig. 4: CO dependence during the long path dependence for different wind speed parameters.

Fig. 4 : Variation de la CO - concentration vers la distance optique et le point de mesure de l appareil en dépendance des paramètres caractéristiques du vent.



Conclusion

Practically the paper focuses both on theoretically and experimentally research concerning numerically simulation and on-line measurement of the CO emission generated from traffic in the cross road B-dul Mihai Viteazu - B-dul Vasile Pârvan.

It is important to point out that the study was accomplished to highlight the difference and uncorrelated results for real situation that may occur during the monitoring campaign.

The studies demonstrate the necessity that the air quality measurement using optical and point instruments should be achieved by specialists only after an initial study of the area. The initial CFD study may be very usefully to select

the best position for the monitoring instruments. The CFD model is done based of the local meteorological database and taking into consideration the statistical distribution of the meteorological and traffic data.

Fig. 5 : Plan-view of the selected area showing the characteristics of the CO pollutant dispersion for low elevation at 1,5 m: a) and for South - West wind with wind speed of 3 m s^{-1}; b) for South - West wind with wind speed of 0.5 m s^{-1}; c) for Southern wind with wind speed of 3 m s^{-1}; d) for North wind with wind speed of 3 m s^{-1}; e) for West wind with wind speed of 3 m s^{-1}; f) for North-East wind with wind speed of 3 m s^{-1}.

Fig. 5 : Section transversale dans le domaine pour l'indication du CO dispersion a élévation réduite de 1.5 m, a) pour un vent de SV a 3 m/s, b) pour un vent de SV a 0,5 m/s, c) pour un vent de S a 3 m/s, d) pour un vent de N a 3 m/s, f) pour un vent de NE a 3 m/s.

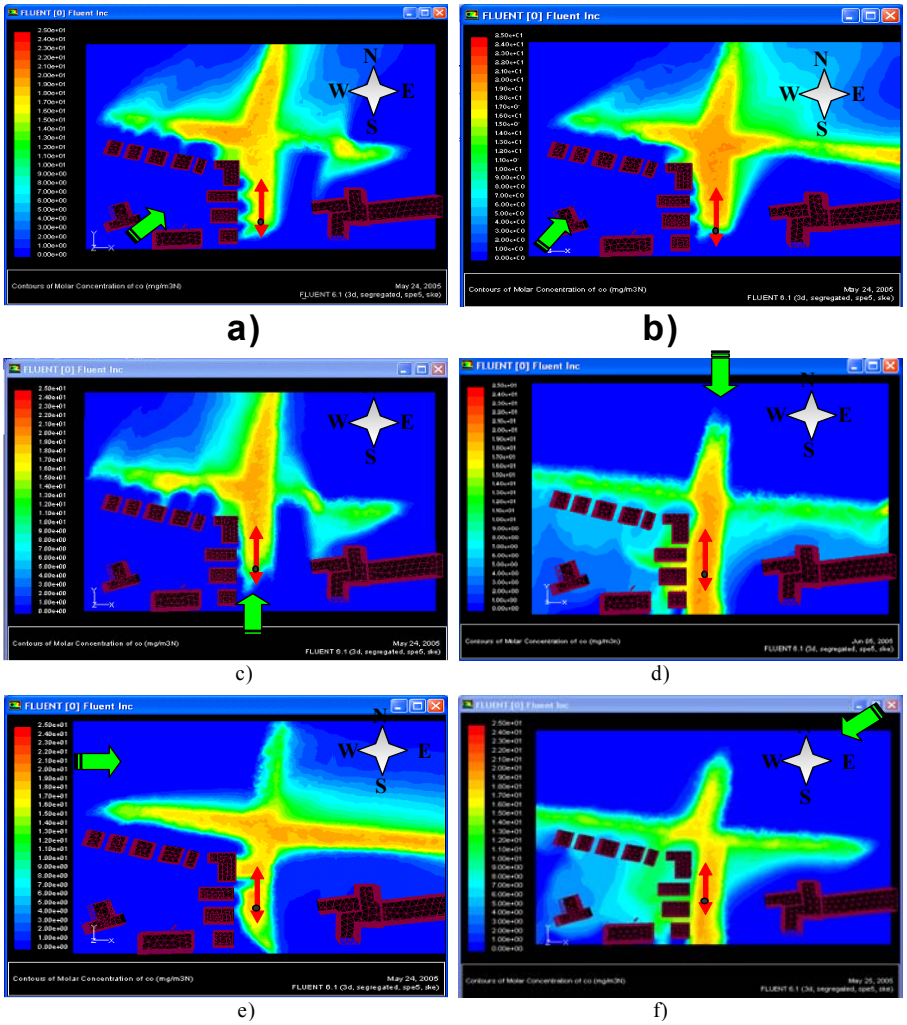


Fig. 5 illustrates that in real and possible meteorological conditions the signal, which activates the CO monitors and is generated from exhaust gases dispersed in the environment air, is not the same all the time and is also variable in space. The placement of the instrument is very important in order to obtain similar results and Fig. 4 shows the computational results that strengthen this idea.

The geometry of the buildings and the roughness of the environment area are extremely important in the air flow in the study domain and practically influence the dispersion process. The buildings' effects are similar to a shelter and the cleaning of the area with external air is possible only from the free spaces between buildings. Most of the time, the optical instrument recorded higher values than the point instrument.

The simulated results match well with the experimental results and offer realistic explanations about the sequential anti-correlation of the comparative results achieved using the classical point source measurement instrument and the ROMT technique.

Acknowledgments

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Assessment of the air quality benefits of a new town by-pass motorway

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Abstract

Air quality monitoring and atmospheric dispersion modeling were used to determine the reductions in ambient air pollutant concentrations attributable to the opening of a new motorway by-pass of a regional town. Continuous measurement of the concentrations of carbon monoxide (by infra-red analysis), nitrogen oxides (by chemiluminesence) and speciated hydrocarbons (by GC-FID within an online monitoring method) was performed adjacent to a stretch of the main road through the town, which had experienced daily traffic congestion and queuing prior to the opening of the by-pass. The diurnal concentration profiles observed before and after the by-pass opened were compared. The measured improvements in air quality were compared with predictions obtained using the CALINE4 dispersion model with actual meteorological data and traffic flows recorded during the monitoring period. CALINE4 is a USEPA-approved model for calculating hourly receptor concentrations due to emissions from highway sources. It requires user-defined composite emission factors, which in this case were determined using data in the UK Emission Factor Database and COPERT III. The predicted changes in the diurnal profiles of the concentrations of the different pollutants agree reasonably well with those suggested by the monitoring data. The results indicate the level of accuracy to be expected in the air quality impact assessments of future inter-urban route developments.

Key-words: *Air quality monitoring, atmospheric dispersion modelling, CALINE4, carbon monoxide, nitrogen oxides, hydrocarbons.*

Introduction

Emissions from road traffic have been identified by the Irish EPA as the primary treat to the air quality of Ireland (EPA, 2004). Considering the period from 1990 – 2003,the total number of vehicles in Ireland increased from 1,054,259 (1990) to 1,937,429 (2003). Over the same period, CO_2 emissions from road transport grew from 4,642 kilotonnes in 1990 to 10,993 kilotonnes in

2003 (CSO, 2004), while fossil fuel consumption grew by 53% over the same period (Faughnan C., 2004). Under the EU air quality framework directive and its subsequent daughter directives, ambient levels of key traffic related air pollutants have been identified that if adhered to will avoid, prevent and reduce harmful effects on human health and the environment. Key tasks in complying with these air quality standards include both monitoring and modelling of ambient air quality on both existing and proposed road developments. As part of any new proposed road development, air quality modelling is required as part of the Environmental Impact Statement to predict the future impact of road traffic volume on air quality (Budd U. *et al.,* 2004). Results of recent monitoring and modelling campaigns in Ireland indicate that compliance with the new stringent PM10 and NO_2 standards may present problems in some urban areas subject to heavy traffic.

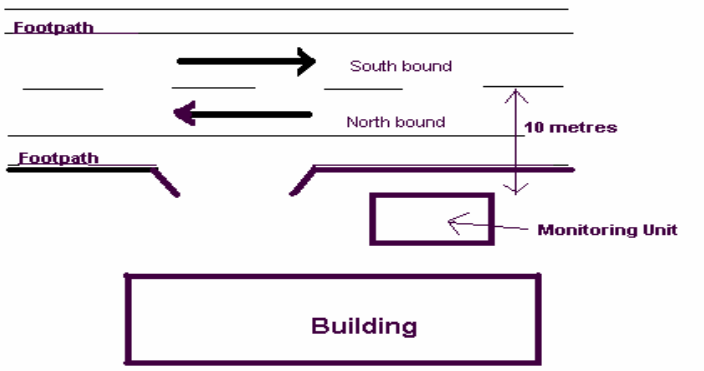
In this paper, The CALINE4 line source model developed by the California Department of Transport is used to predict pollutant concentration at roadside sites (Benson P.E., 1992). The main objectives of the study were 1) to assess the level of change in ambient air quality before and after the opening of the bypass, 2) to assess the model's performance through comparison with monitored results from the site.

Monitoring Methods

1. Site

The monitoring campaign was conducted in the town centre of Monasterevin, Co Kildare form October 2004 to January 2005. The monitoring unit housing all the necessary equipment was located at a Police station to the North of the N7 road. The unit was positioned 10metres from the centre of the road behind a wall approximately 0.5m in height. The road is comprised of two lanes catering for north bound and south bound traffic aligned east to west. The N7 is one of the busiest primary routes in the country connecting the urban centres of Limerick and Cork with Dublin.

Figure 1: Location of Monitoring Unit at N7, Monasterevin



2. Monitoring

2.1. Carbon Monoxide measurement

CO was measured using an API Model 300 gas filter correlation CO analyser. The basis of this method is IR spectroscopy. Units are in CO ppm.

2.2. Nitrous Oxides measurement

Nitric oxide (NO) and total NO_X were measured with an API Model 200a NOx analyser, which determines nitrogen dioxide as the difference between the two measured concentrations. NO is measured from the light intensity of the chemiluminescent gas phase reaction of NO and O_3. Units are in ppb.

2.3. Hydrocarbon Measurement

Hydrocarbons were measured using GC-ATD-FID. Units are in HC's ppb.

2.4. Meteorological and Traffic Measurement

Meteorological data comprising wind speed and wind direction were recorded on site. Met Eireann also provided wind speed, wind direction and pasquill stability classes. This data was gathered at Casement Aerodrome 40kms north of Monasterevin near the M7. The National Roads Authority provided hourly traffic data during the before period. Manual counts were conducted during the after period to assess the adjusted traffic volumes.

Modelling Methods

The USEPA approved CALINE4 line source model was used for pollutant prediction. CALINE4 is a short term (hourly) gaussian dispersion model that requires hourly traffic data (traffic volume, emission factor) and meteorological data (wind speed, wind direction, atmospheric stability) to predict concentrations at receptor points downwind of source. Composite emission factors (CEF's), based on COPERT III data and a vehicle fleet profile of 85.6% passenger cars (diesel and petrol) and 14.4% goods vehicles (petrol and diesel light duty vehicles, heavy goods vehicles) are presented in Table 1.Two sets of emission factors were used to reflect the different average vehicle speeds before and after the opening of the bypass. The section of road studied was modelled as 3 links.

Table1: Composite Emission Factors

ANALYTE	NOX	CO	HCS
CEF G/MILE(25KM/HR)	0.831	3.31	0.023
CEF G/MILE(45KM/HR)	0.672	2.05	0.015

Results

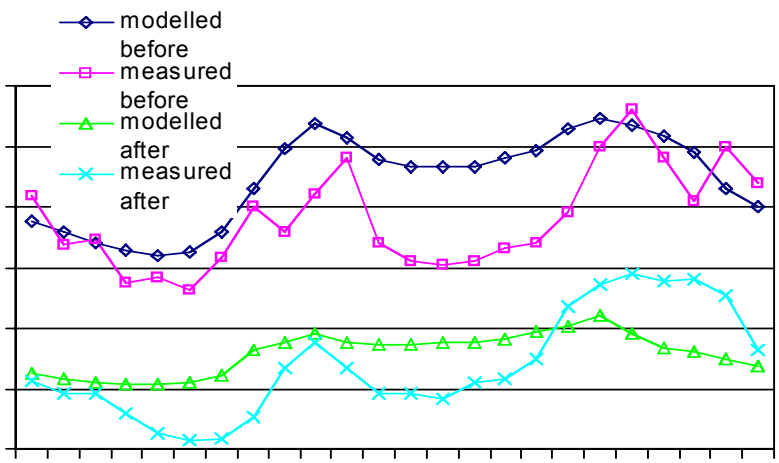
1. Traffic

The annual average daily traffic (AADT) for before the opening was 24106 vehicles, of which 4060 (16.8%) were HGV's. The annual average peak flow was 1898 vehicles per hour (vph), for the hour ending 18:00. The AADT for after the opening of the bypass was 11982 vehicles of which 719 (6%) were HGV's. The annual average peak flow was 984 vehicles for the hour ending 09:00

2. Meteorology

The prevailing winds at the monitoring unit were from the west while the Met Eireann data showed that the prevailing winds were from the southwest. Stability class D was most frequent over the course of the study (81% of total hours). Stable conditions (classes E, F, G) never occurred between 09:00 and 16:00.

Figure 2: Diurnal variation of modelled and measured CO



3. Measured and Modelled CO

The measured before and after hourly averaged diurnal profiles for CO shown in Figure 2 display an average reduction of 0.12ppm CO. The maximum difference occurs at 10:00 (0.17ppm CO) while the minimum difference occurs at 21:00 (0.07ppm CO). Two peaks occurring at 09:00 and 18:00 that can be attributed to peak traffic volumes occurring at these times. The CO background concentration for modelling was taken to be the measured CO concentration

when traffic volume was at a minimum (04:00). For both periods, the predicted diurnal profiles agree reasonably well with the measured values, but with less variation in the modelled data over the course of the day.

4. Measured and Modelled NOx

The measured before and after hourly averaged diurnal profiles for NOx show an average reduction of 23.7ppb NOx with a maximum reduction of 44.6ppb NOx at 07:00 and a minimum reduction of 8.9ppb NOx at 16:00 (Figure 3). The model shows good agreement with the measured results especially during daytime hours when traffic levels are highest.

Figure 3: Diurnal variation of modelled and measured Nox

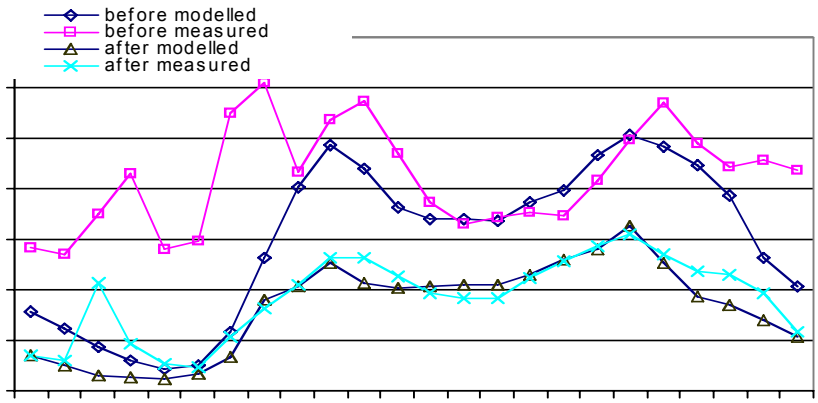
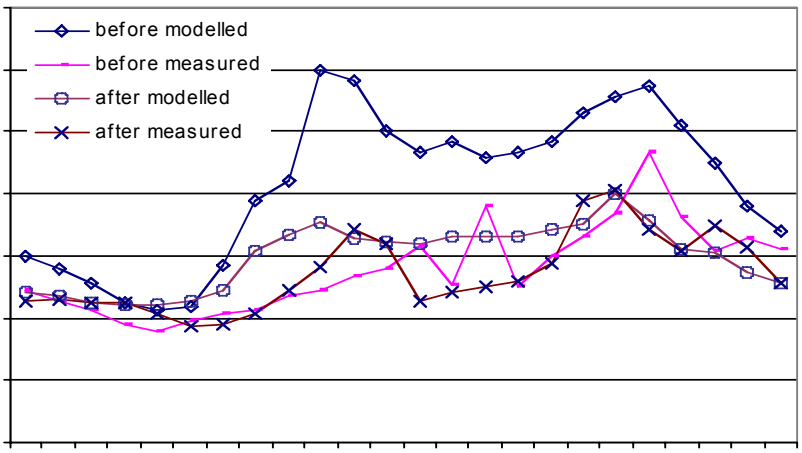


Figure 4: Diurnal variation of modelled and measured HC's



5. Modelled and Measured Hydrocarbons

The results presented here are the sum of five hydrocarbons quantified relative to propane for the before and after cases. The hydrocarbons quantified are ethane, ethene, propane, propene and acetylene. The background concentrations used for modelling hydrocarbons were obtained when the traffic volume was at a minimum (04:00). The before and after averaged hourly diurnal profiles show an average reduction of 0.06ppb HC's with a maximum reduction of 1.3ppb (14:00) and a minimum reduction of -0.8ppb (10:00) (figure 4). The model predictions agree well for the after case with all values lying well with ±50% of the measured concentrations. However the model over predicts in the before case by more than 50% for many values. This is partly attributable to problems with the instrumental set up that reduced the data set in the before case. The baseline signal to noise ratio was quite low initially that made compound identification quite difficult. After allowing the instrument to run for a number of days analyte signal response increased.

Discussion

1. Comparison of mean pollutant concentrations before and after opening of the bypass

When compared, the mean concentrations for all pollutants show an improvement in air quality with respect to the reduced traffic volume attributable to the opening of the by pass (Table 2). The pollutant concentration that reduces the most is NOx with the before diurnal average concentration of 42.2ppb being reduced to 18.5ppb in the after case. CO also shows good improvement with a before average concentration of 0.19ppm being reduced to 0.07ppm in the after case.

Table 2. Measured Mean Pollutant Concentrations

	CO (PPM)	NOX (PPB)	HC'S (PPB)
BEFORE	0.19	42.2	2.78
AFTER	0.07	18.5	2.72
DIFFERENCE	0.12	23.7	0.06

2. Comparison of Modelled and Measured Concentrations

The model predictions agree reasonably well with the before and after measured CO and NOx concentrations and for the HC's in the after case. For these pollutants, the modelled concentrations are within ± 50% of the measured concentrations (Table 3). The UK Department of the environment, Transport and the Regions (UK DETR, 2001) states that " if the prediction of an annual mean concentration lies within ± 50% of the measurements, a user would not consider that the model has behaved badly. The daughter directiveS (CEC, 1999, 2000) 'allows 50% uncertainty in modelling of the eight hour average concentration.

Table 3: Modelled Pollutant Diurnal Averages

	CO (PPM)	NOX(PPB)	HC'S (PPB)
BEFORE (% MEASURED)	0.22 (116)	29.8 (71)	4.15 (149)
AFTER (% MEASURED)	0.08 (114)	16.4 (89)	2.99 (91)
DIFFERENCE (% MEASURED)	0.14 (117)	13.4 (57)	1.16 (1933)

Conclusions

The improvement in air quality experienced due to the opening of a new town by-pass was assessed through air quality monitoring and dispersion modelling. Reductions in ambient pollutant concentrations of up to 50% were observed for some pollutants. It was shown that the use of site-specific input data in the CALINE4 model led to predictions of air quality that agreed well with

the measured values, both in terms of average diurnal profiles and mean concentrations. These results suggest that accurate dispersion modelling can be used to predict changes in urban air quality due to major road developments.

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Methodologies for estimating air pollutant emissions from ships: a 2006 update

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Abstract

A suitable methodology for the estimate of air pollutant emissions from ships, in port environment and in navigation, has been developed in the framework of MEET Project (Methodologies for estimating air pollutant emissions from transport) under the transport RTD program of the European Commission fourth framework program.

In the last year a lot of works was been published containing results on measures of emissions from ships in real case (in cruise and at berth), and to discuss MEET Methodology.

The paper first review the work published after MEET conclusion. Next a discussion and an update of fuel consumption formulae will be presented and new emission factors are proposed. Finally a discussion about differences of the update methodology with the previous one will be presented

Keys-words*: Air pollutant emissions, Fuel consumption, MEET, Ships, Ports.*

Introduction

A suitable methodology for the estimate of air pollutant emissions from ships, in port environment and in navigation, has been developed in the framework of MEET Project (Methodologies for estimating air pollutant emissions from transport) under the transport RTD program of the European Commission fourth framework program (Trozzi & Vaccaro 1999a).

A complete review of all the emission factors available in literature was the basis of the original MEET selected factors (Alexandersson *et al.*, 1993; Bouscaren, 1990; Cooper *et al.*, 1996; Klokk, 1995; Hadler *et al.*, 1994; Flodström, 1997; Lloyd's Register, 1990, 1993a, 1993b, 1993c, 1995; Melhus, 1990; Melhus, 1990; NMTRI, 1990; Rideout, 1997; SET, 1981; Sowman, 1996; TRI, 1992; USEPA, 1985, 1995).

The methodology was reviewed in two specialty conferences on marine combustion engines (Trozzi & Vaccaro 1998) and ports (Vaccaro et al, 1998) and in the conference on EC COST action (Trozzi & Vaccaro 1999b). Specific software was developed (Trozzi et al. 1999) and the methodology has been applied at local and national level in the last years (Trozzi et al. 2002).

Recently the Commission of the European Communities has prepared a European Union strategy to reduce atmospheric emissions from seagoing ships (COMMISSION OF THE EUROPEAN COMMUNITIES, 2002a; 2002b). In 1999, United States Environmental Protection Agency (USEPA, 1999a, 1999b) identified three categories of marine diesel engines, based on the engine's displacement per cylinder and general use; the final emission standards for very large high-power engines (Category 3) were published in 2003 (USEPA, 2003).

After the conclusion of MEET project several applications used MEET methodology. Also a lot of works has been published as containing measured emissions from ships (in cruise and at berth), and to discuss MEET methodology (Cooper et al. 1996; Cooper, 2001; 2003; Cooper & Gustafsson, 2004, Corbett & Koehler 2003; Entec, 2005a; 2005b).

The paper review the work published after MEET conclusion and discuss and update fuel consumption formulae and emission factors. Finally a discussion about differences of the update methodology with the previous one will be presented.

Methodology

In shipping activity it is customary to distinguish between (a) approaching and docking in port; (b) hotelling in port (or *at berth*); (c) departing from the port; (d) cruising. Phase (a) starts when the ship's deceleration begins and ends at the moment of the docking, while phase (c) starts with departure from the berth and ends when cruising speed has been reached. For liquid bulk ships power requirements of the cargo pumps for tanker off-loading and of the ballast pumps for tanker loading must be also take into account. In smaller tankers, the pumping power requirement will add to the electrical load whereas for larger tanker steam turbine driven pumps are generally used (even on motor tankers) with a consequent boiler load. As these power requirements can be relatively high, the emissions will be separately estimated.

In order to estimate emissions in a detailed manner it is necessary to known statistics on navigation (along a line and in ports) reporting GT and fuel use distribution of ships and average times spent in different mode. From such information is then possible to estimate the number of working days in the different mode for each class of ships equipped with different engine type and using different fuel. The following pollutants are taken into account: Nitrogen oxides, Sulfur oxides, Carbon monoxide, Volatile Organic Compounds, Particulate matter and Carbon dioxide.

The emissions are obtained as:

$$E_i = \Sigma_{jklm} S_{jkm}(GT) \cdot t_{jklm} \cdot F_{ijlm}$$

where: i pollutant, j fuel (Bunker fuel oil – BFO, Marine diesel oil - MDO, Marine gas oil – MGO, Gasoline fuel – GF), k ship class for use in consumption classification (Solid Bulk, Liquid Bulk, General Cargo, Container, Passenger/Ro-Ro/Cargo, Passenger, High speed ferries, Inland Cargo, Sail ships, Tugs, Fishing, Other), l engines type class for use in emission factors characterization (Steam turbines, High speed motor engines, Medium speed motor engines, Slow speed motor engines, Gas turbines , Inboard engines - pleasure craft, Outboard engines, Tanker loading and off-loading), m mode (Cruising, Manoeuvring, Hotelling, Tanker offloading), E_i total emissions of pollutant I, F_{ijlm} average emission factors of pollutant i from fuel j in engines type l in mode m (for SO_X, taking into account average sulfur content of fuel), GT gross tonnage, S_{jkm}(GT) daily consumption of fuel j in ship class k in mode m as a function of gross tonnage, t_{jklm} days in navigation of ships of class k with engines type l using fuel j in mode m.

For *hotelling* mode, auxiliary engines are evaluated without distinction between slow, medium and high speed; the hypothesis is assumed that auxiliary diesel engines are used when main engines are *High, Medium, Slow speed motor engines* and *Gas turbines*;

In ferry traffic, the hotelling and manoeuvring modes are important only for short passages; as the length increases (i.e. over a few hours) their relative contribution will reduce and could be neglected. For short passages ferry traffic, to take into account also hotelling and manoeuvring emissions, it's possible to use only cruise mode, with t_{jkl} equal to the sum of days in cruising and half of days in hotelling and manoeuvring (as in these modes fuel consumption are about an half of cruising ones).

Emission Factors

Table 1 reports updated default emission factors proposed for the different phases (the inboard pleasure craft and outboard craft hotelling phase emissions are negligible as they use port facilities to obtain auxiliary energy).

Table 1: Updated proposed emission factors (kg/ton of fuel)

Phases	*Engine types*	*NO_x*	*CO*	*CO_2*	*VOC*	*PM*	SO_x(°)
Cruising	Steam turbines – BFO	6.98	0.431	3200	0.085	2.50	54
	Steam turbines – MDO	6.25	0.6	3200	0.5	2.08	10
	High speed diesel engines – MDO	60	2,8	3200	1,0	0,52	10
	Medium speed diesel engines – MDO	57	7.4	3200	2.4	1.2	10
	Slow speed diesel engines – BFO	87	7.4	3200	2.4	7.6	54
	Gas turbines – MDO	18	0.8	3200	0.3	0.01	10

	Pleasure – Inboard diesel	48	20	3200	26	neg.	4
	Pleasure – Inboard gasoline	21.2	201	3000	13.9	neg.	0,1
	Outboard gasoline engines	1.07	540	3000	176	neg.	0,1
Manoeuvring	Steam turbines – BFO	6.11	0.19	3200	0.85	2.50	54
	Steam turbines – MDO	5.47	0.27	3200	5.0	2.08	10
	High speed diesel engines – MDO	54	10,6	3200	1,5	0,52	10
	Medium speed diesel engines – MDO	51	28	3200	3.6	1.2	10
	Slow speed diesel engines – BFO	78	28	3200	3.6	7.6	54
	Gas turbines – MDO	18	0.8	3200	0.3	0.01	10
	Pleasure – Inboard diesel	48	20	3200	26	neg.	4
	Pleasure – Inboard gasoline	21.2	201	3000	13.9	neg.	0,1
	Outboard gasoline engines	1.07	540	3000	176	neg.	0,1
Hotelling	Steam turbines – BFO	4.55	0	3200	0.4	1.25	54
	Steam turbines – MDO	3.11	0.6	3200	0.5	2.11	10
	Diesel auxiliary engines(°°)- MDO	63	4	3200	1.9	1.1	10
	Pleasure – Inboard and outboard	neg.	neg.	neg.	neg.	neg.	neg.
Tanker loading/off-loading		12	1	3200	0.01	2.11	20s

(°) for gasoline engines emission factors valid from 2005 (emission factor 0.8 up to 1999 and 0,3 from 2000 to 2005)

(°°) auxiliary engines are evaluated without distinction between slow, medium and high speed; the hypothesis is assumed that auxiliary diesel engines are used when main engines are *High speed motor engines*, *Medium speed motor engines*, *Slow speed motor engines* and *Gas turbines*.

Steam turbines emission factors in hotelling and cruise are from USEPA (1985); for manoeuvring, the same ratio manoeuvring/cruise as in SET (1981) is applied to data from USEPA (1985).

Medium and slow speed diesel engines emission factors in manoeuvring and cruise are from Lloyd's Register (1995). Respect to original MEET proposed emission factors, according to the suggestion from ENTEC (Entec, 2005a), for PM is assumed that slow speed diesel engines use BFO and the value is updated to 7,6 kg/tonne (Lloyd's Register, 1995). High speed diesel engines emission factors in cruise [former from NMTRI (1990)] are updated

using data from Cooper (2001); the ratio emission in manoeuvring, emission in cruise calculated for medium speed is applied to estimate high speed diesel engines emission in manoeuvring. A recent work (Corbett & Koehler, 2003) report emission factors for NO_x in function of load that confirm emission factors selected for medium speed diesel engines; for slow speed diesel engines results shows an hard increase in emissions at reduced power; for high speed diesel engines results are less than for medium speed diesel engines while data we selected (Cooper, 2001) show a little increase.

For hotelling of ships equipped with diesel engines, in MEET project, the ratio hotelling/cruise obtained from data for steam turbines was applied to Lloyd's Register data in cruise. New information available make reasonable that it is more correct for ships equipped with these main engines to assume that in hotelling they use auxiliary diesel engines and to utilize emission factors for these engines. The selected emission factors for auxiliary diesel engines in hotelling are average from different kind of ships (Cooper, 2003). The results (these emission factors are significantly higher than former ones) shows as important are port policies on emissions controls.

Gas turbines emission factors in cruise are updated from MEET using data from Cooper (2001); for NO_X, the emission factor of 24,1 kg/ton is significant higher than the former one (16 kg/ton) derived from land-based gas turbines (EMEP, 1996) and gross estimates (Sowman, 1996). The ratio emission in manoeuvring, emission in cruise calculated for medium speed diesel engines is applied to roughly estimate gas turbines engines emission in manoeuvring.

Inboard engines pleasure craft and outboard engines emission factors in manoeuvring and cruise coming from USEPA (1995).

For SO_x the emission factor depends on the sulphur content of fuel while for CO_2 is taken an average emissions factor for oil and a different factor for gasoline. From the sample of 11000 vessels used in statistical analysis results that 90% of diesel engines operate with marine diesel oil (MDO) and only 10% with bunker fuel oil (BFO). For sulphur content averages of 3% for BFO, of 1% for MDO and of 0,2% for marine gas oil (MGO) (CONCAWE, 1994, 1998) was assumed in the original MEET work. A more recent review (Endresen et al., 2005) reports an average of 2,7% for BFO and of 0,52% for MDO. For gasoline in European Union the following limits apply 0.04% up to 1999, 0,015% from 2000 to 2005, and 0,005% from 2005. In Table 4 updated average sulphur oxides emission factors are reported. For BFO engines emission factor is 10% lower than former one while for MDO emission factor is 50% down. These emissions factors are more accurate than ones used in TRENDS modeling (Georgakakia, 2005).

Table 4: Emissions reduction factors

Scenario / *Engine types*	*High reduction*		*Medium reduction*		*Low reduction*	
	NOx	*SOx*	*NOx*	*SOx*	*NOx*	*SOx*
Steam turbines – BFO engines	1	0.333	1	0.5	1	0.667
Steam turbines – MDO engines	1	0.2	1	0.2	1	0.2
Diesel engines – BFO	0.2	0.333	0.7	0.5	0.9	0.667

Diesel engines – MDO	0.2	0.2	0.7	0.2	0.9	0.2
Gas turbines	1	0.2	1	0.2	1	0.2

A first estimate of PM_{10} fraction and $PM_{2.5}$ fraction can be derived for ship at berth (Cooper, 2003) as 87-90% fraction of PM as PM_{10} and 50%-55% fraction of PM as $PM_{2.5}$ (lower percentage are for residual oil and higher for marine gas oil).

Specific Fuel Consumption

In MEET project, for determination of specific fuel consumption figures the database of Lloyd's Maritime Information Services Ltd. was been used. The database contained the world merchant fleet of 100 gross tons and above (86,000 vessels). Approximately 50% of these vessels were cargo carrying vessels (an estimated 40,000) whereas many of the other vessels were small non-cargo carrying vessels such as fishing vessels (over 22,000) and tugs (over 9,000). In the database there were approximately 15,000 vessels with fuel consumption data. Approximately 11,000 of these vessels had tonnage measured in concordance with the 1969 International Tonnage Convention and are used in statistical analysis. A linear regression analysis was been made on fuel consumption at full power vs. gross tonnage for each ship class with the exception of inland navigation (for which data on general cargo must be used). In a recent work conducted in the frame of Transport and Environment Database System (TRENDS) project a power curve is used to estimate the FC of the ships within the DTU database (Georgakakia, 2005). The authors considered this to give a better representation of the relationship with gross tonnage, especially for the smaller vessels.

In the following a non linear trend in consumptions vs. gross tonnage is taking into account using a statistical regression model. The model is based on multiple linear regression methods through interpolation in the space of the fuel consumption. The model is the following:

$$C_k = d_0 + d_1G + d_2G^2 + d_3G^3 + d_4G^4 + d_1G^5$$

where C_k is the fuel consumption of ship class i, G is the gross tonnage, C the concentration and f a explaining variable. A stepwise procedure is used in the application of regression model. The stepwise procedure introduces variables (higher powers) at steps and use analysis of variance to decide if introduces a new variable and which variable is to be introduced. In such procedure we adopt a statistical criterion to decide if introduce higher power of the model.

The effective fuel consumption can be obtained as:

$$S_{jkm}\,(GT) = C_{jk}\,(GT) * p_m$$

where: C_{jk} (GT) daily consumption at full power of fuel j in ship class k as a function of gross tonnage, p_m fraction of maximum fuel consumption in mode m

Figure 1: Consumption at full power (t/day) versus gross tonnage (t) [all ships]

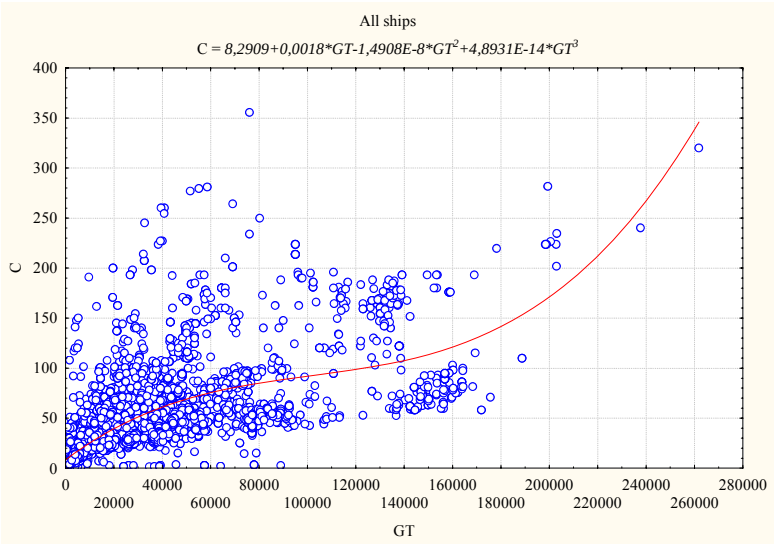

Table 2: Consumption at full power (t/day) versus gross tonnage

Ship types	*Consumption*	*Max GT*
Solid bulk	C = 12,0724+0,0012* GT -1,1501E-8* GT2+4,6484E-14* GT3	180000
Liquid bulk	C = 7,2194+0,0015*GT-9,1885E-9*GT2+2,6803E-14*GT3	260000
General Cargo	C = -2,2602+0,0049*GT-1,6401E-7*GT2+1,7394E-12*GT3	60000
Container	C = 0,0919+0,0038*GT-6,1565E-8*GT2+6,7917E-13*GT3	70000
Passenger/Ro-Ro/Cargo	C = 6,3501+0,0013*GT+1,6852E-7*GT2-6,2691E-12*GT3+ 5,699E-17*GT4	100000
Passenger	C = 5,2159+0,0034*GT-3,373E-8*GT2+2,062E-13*GT3	100000
High speed ferry	C = -9,735+0,0486*GT-4,6603E-6*GT2+1,3911E-10*GT3	20000
Inland cargo	C = -2,2602+0,0049*GT-1,6401E-7*GT2+1,7394E-12*GT3	60000
Sail ships	C = .42682 + .00100 * GT	6000
Tugs	C = 1,0857+0,0259*GT-1,0279E-5*GT2+1,6828E-9*GT3	4000
Fishing	C = 1,2744+0,0062*x-6,4603E-7*x^2+5,5193E-11*x^3	6000
Other ships	C = 1,2744+0,0062*x-6,4603E-7*x^2+5,5193E-11*x^3	140000
All ships	Cjk = 16.263 + 0.001 * GT	260000

In Figure 1 the regression for all ship classes is shown; Table 2 contains the derived functions for ship class. The default fraction of Table 3 can be used for the different mode. For tanker loading and off-loading a fuel consumption of 0.7 kg/ton of product or ballast offloaded can be used as default (SET, 1981). The regression equations have a very high statistical significance (F test is very good for all the regression), the uncertainty introduced with regression equation is acceptable taking into account the different sources of uncertainty involved in the emission estimates.

Table 3: Fraction of maximum fuel consumption by different mode

Mode	*Default*	*Specific*		
Cruising	0.80			
Manoeuvring	0.40			
Hotelling		*passenger*	*tanker*	*other*
	0.20	0.32	0.20	0.12
Tug		*ship assistance*	*moderate activity*	*under tow*
	0,50	0.20	0.50	0.80

Future emissions

Future emissions can be obtained as:

$E_{is} = E_i \cdot f_{is}$

where: i pollutant, s scenarios (high, medium, low), E_{is} total emissions of pollutant i in the scenario s, E_i total emissions of pollutant I, f_{is} reduction factors of pollutant i in the scenario s. In Table 5, the default reduction factors for three different scenarios are reported.

Table 5: Emissions factors for SCR equipped ships

Engine types	*NO_x*	*CO*	*CO2*	*VOC*	*PM*	*SO_x*
High speed diesel engines	10	4,4	3200	0,2	0,52	0,8

For sulphur oxides upon entry into force of Annex VI to MARPOL on the 19 May 2005, the SO_x emissions from ships will be controlled by setting a limit of 4.5% on the sulphur content of marine fuel oils. Further, a limit of 1.5% on the sulphur content of marine fuel oil will apply in designated SO_x Emission Control Areas (SECAs). The first designated SECA is the Baltic Sea Area which has been agreed that will enter into force on the 19 May 2006. The second area, the North Sea Area and the English Channel has also been agreed, but due to the amendment process in IMO, it has been indicated that it will not enter into force as a SECA until 19 November 2007. It is expected that further SECA's will be designated in the future. For sulphur oxides in the last years was proposed a directive of the European Parliament and of the Council amending Directive 1999/32/EC as regards the sulphur content of marine fuels. The proposal contains new limits on the maximum sulphur content of marine fuels, specifically: a 1.5% fuel S limit for all ships in the North Sea, Channel & Baltic Sea, in line with the SO_x Emission Control Area agreed at the International Maritime Organization; a 1.5% fuel S limit for passenger vessels on regular services to/from any EU ports, in line with established EU policy of high standards for passenger vessels; a 0.2% fuel S limit for ships at berth in EU ports, and all inland vessels. For the sulphur oxides was assumed that: all the marine diesel oil and marine gas oil sold in the EC in the future scenarios have a maximum of 0,2% sulphur content; heavy fuel oil has average sulphur

contents of 2% in the low reduction scenario, 1,5% in the intermediate reduction scenario and 1% in the high reduction scenario.

For the nitrogen oxides only reductions for diesel engines are assumed. Particularly, an emission reduction of 10% in the low reduction scenario (obtained from injection timing retard, intake air treatment); an emission reduction of 30% in the intermediate reduction scenario (obtained from water injection, emulsified fuel, exhaust gas recirculation); a recent study (Radloff et al. 2004) show an increase of PM emissions when water injection is used with MFO; an emission reduction of 80% in the high reduction scenario (obtained from non-catalytic and catalytic reduction). A recent study commissioned by European Commission (ENTEC, 2005a) uses a reduction factor for NOx of 16% (between the low and medium reduction scenario of MEET). Selected Catalytic Reduction can reduce PM by 60 – 90% (Man B&W Diesel quoted in Taylor R.B. 2005). Some first measurement of emissions obtained from high speed diesel engines with selective catalytic reduction (SCR) was reported (Cooper, 2001) and confirm the reduction hypothesis in MEET.

It is possible to reduce emissions of ships during their stay in port by a shore-to-ship electricity system (cold ironing), a process where shore power is provided to a vessel, allowing it to shut down its auxiliary engines. Thus, all the engines of a vessel could be shut down at berth. This is likely to reduce net emissions, assuming that shore-side electricity generation is subject to higher emissions standards than ship engines (Harrison et al. 2004). The efficiency of shore-to-ship electricity to reduce emissions improves when berthing time is rather long, energy usage of a ship is high and the ship has relatively frequent port calls.. An example of application of cold ironing comes from Port of Göteborg (Port of Göteborg, 2003). It is recommended (Union of the Baltic Cities, 2005) that the ports study the cost and environmental efficiency of constructing a shore-to-ship electricity system.

A recent investigation of the costs, emission reduction potential and practicalities of ship emissions abatement technologies was conduced by the European Commission (Entec, 2005b).

Conclusion

The methodology for the estimate of air pollutant emissions from ships developed in the frame of MEET project can effectively be still used but with updated emission factors, formulae for fuel consumption evaluation and reduction factors to quantify control measures. More attention must be devoted in future works toward the evaluation, with an accuracy comparable with one of main pollutants, of emission factors of PM_{10}, $PM_{2.5}$ and Polycyclic Aromatic Hydrocarbons.

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Activity based emission model for sea-going vessels

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Abstract

The objective of the presented paper is the demonstration of an activity based emission model for maritime transport in Belgium. Important parameters in this model are: characteristics of the sea-going vessels; duration of the stages of navigation; technology dependant emission factors. Emissions for the year 2004 are based on statistical activity data, those for the year 2010 are calculated by using activity growth factors, fleet evolution, existing legislation and detailed data from 2004. The IMO regulation decreases the NO_X emissions of the main engines with merely 1 % in 2010. The IMO and EU regulation on the sulphur content in maritime fuels has a large effect on the SO_2 emissions (decrease of 50 - 53 %). Currently, the Belgian national inventory of maritime transport emissions is based on the national energy statistics (top-down approach). The reported CO_2 emissions with the top-down approach are fifteen times higher than those derived from the bottom-up approach.

Keys-words: *sea-going vessels, territorial waters, harbours, activity based, energy and emissions*

Introduction

The share of emissions from sea-going vessels will increase in the future as the exhaust emissions of other transport modes decrease. This is due to the more stringent emission regulation and fuel specifications for road transport, railway traffic and inland navigation Amann (2005).

Emissions of sea-going vessels are not locally based and it is acknowledged worldwide that these emissions should be treated on an international scale. As in many other countries, the current methodology for the estimation of emissions from sea-going vessels in Belgium is based on bunker fuels allocated to the country (top-down approach). In this paper, we mainly discuss an alternative approach, namely an activity based methodology (bottom-up approach). Our comparison of both alternative approaches provides valuable new information to policy makers but will complicate international discussions

concerning the allocation of greenhouse gases and other air pollutants from sea-going vessels.

Objectives

In this paper we want to demonstrate an activity based emission model to map historical emissions and to make emission projections for the near future for sea-going vessels. Next, we want to compare the bottom-up and top-down emission inventory approach for maritime transport.

We defined the following subsidiary aims:

- To describe the activity based bottom-up approach for the calculation of an emission inventory of maritime transport within Belgian jurisdiction.
- To demonstrate the activity based method by quantifying the CO_2, SO_2, NO_X, CO, HC and PM emissions for sea-going vessels in the Belgian territorial waters for the year 2004.
- To calculate the forecasted emissions of sea-going vessels in Belgium for the year 2010 under a well-defined baseline scenario.
- To analyse the effect of the IMO en EU legislation on the emissions of sea-going vessels in the year 2010.
- To compare and discuss the CO_2 results obtained from the bottom-up approach to those from the top-down approach.

Activity based maritime transport emission model

The scope of the activity based maritime transport emission model is to calculate the energy consumption and CO_2, SO_2, NO_X, CO, HC and PM exhaust emissions for the cruising and hotelling of sea-going vessels in the 12 mile zone of the North sea, the Belgian territory of the river Scheldt and the four major Belgian harbours (Antwerp, Ghent, Ostend and Zeebrugge). We included the most important types of sea-going vessels: chemical tankers, containers, dry bulk carriers, gas tankers, general cargo, LNG tankers, oil bulk (crude), passenger ships, reefers and RoRo vessels. Energy for loading and unloading can either be supplied from the vessel engines or from the harbour energy facilities. The energy consumption and the subsequent emissions for loading and unloading are not included into the model.

1. Bottom-up methodology

We evaluated different European activity based methodologies MEET (1999), ENTEC (2002), ENTEC (2005), EMS (2003) and TRENDS (2003) used to estimate emissions for maritime transport. We screened the utility of the different methodologies for mapping emissions from sea-going vessels in Belgium on the basis of a list of strengths and weaknesses. Transparency, reproducibility, the integration of technical aspects of the sea-going vessels and the amount of detail were important selection criteria for the methodology.

Therefore, we finally decided upon an approach similar to the one used in EMS (2003), but with specific adaptations to the Belgian situation.

The model is designed to calculate emissions and energy consumption for the different stages of navigation for every voyage and hotelling period (cruise speed, reduced speed, manoeuvring, hotelling and anchoring). Therefore, detailed activity data (the duration of the different stages of navigation for every voyage) is an essential input parameter in the emission model.

We determined the emissions through the energy use, taking into account the length, building year and other technical aspects of the sea-going vessels, and the power use during each stage of navigation. The characteristics of each ship were extracted from the Lloyd's Register Fairplay database. A distinction is made between the exhaust emissions of auxiliaries (e.g for on board electricity production) and the main propulsion engines. For the latter, we distinguish 3 types of main engines, namely 2-stroke engines, 4-stroke engines and steam turbines.

Technology related emission factors from EMS (2003) were used to compute the NO_X, CO, HC and PM emissions. The emission factors depend on the building year of the vessel and the percentage of the maximum continuous rate (MCR). The emission factors for CO_2 are tuned to those of Aernouts and Jespers (2005), which correspond with the IPCC CO_2 emission factors. The present average sulphur content in maritime fuels was taken from EC (2002). For 2010 the IMO (2005) and EC (2005) regulations for the sulphur content of maritime fuels was taken into account (table 1).

For any statistical year, we use detailed a) activity data from the harbours themselves to integrate the specific geometry of the Belgian harbours in the model and b) vessel activities from the Belgian/Dutch Vessel Traffic System (VTS) for the North sea (12 mile zone).

Future energy consumption and emissions are calculated in the model by using activity growth factors, fleet evolution, existing legislation and detailed data from the last statistical year. The determination of the activity growth factors is exogenous to the model. We used low and high economic growth rates (transported freight in tonnes) to model future activities (low and high baseline scenario). We assumed that an increase in activity is filled in by newly built sea-going vessels. We determined how many visits the new ships would make by taking into account the gross tonnage of the new ships. We then made the following assumptions to define the ship characteristics of the new sea-going vessels for each harbour and each ship type to take into account the geometry of the harbours and the docks:

- new ships have the length of the largest ship visiting in the last statistical year;
- the characteristics (weight, technical aspects…) of a new ship are based on average ship characteristics from all available ships in our emission model with the corresponding length that were built from 2000 on.

We took the IMO and EU legislation into account for future projection (baseline scenario). We calculated average durations for every stage of

navigation of a voyage based on statistical activity information for existing ships and activities of the last statistical year.

Table 1: overview of the CO_2 and SO_2 emission factors (kg/ton fuel)

Table 1: sommaire des facteurs d'émission de CO_2 et SO_2 (kg/ton combustible)

Emission factor (kg/ton)	*Heavy fuel oil*	*Diesel and gas oil*	*Gas boil off*
CO_2	3 110	3 100	2 930
SO_2 (... - 18/05/2006)	54	4	~0
SO_2 (19/05/2006 - 2009)	30	4	~0
SO_2 (2010 - ...)	30	4 or 2*	~0

*2 kg SO_2/ton diesel or gas oil at berth (minimum duration of 2 hours)

2. Results

The year 2004 is the first year of the baseline scenario because reliable statistical data is available for this year. We also made predictions of emissions in the near future (2010).

The fleet and traffic data for the year 2004 is based on statistical data. We only implement the IMO Annex VI regulation for NO_X emissions on passenger ships built after 1999. We present the emissions of the main engines and auxiliaries of the sea-going vessels (in Belgium) for the year 2004 in table 2. They are the sum of the emissions in all regions (North sea (12 mile zone), the Scheldt river and the four harbours) and for all different stages of navigation (cruise speed, reduced speed, manoeuvring, anchoring and hotelling). The implementation of the IMO Annex VI regulation for passenger ships built after 1999 results in a NO_X reduction of merely 45 ton or 0,3 % of the total NO_X emissions for sea-going vessels in the year 2004 in Belgium. The CO_2 emissions (Belgium, 2004) of the different vessel types are presented in figure 1.

The container, general cargo and RoRo vessels emit ~70 % of the total CO_2-NO_X- and SO_2 emissions of maritime transport for the year 2004 in Belgium. The auxiliaries of the general cargo vessels emit more CO_2, NO_X and SO_2 emissions than the main engines of these vessels. This is due to the large amount of used auxiliary power compared to the used main engine power. The opposite is true for containers, LNG tankers and RoRo vessels. The contribution of the auxiliaries is small because of the large amount of used main engine power compared to the used auxiliary power (total energy consumption (TJ) of auxiliaries < 20 %).

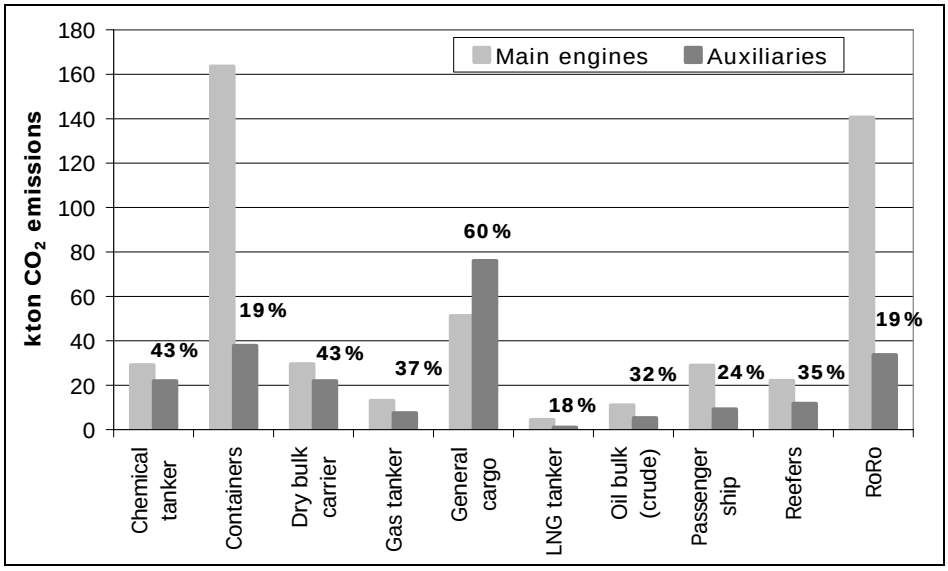
Table 2: emissions (kton) of sea-going vessels for the year 2004 in Belgium

Table 2: émissions (kton) des navires marins pour l'année 2004 en Belgique

KTON	MAIN ENGINES	AUXILIARIES	TOTAL
CO_2	494	226	720
SO_2	8,09	2,82	10,9
NO_X	12,7	4,21	16,9
PM	1,04	0,236	1,28
CO	1,97	0,801	2,77
HC	0,389	0,179	0,569

Figure 1: CO_2 emissions of the different ship types for the year 2004 in Belgium

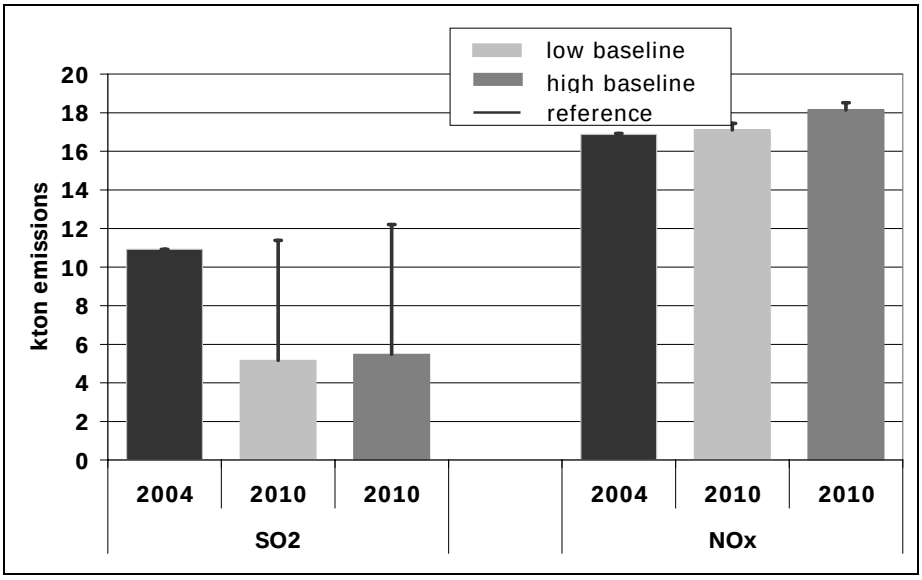
Figure 1: émissions de CO_2 par type de navires pour l'année 2004 en Belgique



We made predictions of the emissions of maritime transport in Belgium for the near future (2010) by taking into account, in a low and a high baseline scenario, the traffic evolution, the fleet evolution and the existing legislation (IMO and EU). To compute the effect of the existing legislation, we calculated the emissions for the year 2010 only taking into account the traffic and fleet evolution (reference scenario). We present the emission results for the year 2010 in the low and high baseline scenario in table 3. A distinction is made between main engines and auxiliaries. In figure 2 we present the regulated emissions SO_2 and NO_X of sea-going vessels in Belgium for the years 2004 and 2010 in the reference, low baseline and high baseline scenario.

Figure 2: SO_2 and NO_X emissions of sea-going vessels in the reference and baseline scenarios

Figure 2: émissions de SO_2 et NO_X des navires marins dans les scénarios de référence et de base



The CO_2 emissions increase with 2 % in the low baseline scenario and 9 % in the high baseline scenario over the period 2004-2010 due to an increase in activity. The NO_X emissions increase slightly (1 %) in the low baseline scenario, the increase in activity offsets the reductions of the IMO en EU regulations. An increase of 8 % of the NO_X emissions takes place in the high baseline scenario between the years 2004 and 2010. The IMO en EU regulations are most effective for the reduction in SO_2 emissions. A decrease of 53 % (low baseline) and 50 % (high baseline) in SO_2 emissions is accomplished despite the increase in activity between the years 2004 and 2010. The PM emissions of sea-going vessels decrease with 2 % (low baseline) or increase with 5 % (high baseline) over the time period 2004-2010. The CO emissions increase with 4 % or 12 %, respectively in the low and high baseline scenario, the HC emissions increase with 2 % or 8 %.

Table 3: emissions of sea-going vessels in the year 2010 (Belgium) in a low and high baseline scenario

Table 3: émissions des navires marins pour l'année 2010 (Belgique) dans un scénario de base limité et élevé

	Main engines		Auxiliaries		Total	
kton	low	high	low	high	low	high
CO2	509	540	226	243	735	783
SO2	4,66	4,94	0,499	0,538	5,16	5,48
NOX	13,0	13,8	4,12	4,37	17,1	18,1
PM	1,09	1,17	0,166	0,177	1,25	1,34
CO	2,10	2,28	0,785	0,832	2,89	3,11
HC	0,404	0,429	0,175	0,185	0,579	0,614

In table 4 we present the effect of the IMO and EU regulations for emissions of maritime transport in the year 2010 by comparing the baseline scenarios with the reference scenario. The IMO regulation results in a reduction of merely 1 % of the NO_X emissions of main engines in the year 2010. The total reduction of 55 % in SO_2 emissions is due to both the IMO and EU regulations:

- a decrease of the sulphur content for heavy fuel oil;
- a decrease of the sulphur content for fuels used at berth, which also implies a switch from heavy fuel oil to diesel oil for vessels at berth built after 1984.

The switch form heavy fuel oil to diesel oil for vessels at berth results for the auxiliaries in a large emission reduction (33 %) for PM and small emission reductions for CO_2 (5 %), NO_X (5 %), CO (4 %) and HC (4 %).

Table 4: emission reduction in the year 2010 (baseline to reference) due to the IMO en EU regulations

Table 4: réduction (base par rapport à référence) des émissions en 2010 suite aux réglementations IMO et EU.

	Main engines	***Auxiliaries***	***Total***
CO_2	0%	-5%	-2%
SO_2	-44%	-84%	-55%
NO_X	-1%	-5%	-2%
PM	0%	-33%	-6%
CO	0%	-4%	-1%
HC	0%	-4%	-1%

Comparison bottom-up and top-down approach

As presented earlier (table 2), the total amount of the CO_2 emissions of shipping activities for the year 2004 in Belgium calculated with the activity based methodology (bottom-up) are equal to 0,7 Mton.

At this moment, the official emission calculations for maritime transport are based upon the total amount of bunker fuels for maritime transport allocated to Belgium (top-down). The total quantity of bunker fuels has been defined as the sum of 'international bunkering' and 'local bunkering' as reported in the national energy statistics. By multiplying the total amount of bunker fuels with the IPPC CO_2 emission factors, VITO computes CO_2 emissions of maritime transport. The reported CO_2 emissions in Aernouts and Jespers (2005) for maritime transport in Belgium are equal to 24,2 Mton for the year 2004, thirty-five times more than the calculated CO_2 emissions with the bottom-up approach.

Besides the overestimation of the Belgian maritime fuels due to:

- the summation of local and international bunkers (~5 %);
- the attribution of as much heavy diesel fuel as possible to international bunkering because these are free from duties (~20%);

there is also a discrepancy between the bottom-up and top-down approach with respect to where the CO_2 emissions are emitted. The bottom-up approach makes an inventory of the CO_2 emissions emitted in Belgian territory, where the top-down approach makes an inventory of the CO_2 emissions of fuels sold on Belgian territory. Policy makers have to be aware that the use of the top-down or bottom-up methodology for emission assignment, within the scope of post-Kyoto 2012, to Belgium and other maritime bunker countries makes an enormous difference.

Conclusions

The technological evolution of sea-going vessels is slower than that of other transport modes. An increase in activity between 2004 and 2010 offsets the technological improvements for most pollutants. CO_2 emissions increase with 2 - 9 % between 2004 and 2010. The IMO and EU legislation have the largest affect on the SO_2 emissions. A decrease of 50 -53 % between 2004 and 2010 was calculated in the baseline scenario. The IMO regulation has only a small reducing effect on the total NO_X emissions of sea-going vessels in the year 2010.

Policy makers have to be aware that the activity based methodology (bottom-up) and the methodology based on the amount of bunker fuels for maritime transport allocated to Belgium (top-down) result in very different emission estimates for maritime transport.

Acknowledgments

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In-use load and emission factors characterization for industrial engines based on exhaust gas analysis

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Abstract

An airport ground support equipment (GSE) fleet, composed of several kinds of vehicles and equipment have been studied to determine their load and emission factors from their pollutant emission measurement.

On board exhaust gas analyzers have been used. Each GSE has been studied thought several real driving cycles in the most useful conditions and always manoeuvred by its operator.

To calculate the load factor, a simple model has been developed that proposes a "whole use of fuel" load factor definition including idle operation as a non zero load situation.

As a main result, the load factor is the most determinant parameter when estimating emissions from a vehicle fleet. Although attention usually relays in engine emission factors the uncertainty of load factor is the biggest source of error. Load factor defined and calculated this way results in a more intelligible tool to provide a whole idea of engine operation.

Keywords: *Load factor, emission factors, emissions, on-board measurements, ground support equipment, heavy-duty engines.*

Introduction

Several studies have demonstrated that for Heavy-Duty Engines (HDE) the existing databases for pollutant emissions assessment underestimates the

results when compared with real data (Hausberger S. et al. 2003). Even the Heavy-Duty Vehicles (DHV), which normally are better characterized than HDE, have still inaccuracies in their existing databases (Parrish D., 2006). In addition other studies have shown the importance of idle operation in HDE (Robert L., 2000; Tao Huai et al., 2006). This will be critical when estimating the pollutant emissions from HDE's, so a special treatment will be given in this work.

An accurate characterization of pollutant emissions from a given GSE requires detailed information about load and emission factors (Sierra Research, 1998; Ntziachristos L. et al. 2000). Equation 1 gives the procedure to calculate de pollutant emissions for one type of GSE.

$$E = n \cdot H \cdot P_n \cdot f \cdot e \qquad (1)$$

Where *E* (g) are the total emissions due to the vehicle fleet in the period of study, *n* the number of vehicles-equipment (GSE) to study, *H* (h) the mean time of operation for each GSE, P_n (kW) the engine rated power, *f* the load factor and *e* (g/kW) the emission factor for the pollutant to study.

Every engine in this study has a rated power above 25 hp so in homologation test they should pass the emissions standards ISO 8178 C1. Emission factors obtained from this test procedure are calculated for a mean load factor of 0,56. Experience has demonstrated that this emission factors are adequate when working around ± 0,2 the test mean load factor. The EPA provides data about load factor mean life and annual activity of several industrial equipments (Lindhjeim C.E. and Beardsley M., 1998). The load factor is above all the most imprecise variable in this problem. For example, the time that an engine operates at idle varies substantially, and in extreme cases, when idle mode percentage is very big, load factor becomes very close to zero because load factor stands for the amount of power used from the engine with respect the rated power the engine can provide. In this situation using equation 1, the pollutant emissions might become very small, even zero if idle is the exclusively mode of operation, which is obviously false. This obligates us to redefine the load factor concept.

This work pretends, first of all to develop a more appropriated load factor definition for HDE, and in second place evaluate the load and emission factors for the most used GSE in an airport.

Experimental methodology

In order to reduce costs a selection of the 10 types of GSE with more hours of accumulated work has been made. This selection of GSE is exposed in table 1. For each type of GSE only one equipment or vehicle has been evaluated.

To carry out the experiments a portable multigas analyzer has been installed onboard into the equipment-vehicles GSE which operate mainly on movement (Auxiliary Truck and Bus). This analyzer is a SENSORS Automotive Microbench AMB II, and it measures concentrations of HC, CO and CO_2 by NDIR (Non Dispersive InfraReds), and of NO_x and O_2 by chemical sensors. Although HC and CO gases can't be measured correctly because the analyzer is prepared for gasoline engines, and the range and type of technique of

analysis is not well suited for diesel ones, it does well whit CO_2 and NO_x. Those GSE that don't operate in movement have been measured with a exhaust gas laboratory installed in a vehicle, this vehicle-laboratory is equipped with gas analyzers better suited for diesel pollutant emissions. The analyzers are Signal 3000 HM to measure total HC by a Flame Ionization Detector (FID), 4000 VM to measure NO_x by a chemiluminescence detector, and 9000 MGA to measure CO and CO_2 by NDIR. It can be seen in the photographs of figure 1 the portable multigas analyzer installed on-board into an auxiliary truck and the vehicle-laboratory measuring an electric generator which is supplying electricity to an aircraft.

Table 1: Total working hours for the fleet by GSE type and measured load and emission factors. Values in parenthesis are estimated.

GSE denomination		Total working hours	Load factor "f"	CO (g/kW)	NOx (g/kW)	HCs (g/kW)
Auxiliary truck	Gorris TG-5000	247.898	0,2	(1,7)	8	(1)
Bus	Cobus 3000	138.666	0,2	(1,6)	4,6	(0,9)
Passenger Stairs	FMC UDS-2	24.721	(0,2)	2	9,1	0,4
Electric generator	Houching 762, 690, 690C	72.654	(0,8)	1,8	8,5	0,9
Beltloader	Einsa CDA-14C	37.982	(0,2)	1,7	9,1	0,6
Cargo loaders	FMC CL-8	30.125	(0,2)	2,7	9,2	1,3
Transfer	FMC CPT-7	27.837	(0,3)	1,5	8,1	0,4
Towbarless	Tracma TPX-200 S	30.629	(0,2)	2	9,1	0,6
Electric generator	Indar	22.632	(0,8)	1,5	8	0,8
Electric generator	Strüver Jet Electric 90	20.417	(0,8)	1,6	8,4	0,8

To measure the exhaust gas flow rate a Pitot tube has been used because is well suited for dirty flows with particles, typical in diesel exhaust gases. The Pitot tube is a TESTO one with a differential pressure manometer.

Figure 1: On the left the vehicle-laboratory measuring an electric generator which is supplying an aircraft. On the right an auxiliary truck equipped with the onboard portable multigas analyzer.

Analytical methodology

To obtain the load and emission factor of the GSE in real use measured total emissions have been used. By means of a modal analysis, measuring exhaust gas concentrations, temperature and flow rate, each pollutant gas has been studied quantifying its mass flow rate as shown in equations 2-4.

$$Q_{gas} = [gas] \cdot Q_e \quad (2) \qquad \dot{n}_{gas} = Q_{gas} \cdot \frac{P}{R \cdot T_e} \quad (3) \qquad \dot{E} = \dot{n}_{gas} \cdot Pm_{gas} \quad (4)$$

Where Q_{gas} (m^3/s) is the specific flow rate, [*gas*] (ppm or %) the gas concentration in a wet basis (in ppm it should be divide by 10^6 an in % it should be done by 100), Q_e (m^3/s) the exhaust flow rate, $\dot{n}_{gas}$ (moles/h) the specific molar flow rate , P (Pa) the atmospheric pressure, R (kJ/(mol·K)) the ideal gas universal constant, T_e (K) the exhaust gas temperature, $\dot{E}$ (g/s) the specific mass flow rate and Pm_{gas} (g/mol) the molecular mass of the pollutant gas.

It should be notice that those gas analyzers based in NDIR measures should need to dry the exhaust gases because water vapour interacts with the measure so the measures should be changed from a dry basis into a wet one (Edwards J.B. 1974).

Once the emissions are characterized we proceed to abstract the load and emission factor from them.

With a visual inspection it can be observed that idle is a common mode of operation, and in this situation they produce a not negligible amount of pollutant emissions. So in order to include these emissions in the load factor a new definition of this one has been proposed. The proposed new definition is the same way as before but in terms of gross power (equation 5). This way, idle mode of operation has no more a zero load factor and its pollutant emissions can be comprised.

$$f = \frac{P_u}{P_b} \quad (5)$$

Where f is the load factor, P_u (kW) the gross power used and P_b (kW) is the total gross power at the rated power of the engine.

We can express the gross power as in equation 6 (Muñoz M. Payry F., 1989). And we can obtain the fuel-air ratio with the equation of combustion and the fuel composition from the CO_2 concentration (Heywood J. B., 2002).

$$P = \eta_i \cdot F \cdot \dot{m}_a \cdot H_f \quad (6)$$

Where P (kW) is the gross power, η_i is the indicated efficiency, F *is* the fuel-air ratio, $\dot{m}_a$ is (kg/s) the air mass flow rate and H_f (kJ/kg) is the fuel combustion enthalpy.

To express those variables with the parameters we measure we use equations 7 and 8.

$$\dot{m}_a = \frac{\dot{m}_e}{(1+F)} \quad (7) \qquad \dot{m}_e = Q_e \cdot \frac{P}{R \cdot T_e} \cdot Pm_e \quad (8)$$

Where $\dot{m}_e$ (kg/s) is the mass flow rate of the exhaust gases and Pm_e (g/mol) is the mean molecular mass of the exhaust gases.

This way the new load factor definition can be expressed as in equation 9:

$$f = \frac{P_u}{P_b} = \frac{\eta_t \cdot \frac{F}{(1+F)} \cdot Q_e \cdot \frac{P}{R \cdot T_e} \cdot Pm \cdot PCI}{\eta_t^m \cdot \frac{F^m}{(1+F^m)} \cdot Q_e^m \cdot \frac{P}{R \cdot T_e^m} \cdot Pm^m \cdot PCI} \quad (9)$$

Where super index ^{m} means that variables are evaluated at rated power conditions.

To simplify, some suppositions are needed. First of all, an indicated efficiency constant all over the working modes is assumed. This is not true but in order to keep simplicity this supposition is adopted. Another simplification is that terms $1+F$ and $1+F^m$ are similar because the highest value F can reach is 0,0705. The last simplification is that Pm_e is constant, although it depends of fuel-air ratio, actually it does not change quite a lot. Then the load factor can be expressed as in equation 10.

$$f = \frac{F \cdot Q_e \cdot T_e^m}{F^m \cdot Q_e^m \cdot T_e} = \frac{Fr \cdot Q_e \cdot T_e^m}{Fr^m \cdot Q_e^m \cdot T_e} \quad (10)$$

The values of the parameters at the engine rated power can be obtained from the engine operating characteristics provided by the engine manufacturer and can be checked or adjusted in the tests.

The emission factor calculation is a consequence of emission measurement and the load factor determination. If we consider the equation 1 evaluated for a single equipment or vehicle and considering the emissions per unit of time, we can measure its pollutant emissions and calculate its load factor and then deduce the emission factor for each pollutant gas as equations 11 and 12 explain.

$$\dot{E} = P_n \cdot f \cdot e \quad (11) \qquad e = \frac{\dot{E}}{P_n \cdot f} \quad (12)$$

Note that in this case P_n is the gross rated power, i.e., the rated power plus the mechanical losses power.

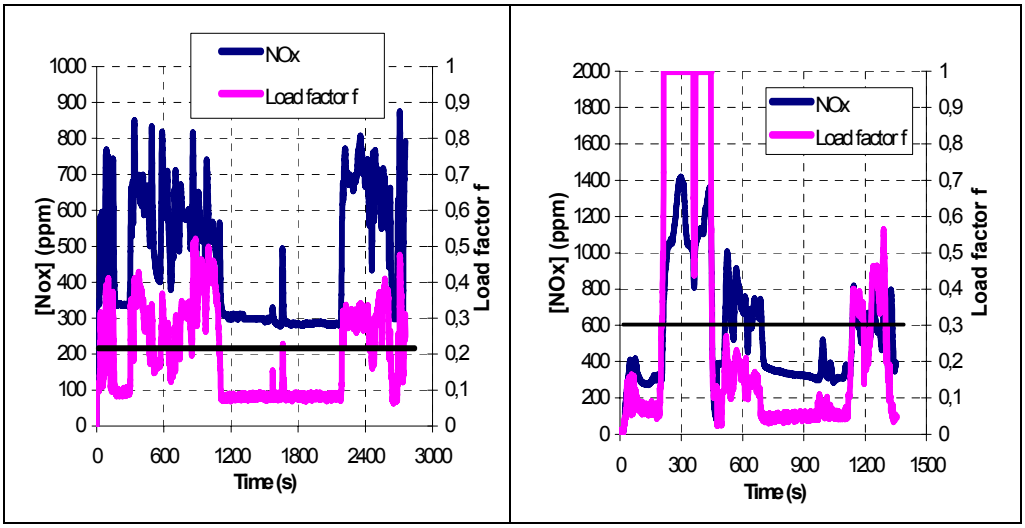
Results and discussion

In figure 2 we can observe a typical operating cycle of an auxiliary truck, carrying suitcases, and a cycle of heavy load, the maximum admissible (14000 kg). It can be stated that the mean load factor is quite low, even the heavy

loaded cycle has a mean load factor not bigger than 30%. We can also observe that in idle the load factor is not zero (a stable zone for *f* and [NO_x]). That is consequence because of the new definition, and that amount of load factor is used for the mechanical looses, so a typical idle load factor is about 7 to 10%. Although with heavy loads the load factor some times reaches the maximum 100% and quite often it is around a 50% the amount of time the engine expends at idle reduces it to a 30%. When we compare this heavy cycle with the normal one we observe that a stable load factor is around a 60-70%, which is still been very high, but the mean load factor is about 20%. And those man load factors are not quite bigger than the idle one.

In the graphics of figure 2 the NO_x concentration evolution has been displayed because of the importance of this pollutant for diesel engines. The other pollutants can't be well characterized with the portable analyzer. The NO_x concentrations are almost proportional to load factor, which is coherent because the engines have no EGR or any other pollutant control mean. It can be observed that at idle the concentration is about 300 ppm, what is still being important.

Figure 2: Evolution of load factor and NO_x concentration for two cases. On the left, it is shown a typical cycle of the auxiliary truck. On the right, it is shown a full loaded cycle (14000kg) of the auxiliary truck. The mean load factor is represented by the straight horizontal line in the graphics.



In table 1 the results for all the GSE are studied. Load factor has not been measured for the equipment working in stationary, but the results for the auxiliary truck and the bus permit to estimate it for the rest of the equipment. Even tough the cycles have not been measured, all the pollutant emissions have been measured correctly, so in this time the incertitude resides in load factor.

For those engines for which there are certificated emission factor values results are quite close. In general NO_x emission factors are a little bit smaller

than those certificated and CO and HC emission factors are higher. Notice that certification mean load factor is 56%, while in our cases it is not bigger than 30% for engines working in multiple modes.

Conclusion

It has been demonstrated that with this new definition of the load factor its value is between 10% at idle value and a value that depends of the mode of operation of the engine in other operation modes. This value can be stabilised as a maximum of 30% for engines with working periods at idle, considering 20% as the most appropriated value. When the engine is operated always in load mode, without idle mode except start and stop operations, the load factor depends on the relation between the engine characteristics and the work to be done.

This new definition of the load factor is better suited to characterize the operation mode of HDE, above all if they operate at idle at any time, keeping the homologation emission factors correct for fleet emission assessment. This way on board measurements leads to a more accurate estimation of load and emission factors.

It should be considered that this is a simple approximation for pollutant emissions estimations and that emissions are a function of load factor.

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PAHs in aircraft emissions: problem or tool ?

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Abstract

Pollution issues by air vehicles are generally related to exhausts gases emissions and formation of soot and solid particles in the higher atmosphere or to local critical situations (airports). As some pre-flight operations, such as engine tests, taxing and take-off, are carried out at ground level, they deserve a deeper environmental evaluation, also for workers health protection.

This study addresses the characterization of particulate matter produced by military gas-turbine engine aircraft during engine tests in ground operation. In particular, PAHs content from PM_{10} samples was quantified by GC-MS-SIM analysis. The PM_{10} samplings were carried out inside the emission cone behind the aircrafts and in the engineer workers area. PAHs in PM_{10} samples were chosen to evaluate their influence on air quality during aircraft engine test. Moreover PAHs content was correlated with aircraft engine temperature to find a diagnostic relationship for combustion quality. PAHs content detected in the cone emission of aircrafts lies in the range 15 - 70 ng/m^3, while in the engineer workers area it was found to be 8 - 20 ng/m^3.

Benzo(a)Pyrene and Benzo(g,h,i)Perylene concentrations were found to be correlated with the temperature of aircraft gas-turbine engine, allowing this test to be considered as a tool to evaluate the quality of combustion.

Keys-words: *PM_{10}, PAH, Aircraft, gas-turbine engine*

Introduction

Combustion processes of engines have been historically addressed to optimise fuel features. Chemical properties (aromatics, sulphur and hydrogen contents), physical properties (density and distillation curve) and technological properties (thermal stability and smoke point) have been correlated with fuel

performances as net heat value and issues as soot formation and radiant heat transfer propensity (1-4).

The combustion processes research also concern their effects on human health: many studies were addressed to the composition and quantification of exhausts gases produced by internal combustion and gas-turbine engines (5-7). An important aspect of atmospheric pollution is the particulate matter emission by anthropogenic sources (8), focusing the attention to the fraction with average aerodynamic diameter < 10 μm, generally indicated as PM_{10}, due to its harmfulness for human health involving the respiratory apparatus and lungs (9).

The effects of combustion processes on human health and environment were also featured by measuring specific analytes such as PAHs (10), well known for their toxicological properties. Pollutants produced by human activity are often linked with emissions of vehicles (11), industrial or disposal plants as incinerators, while there is not sufficient attention about the contribution of air traffic as it is often considered less significant than ground pollution being the emission at altitude up to 9000 m (12). Nonetheless, some pre-flight operations, such as engine tests, taxing and take-off, are carried out at ground level and therefore deserve a deeper environmental evaluation.

This work is featured by two different aims: the first is the health protection of workers operating in the aircraft engine tests area. It was carried out by characterizing aircraft PM_{10} in terms of morphology, composition and PAHs content. The second one is to find a diagnostic relationship for combustion quality of aircraft engine by PAHs emission.

The study is centred on the emissions of three different military aircrafts during 25 engine tests carried out at Test Flight Centre - Pratica di Mare Air Force Base. PM_{10} was sampled inside the emission cone behind the aircrafts and in the engineer workers area with an inertial impact based sampler. Morphology and composition of particles were carried out by SEM-EDS analysis. PAHs content of PM_{10} and aircraft fuel samples was carried out by GC-MS. PAHs content detected in the cone emission of aircrafts lies in the range 15 - 70 ng/m^3 , while in the engineer workers area it was found to be 8 - 20 ng/m^3. Benzo(a)Pyrene and Benzo(g,h,i)Perylene concentrations were found to be correlated with the maximum temperature of aircraft gas-turbine engine, allowing this test to be considered as a tool to evaluate the quality of combustion.

Materials and methods

Military aircrafts equipped with different gas turbine engines were involved in this study. PM_{10} sampling was carried out with high-volume samplers by Sierra-Andersen (TCR Tecora), with a fixed sampling flux of 1,13 Nm^3/min. PM_{10} was collected on specific PM_{10} filters based on 20 cm x 25 cm glass-fiber sheets at the operative conditions described in table 1. Filters have been conditioned at 450° C for 8 hours before use. After sampling operations, filters have been

stored at -18°C until extraction. Perdeuterated-PAHs standard solutions were added as recovery standards for PAHs quantification.

Table 1: Operative test conditions

	Aermacchi MB-339	**Panavia Tornado**	**AM-X**
Engine type	Rolls-Royce Viper 680	2 x Turbo-Union RB-19934R Mk 103	Rolls-Royce SpeyRB 168-807
Engine tests	9	4	12
Sampler distance	20 - 26 m	50 - 80 m	20 - 26 m
Test duration	20 - 80 min	40 - 45 min	20 - 160 min
Fuel consumption	3 - 35 Kg/min	13 - 15 Kg/min	3 - 15 Kg/min
Air volume sampled	11 - 90 m^3	43 - 50 m^3	22 - 186 m^3

PAHs extraction from PM_{10} filters was performed with an high pressure extractor DIONEX ASE 200. After extraction, samples have been fractionated on 23 x 0,8 cm glass column filled with 3g of SiO_2 70/230 mesh and eluted first with 15 mL of n-Hexane and then with 20 mL of n-Hexane/CH_2Cl_2 (1:1) to obtain the aromatic and PAHs fraction. Volume reduction to 500 μL of the aromatic and PAHs fraction has been carried out before GC-MS analysis. Fuel samples have been diluted with n-Hexane before GC-MS analysis. PAHs determination was carried out with a Thermo TRACE GC-MS apparatus. Separation was carried out on a DB-5ms fused-silica capillary column (J & W Scientific, Folsom, CA, USA), 60 m x 0.25 mm and 0,25 μm film thickness. Chromatographic conditions are described in table 2. Solvents and reagents were for residue analysis grade. Morphology and composition of PM_{10} was determined with a SEM (JEOL) and an EDS analyzer (Oxford).

Table 2: Chromatographic conditions for PAHs analysis on PM_{10} samples

Gas carrier, Carrier flow	He 55, 1 ml/min
Injector Program	PTV from 80°C to 280 °C
Injection Volume	1 μL
Injection type	Splitless and Split 1/50 after 1 min
Programmed temperature	Initial temperature: 60 °C x 2 min 1st step: 30 °C/min to 160 °C x 1 min 2nd step: 4 °C/min to320 °C x 10 min

Results and Discussion

1. PM_{10} morphology and composition

The PM10 particles morphology is featured by laminated and irregular shape. Composition by EDS analysis is mainly Silicon, due to silicate compounds. Carbonaceus particles due to soot formation were not observed.

2. PAHs determination

The PAHs analysis was carried out on the compounds described in table 3. PAHs content of PM_{10} sampled before and during engine tests are reported in figure 1. PAHs was also measured in aircraft fuel samples (kerosene type grade JP-8, NATO Code F-34)

Table 3: PAHs: physical properties and IARC toxicological evaluation

	Name	IARC		Name	IARC
NA	Naphthalene	3	**BaAN**	Benzo(a)anthracene	2A
ACL	Acenaphtylene	3	**CHR**	Chrysene	3
AC	Acenaphtene	3	**BbFA**	Benzo(b)fluoranthene	2B
FL	Fluorene	3	**BkFA**	Benzo(k)fluoranthene	3
PHE	Phenanthrene	3	**BaP**	B(a)pyrene	2A
AN	Anthracene	3	**IP**	Indenopyrene	2B
FA	Fluoranthene	3	**DBahA**	Dibenzo(ah)anthracene	2A
PY	Pyrene	3	**BghiP**	Benzo(ghi)perylene	3

Discussion

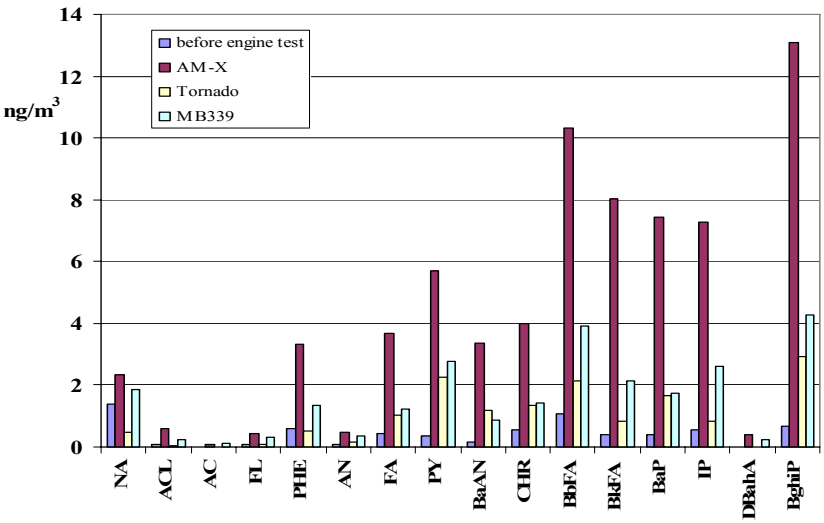
The absence of soot and carbonaceus residues in the PM_{10} composition is indicative of a clean combustion process although more information could be obtained with the insertion of a metallic/ceramic particles collector in the engine (13).

The concentration of PAHs in fuel samples is mainly featured by low boiling point PAHs as naphthalene, alkyl-naphthalenes. The high boiling point PAHs were not detected, according to the limit of 300 °C fixed by the present directives for the final distillation point of aviation turbine fuel grade JP-8.

The concentration of PAHs in the workers area before engine tests is quite low. In particular two different parameters were used as monitor of air quality in environmental evaluation of human activity: total PAHs was 7 ng/m^3 and Benzo(a)Pyrene was 0,4 ng/m^3. These concentrations are typical of a rural

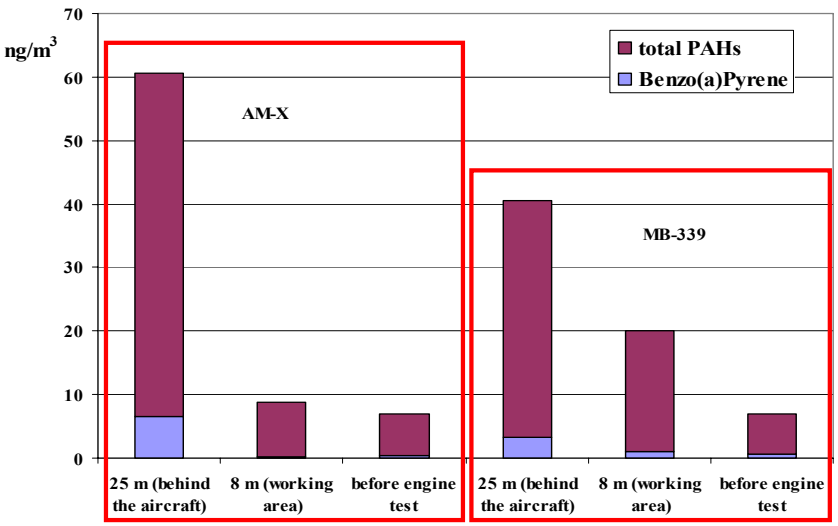
area. The distribution of PAHs species is mainly characterized by low molecular weight PAH such as Naphthalene.

Figure 1: PAHs distribution after engine tests



PAHs levels in the workers area during aircraft ground tests is related to the different type of engines and their different configuration. In particular, a comparison carried out during the same engine test for AM-X and Aermacchi MB-339 aircrafts is shown in figure 2.

Figure 2: PAHs from PM_{10} sampled in the working area. Comparison for AM-X and Aermacchi MB-339.



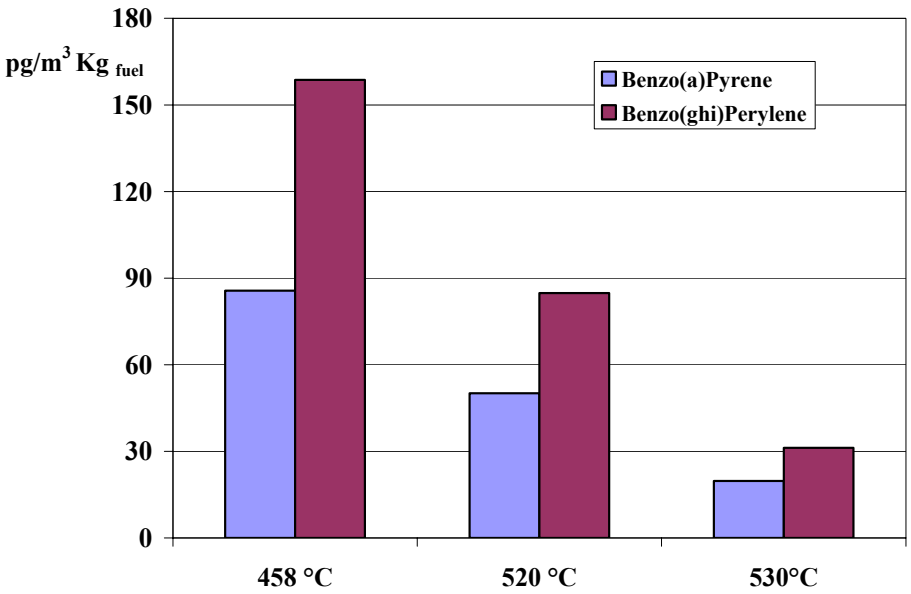
The distributions of PAHs species found during engine tests is mainly characterized by Benzo(g,h,i)Perylene, Benzo(b)Fluoranthene and Benzo(k)Fluoranthene.

The PAHs determination during engine tests was carried out with different positions of samplers to evaluate the distributions of PAHs in the emission cone behind the aircrafts. There is a significant decrease of total PAHs within 30 m from the emissions source. Due to the high flow rate of emission, distribution of PM_{10} in the sampled area is not influenced by rate and direction of wind.

The average concentration of total PAHs in the different conditions in the emission cone of the aircrafts during engine tests was 46 ng/m^3 while Benzo(a)Pyrene was 5 ng/m^3. This value is comparable with a polluted urban area.

PAHs presence is indicative of an incomplete combustion process. A diagnostic evaluation of the efficiency of the engine combustion was performed during AM-X engine test by measuring high boiling point PAHs Benzo(g,h,i)Perylene and Benzo(a)Pyrene, in three different engine conditions. The results have been normalized for fuel consumption. They feature a decreasing concentration of Benzo(g,h,i)Perylene and Benzo(a)Pyrene with maximum temperature of the engine as shown in figure 3. In this way PAHs concentration could be used to compare different engines setup operating at similar maximum temperatures.

Figure 3: Correlation with Engine T_{max}



Conclusion

Particulate matter PM_{10} produced by military gas-turbine engine aircraft emissions during engine tests in ground operation has been evaluated for morphology and composition. The engine tests have been carried out at Pratica di Mare Air Force Base, Italy on three different aircrafts (MB-339, Panavia Tornado and AM-X) equipped with different gas-turbine engines. In particular the PAHs content of PM_{10} samples have been determined. A comparison with PAHs concentration of fuel samples have been made to identify the influence of fuel composition on PAHs emissions.

PAHs levels before the engine tests are in the same order of magnitude of a rural area.

PAHs content detected in the cone emission of aircrafts was 46 ng/m^3 and lays in the range 15 - 70 ng/m^3, while in the engineer workers area it was found to be 8 - 20 ng/m^3.

PAHs in fuel samples are mainly represented by low boiling point compounds such as naphthalene and alkyl-naphthalenes with concentration within the specification limit and in the range of 0,2 % (v/v).

Benzo(a)Pyrene and Benzo(g,h,i)Perylene concentrations normalized for fuel consumption were found to be correlated with the maximum temperature of aircraft gas-turbine engine, allowing this to be considered as a tool to evaluate the quality of combustion.

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Experimental verification of the variation of aircraft exhausts composition in dependence from ambient and other conditions

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Abstract

The emission indices of aircraft engine exhausts must be known to calculate precisely the emissions of aircraft on airports during different operational scenarios. Non-intrusive optical measurements by FTIR spectrometry of CO_2-, CO- and NO-mixing ratios were performed as basis to calculate the emission indices of these gases. Measurement campaigns with in-service aircraft operated nearby the gates are reported. The accuracy of the measurement method is in the order of ±10 up to ±20 %. The results of a summer and winter measurement campaign at Vienna airport are given: emission indices of main exhaust compounds during an extra stop of the aircraft at idle thrust of the main engines.

Keys-words*: remote sensing, FTIR, aircraft exhaust emissions.*

Introduction

The variations of the emission indices of in-service aircraft engines are not available up to now from measurements during operational conditions. Emission indices for NO_x and CO are listed for each engine in a data base of the International Civil Aviation Organisation (ICAO) for four different thrust levels (taxi or idle, landing, cruise and take-off, i.e. 7, 30, 85 and 100 % maximum thrust or power setting) from certification measurements (ICAO, 1993). Only these data can be used to develop airport emission inventories.

Non-intrusive measurement methods, e.g. Fourier-Transform-Infrared (FTIR) emission spectrometry, are suitable for this task and used in our study. Several gases can be determined simultaneously by a single measurement in a passive mode. No installations nearby or behind the aircraft are necessary, so that the routine operations at the airport are not disturbed.

Field studies were conducted at Vienna airport. A fruitful co-operation with AUA as well as the airport authorities supported this work.

Objectives

The emissions of the main engines of different types at the ground were investigated during idle thrust level at different ambient conditions.

Methods

Fourier-Transform-Infrared(FTIR) emission spectrometry as a passive method was used. FTIR spectrometry is based on the physical effect that many trace gases in ambient air and exhausts absorb or emit radiation in the infrared spectral range. In this passive measurement mode the infrared radiation from hot exhaust gases in a distance of about 50 m is detected. The field of view of the spectrometer K300 with telescope which is installed in a van is orientated to the exhaust plume behind the turbine nozzle exit (if possible in a perpendicular position, see Figure 1). The hot molecules (CO, CO_2, NO) emit infrared radiation at specific wavelengths and show characteristic signatures. The concentrations of the emitting species are obtained from the measured spectra by the PC software Multicomponent Air Pollution Software (MAPS) of IMK-IFU (Haus et al., 1994; Heland and Schäfer, 1997; Schäfer et al. 2000; Schäfer et al., 2004).

Table 1: Measured emission indices including standard deviations of main engines of different aircrafts and mean fuel flow for the summer campaign (bdl: below detection limit, i.e. a signature in the measured spectra cannot be inverted; minimum and maximum values of all measured data are given in brackets; No.: number of measured aircraft). The corresponding ICAO data are also given.

Aircraft	No.	Engine type	N1 [%]	Fuel Flow [kg/h]	EI CO [g/kg]	EI NO [g/kg]	EI NOx [g/kg]
A320-214	**8**	**CFM56-5B4/2P**	**Idle**	**392.8 ± 15.4 ICAO: 432**	**50.8 ± 12.4 (21.3 - 72.6) ICAO: 40.10**	**0.6 ± 0.18 (bdl - 0.8)**	**0.9 ± 0.28 (bdl - 1.2) ICAO: 3.90**

A321-111	3	CFM56-5B1	Idle	428.0 ± 50 ICAO: 421.2	49.9 ± 12.40 (23.0 - 71.9) ICAO: 28.40	0.6 ± 0.18 (0.5 - 0.7)	0.9 ± 0.28 (0.7 - 1.1) ICAO: 4.60
A321-211	2	CFM56-5B3/P	Idle	380.0 ICAO: 414	55.7 ± 5.95 (50.7 - 63.9) ICAO: 19.20	0.5 ± 0.32 (bdl - 0.7)	0.7 ± 0.49 (bdl - 1.0) ICAO: 4.70
A340-211	1	CFM56-5C2	Idle	Not ICAO: 423	6.0 ICAO: 34.00	bdl	bdl ICAO: 4.19
B737-300	1	CFM56-3C1	Idle	Not ICAO: 446.4	29.8 ± 8.85 (19.9 - 37.1) ICAO: 26.80	1.4 ± 0.16 (1.2 - 1.5)	2.1 ± 0.24 (1.9 - 2.3) ICAO: 4.30
B737-600	1	CFM56-7B22/2	Idle	Not ICAO: 378	59.6 ± 19.47 (45.9 - 73.4) ICAO:	0.9 ± 0.37 (0.6 - 1.1)	1.4 ± 0.56 (1.0 - 1.8) ICAO:

					45.35		3.94
B737-800	1	CFM56-7B27	Idle	Not ICAO: 417.6	25.7 ± 8.29 (17.3 - 33.8) ICAO: 17.90	0.7 ± 0.23 (0.4 - 0.9)	1.0 ± 0.35 (0.7 - 1.4) ICAO: 4.80
MD-87	1	JT8D-217C	Idle	500.0 ± 0 ICAO: 493.2	10.3 ± 1.26 (9.4 - 11.2) ICAO: 17.89	bdl	bdl ICAO: 4.05
Fokker 70	10	RR-Tay MK 620	Idle	309.0 ± 9 ICAO: 396.0	23.1 ± 7.32 (11.5 - 46.7) ICAO: 24.10	0.2 ± 0.63 (bdl - 2.6)	0.3 ± 0.96 (bdl - 4.0) ICAO: 2.50
CRJ 100LR	3	GE CF 34-3A1	Idle	Not ICAO: 178.6	37.3 ± 4.99 (31.0 - 46.6) ICAO: 42.60	0.6 ± 0.09 (0.5 - 0.8)	1.0 ± 0.14 (0.8 - 1.2) ICAO: 3.82
CRJ 200LR	8	GE CF 34-3B	Idle	182.0 ± 3	38.9 ± 11.75	0.7 ± 0.09	1.0 ± 0.13

				ICAO: 176	(10.2 - 57.3) ICAO: 47.60	(0.5 - 0.9)	(0.8 - 1.4) ICAO: 3.72
DHC-8-300Q	8	PW 123B	Idle	301.0 ± 37	9.5 ± 6.63 (2.2 - 27.0)	1.1 ± 2.32 (bdl - 9.5)	1.7 ± 3.55 (bdl - 14.5)
DHC-8-400Q	5	PW 150A	Idle	370.0 ± 0	8.3 ± 3.84 (3.3 - 17.0)	0.6 ± 0.39 (bdl - 1.4)	0.8 ± 0.59 (bdl - 2.2)

The required minimum measurement time of these spectroscopic measurements is about 2 minutes.

After the determination of the gas concentrations from the spectra by the passive measurements the average emission index *EI* of a molecule *X* in g/kg is calculated which is defined by

$$EI(X) = EI(CO_2) \times \frac{M(X)}{M(CO_2)} \times \frac{Q(X)}{Q(CO_2)} \qquad (1)$$

where *M* denotes the molecular weights, and *Q* the concentrations (mixing ratios, column densities etc.) of the species. The theoretical emission index of CO_2 was calculated from stoichiometric combustion of kerosene to be 3159 g/kg. Because EI (NO_x = NO and NO_2) is related to the mass of NO_2 this emission index is calculated from measured NO concentrations as EI (NO) x 46/30. In this case EI (NO_x = NO and NO_2) is a minimum i.e. there is no NO_2 emission. If there are measured NO_2 concentrations the EI (NO and NO_2) is the sum of EI (NO) x 46/30 and EI (NO_2).

The measurement campaigns were performed at the airport Vienna-Schwechat at a taxi way from 09 until 13 July 2001 and from 02 until 07 March 2005, i.e. under summer and winter conditions. All results of the summer campaign are published (Schäfer et al., 2003).

Table 2: Measured emission indices including standard deviation of main engines of different aircraft and mean fuel flow for the winter campaign (bdl: below detection limit, i.e. a signature in the measured spectra cannot be inverted; minimum and maximum values of all measured data are given in brackets; No.: number of measured aircraft). The corresponding ICAO data are also given.

Aircraft	No.	Engine type	N1 [%]	Fuel Flow [kg/h]	EI CO [g/kg]	EI NO [g/kg]	EI NOx [g/kg]
A320-214	5	CFM56-5B4/2P	Idle	416.7 ± 45.1 ICAO: 432	39.5 ± 17.93 (8.55 – 54.60) ICAO: 40.10	bdl	bdl ICAO: 3.90
A321-211	1	CFM56-5B3/P	Idle	370 ICAO: 414	19.38 ICAO: 19.20	bdl	bdl ICAO: 4.70
A330	1	PW4168 A	Idle	Not ICAO: 796	39.91 ICAO: 23.51	bdl	bdl ICAO: 4.15
B737-600	1	CFM56-7B22/2	Idle	Not ICAO: 378	13.25 ICAO: 45.35	bdl	bdl ICAO: 3.94
Fokker 70	2	RR-Tay MK 620	Idle	350 ICAO: 396.0	42.2 ± 3.17 (38.9 – 45.3) ICAO: 24.10	bdl	bdl ICAO: 2.50
CRJ 100LR	3	GE CF 34-3A1	Idle	Not ICAO: 178.6	49.8 ± 7.91 (38.0 - 57.3) ICAO: 42.60	bdl	bdl ICAO: 3.82

CRJ 200LR	11	GE CF 34-3B	Idle	Not ICAO: 176.0	50.7 ± 16.03 (27.4 – 90.2) ICAO: 47.60	bdl	bdl ICAO: 3.72
DHC-8-300Q	8	PW 123B	Idle	Not	19.4 ± 8.95 (9.3 – 36.2)	bdl	bdl
DHC-8-400Q	7	PW 150A	Idle	330	18.0 ± 3.39 (12.8 – 21.6)	bdl	bdl

Results

The measured emission indices of main engines of different aircrafts are listed in Table 1 for the summer campaign and in Table 2 for the winter campaign. The mean air temperature was about 22°C (16 – 28°C) during the summer campaign and about -2 °C (-4 – -1°C) during the winter campaign. Under idle conditions, which were about 23 % N1 (20 up to 27 % N1), CO emission indices were different among the engine types compared to ICAO data. Here N1 is the revolution of turbofan which is the only parameter for monitoring engine power aboard the aircraft. During winter conditions the measured values are higher than the ICAO data (out of the CFM56-7B22/2 which was measured once only) but during summer conditions there is no general tendency. On the other hand, the measured NO_x emission indices (for the summer campaign only) are always much lower than reported by ICAO.

Comparisons between summer and winter conditions are possible for the following engines: CFM56-5B4/2P, CFM56-5B3/P, CFM56-7B22/2, RR-TAY MK 620, GE CF 34-3A1, GE CF 34-3B, PW 123B und PW 150A (see Table 3). Compared to summer conditions lower CO emissions are found under winter conditions for the larger engines. The opposite is the case for the smaller engines RR-TAY MK 620, GE CF 34-3A1, GE CF 34-3B, PW 123B und PW 150A.

Table 3: Measured emission indices at idle conditions including standard deviation of main engines of different aircraft and mean fuel flow for the summer and winter campaign (bdl: below detection limit, i.e. a signature in the measured spectra cannot be inverted; minimum and maximum values of all measured data are given in brackets; No.: number of measured aircraft). The corresponding ICAO data are also given.

Aircraft	Engine type	Winter		Summer	
		EI CO [g/kg]	EI NOx [g/kg]	EI CO [g/kg]	EI NOx [g/kg]
A320-214	CFM56-5B4/2P	39.5 ± 17.93 (8.55 – 54.60) ICAO: 40.10	bdl ICAO: 3.90	50.8 ± 12.4 (21.3 - 72.6) ICAO: 40.10	0.9 ± 0.28 (bdl - 1.2) ICAO: 3.90
A321-211	CFM56-5B3/P	19.38 ICAO: 19.20	bdl ICAO: 4.70	55.7 ± 5.95 (50.7 - 63.9) ICAO: 19.20	0.7 ± 0.49 (bdl - 1.0) ICAO: 4.70
B737-600	CFM56-7B22/2	13.25 ICAO: 45.35	bdl ICAO: 3.94	59.6 ± 19.47 (45.9 - 73.4) ICAO: 45.35	1.4 ± 0.56 (1.0 - 1.8) ICAO: 3.94
Fokker 70	RR-Tay MK 620	42.2 ± 3.17 (38.9 – 45.3) ICAO: 24.10	bdl ICAO: 2.50	23.1 ± 7.32 (11.5 - 46.7) ICAO: 24.10	0.3 ± 0.96 (bdl - 4.0) ICAO: 2.50
CRJ 100LR	GE CF 34-3A1	49.8 ± 7.91 (38.0 - 57.3) ICAO: 42.60	bdl ICAO: 3.82	37.3 ± 4.99 (31.0 - 46.6) ICAO: 42.60	1.0 ± 0.14 (0.8 - 1.2) ICAO: 3.82

CRJ 200LR	GE CF 34-3B	50.7 ± 16.03 (27.4 – 90.2) ICAO: 47.60	bdl ICAO: 3.72	38.9 ± 11.75 (10.2 - 57.3) ICAO: 47.60	1.0 ± 0.13 (0.8 - 1.4) ICAO: 3.72
DHC-8-300Q	PW 123B	19.4 ± 8.95 (9.3 – 36.2)	bdl	9.5 ± 6.63 (2.2 - 27.0)	1.7 ± 3.55 (bdl - 14.5)
DHC-8-400Q	PW 150A	18.0 ± 3.39 (12.8 – 21.6)	bdl	8.3 ± 3.84 (3.3 - 17.0)	0.8 ± 0.59 (bdl - 2.2)

Conclusions

The variations in dependence from weather conditions are not of a unique tendency but differ from engine type to engine type.

Measured NO_x emission indices are lower than reported by ICAO from certification measurements. This reflects the results of the strong efforts made by airlines to reduce NO_x aircraft emissions. Still, there is a large variance of emission indices for each engine type under idle conditions.

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ABC Impacts – Aviation and the Belgian Climate Policy : Analysis of Integration Options and Impacts

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Abstract

The ABC impacts project aims at providing Belgian decision-makers and stakeholders with a detailed and integrated analysis of issues related to the integration of international air and maritime transport into European and international climate policy. The analysis of the different inclusion options is of particular interest for Belgium, given the importance of these sectors in its economy and the intensity of air traffic over the country. In this context, the ABC impacts project intends to analyse these options (as well as their consequences) and to provide an in-depth study of the technical, economic and environmental characteristics of the aviation sector. The project will also draw a comparison with the international maritime transport. A synthesis report based on a multi-criteria analysis (political, technical, socio-economic and environmental viewpoints) will be delivered to compare options for integrating international air and maritime transport into climate policy.

Keys-words*: aviation, greenhouse gas emissions, climate policy, climate impacts, international maritime transport.*

Résumé

Le projet ABC impacts a pour objectif de fournir aux décideurs politiques et aux acteurs belges une analyse détaillée et intégrée des enjeux de l'intégration du transport international aérien et maritime dans la politique climatique européenne et internationale. L'analyse des différentes options d'inclusion revêt un intérêt particulier pour la Belgique étant donné l'importance économique de ces secteurs et la concentration spatiale du trafic aérien au-dessus du pays. Dans ce contexte, le projet ABC impacts propose d'analyser ces options (et

leurs conséquences) et d'étudier en profondeur les caractéristiques du secteur de l'aviation sur les plans technique, économique et environnemental. Lorsque cela s'avèrera pertinent, le projet effectuera un parallèle avec le transport maritime international. Une synthèse basée sur une analyse multicritères (aspects politique, technique, socio-économique et environnemental) sera fournie afin de comparer les options d'intégration du transport international aérien et maritime dans la politique climatique.

Mots-clefs : *aviation, émissions de gaz à effet de serre, politique climatique, conséquences climatiques, transport maritime international.*

Introduction

Emissions from international air and maritime transport are currently not covered by the Kyoto Protocol commitments, nor by the EU-ETS, though they have been growing considerably for more than 10 years (e.g.: EEA, 2004). However, the inclusion of these sectors into emission reduction policies is increasingly considered, both within the European Union (the aviation sector should be included in the EU-ETS by 2013 at the latest (EU, 1999)) and in the context of the United Nations Framework Convention on Climate Change. It is thus a major issue in defining post-2012 climate policy at both the European and international levels. Different options for including international air (e.g.: Wit et al., 2005) and maritime transport are thus to be considered, and their analysis is particularly relevant for Belgium given the importance of those sectors in the national economy.

At the international level, several studies are currently being performed concerning the environmental, and particularly the climate-related impacts of aviation and other international transport (e.g.: TRADEOFF, QUANTIFY, etc.). At the Belgian level, current emphasis seems to be put on maritime transport (e.g.: MOPSEA and ECOSONOS projects). However, international studies (e.g.: Sausen, 2005) show, among other things, that the climate-related impacts of aviation, as compared to other international transport, are much more complex and extensive, especially if we take into account the rapid growth of this sector and the non-CO_2 related climatic effects (e.g.: the effects of condensation trails, ozone impacts, etc.). Another conclusion, taken more specifically from the IPCC special report on aviation, indicates that the radiative forcing caused by condensation trails is particularly important over the Belgian territory and around (IPCC, 1999).

Objectives

The Aviation and the Belgian Climate Policy: Analysis of Integration Options and Impacts (ABC impacts) project is part of the "Science for sustainable development" national research programme. This research project serves two main objectives:

- to inform political decision-makers about the environmental, political and socio-economic implications for Belgium of integrating (or not) the

international aviation and maritime transport sectors into climate policy;

- to provide a tool for the preparation and assessment of Belgian climate policy, on the eve of the negotiations concerning the expansion of the European Emission Trading Scheme (EU-ETS) and the post-2012 phase of the Kyoto Protocol.

A multi-criteria analysis will allow our findings on aviation and Belgian climate policy to integrate other issues of concern – such as the other environmental impacts related to air and maritime transport (cf. NO_x, SO_x and PM emissions, etc.), the socio-economic impact of different policies (climate-related or not) on the given sector, etc. It will also allow us to consider the viewpoint of different groups of stakeholders (political agents, airlines, transportation users, etc.).

Description of the project

The two successive phases of the ABC impacts project will result in a new, in-depth analysis of the aviation sector and climate policy options from a technical, environmental and an economic viewpoint, compared to other international transport modes (see Fig. 1).

More specifically, the project's first phase (2006-2007) will include the following work packages:

A state-of-the-art that will summarise available data and knowledge concerning maritime (a.o. the Belgian ECOSONOS and MOPSEA projects) and other transport mode sectors, climate policies (e.g.: GHGs covered, allocation methodologies, etc.) and emission inventory methodologies ;

The design of scenarios describing the probable evolution of the aviation sector by means of a market analysis and traffic projections ;

The identification and assessment of available technologies (current and future) for aircraft propulsion as well as different air routes and possible flight options ;

An evaluation of the emissions from international air transport transiting through Belgium (and the European Union) as well as a comparison with the emissions from other modes of transportation ;

A comparison of the climate-related impacts of emissions from the aviation sector and the impacts of the greenhouse gases concerned by the Kyoto Protocol as well as an assessment of various methods for the spatial and temporal aggregation of climate-related impacts using existing climate models like JCM[13] ;

[13] Initial exploration of the relative impacts of aviation emissions will be made by extending the Java Climate Model (JCM), developed by Dr Ben Matthews in UCL ASTR since 2002 (and previously in KUP Bern, UNEP-GRID Arendal and DEA-CCAT Copenhagen). The climate component of JCM is currently based on the Wigley-Raper upwelling-diffusion energy balance model, using the same parameterisation to fit GCM

An identification and assessment of the options for integrating the aviation and maritime sectors into international climate policy, including environmental and efficiency aspects, the additional charge for Belgium and the effort required from the aviation and maritime sectors as compared to other sectors ;

A multi-criteria analysis aimed at comparing various political options with respect to the priorities of civil society (e.g.: Macharis, 2003).

In the second phase of the project (after 2007), the process will be reiterated on the basis of new scenarios that will integrate:

A model of regional climate impacts, in the aim of analysing mainly the effects of cirrus cloud formation over Belgian territory: after an exploration of new methodologies and datasets and likely sensitivity to different forcings, the ASTR-UCL Regional Climate Model (RCM) MAR[14] (e.g.: Fettweis et al. 2005) will be adapted and validated for North-West European region. Then, physics of RCM will be extended for additional cirrus and ozone forcing in upper troposphere and geographical patterns of such forcing using datasets from other European projects, as well as from WP4, will be derived. After running several scenarios with differing aviation forcing and/or nested in different Global Climate Model (GCM) datasets, results will be analysed in terms of regional temperature, precipitation, sunlight and will be considered in terms of regional impacts (with input from other project partners as well as from literature).

The analysis of other potential political measures aimed at reducing environmental damage (including non-climate related ones) of air and maritime transport ;

The updating of major parameters (for instance : fuel prices and the demand for international transport), the development of potential evolution scenarios for aviation and maritime transport and an assessment of major implications for Belgium, the aviation and maritime transport sectors based on the policy options and scenario chosen.

Towards the end of its second phase, the project will deliver a synthesis report that will compare, from a political, technical, socio-economic and environmental viewpoint, the options for integrating air and maritime transport into climate policy. Finally, it will provide a series of recommendations for Belgian decision-makers, based on the multi-criteria analysis.

Expected results of the first phase (2006-2007)

results as in IPCC TAR. JCM also incorporates the Bern carbon cycle, and atmospheric chemistry and forcing for over 30 well-mixed gases. These core modules of JCM will be updated as the science evolves towards IPCC-AR4. The interactive interface of JCM will also be extended to enable stakeholders to explore the sensitivity of the global climate to different aviation policy options, and also the sensitivity of a relative "GWP" for aviation emissions to different methods of spatial/temporal aggregation and scientific uncertainties. Another interactive module will be added to compare the climate effects from different forms of transport for individual journeys, based on the results from WPs 4 and 5.

[14] Modèle Atmosphérique Régional – Regional Atmospheric Model

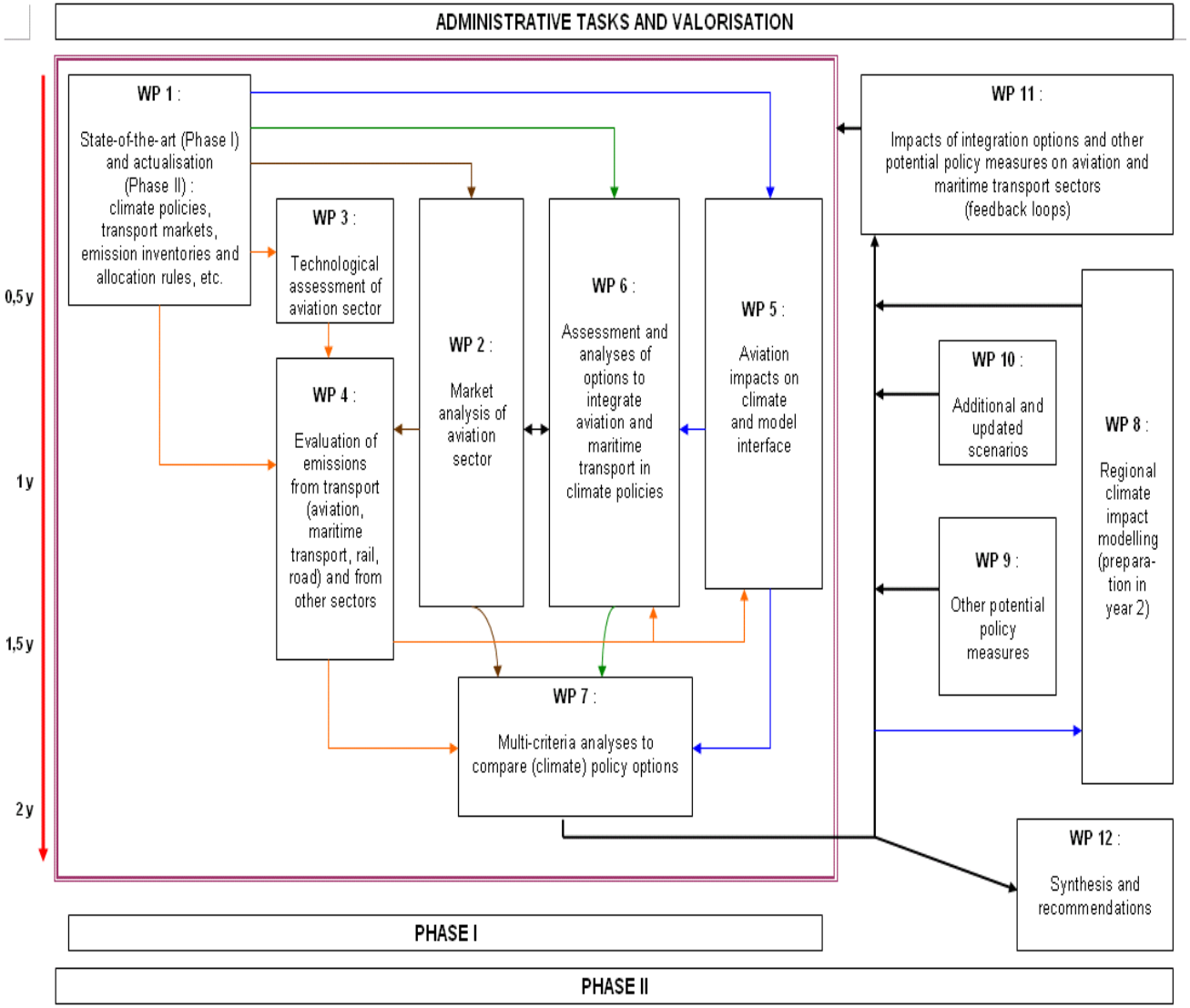
- A first aviation emission inventory (data base) adapted to the Belgian situation (cf. market analysis), compared to other transport emission inventories will be available at the end of the first phase of the project.
- A first comparison of the different emission inventory methodologies and allocation rules of climate policies or climate policy negotiations as far as transport is concerned will be available at the end of the first year of the project.

A synthesis of available methodologies and data for modelling climate impacts of aviation will be carried out for the end of the first year of the project. A simple model of impacts of aviation on global climate, and a more complex model of its impacts on regional climate will be developed respectively at the end of the second and the fourth years, respectively.

- A comparison of policy options (climate policies and other types of policy measures) based on a multi-criteria analysis including environmental, political, technical and socio-economic aspects and identification of their implications for Belgium (political decision support) will be carried out at the end of the first phase of the project. At the end of the second phase, the multi-criteria analysis will be updated and extended to new scenarios and new policy options, and feed-back loops will be analysed to assess socio-economic and environmental impacts of the scenarios studied in Belgium (e.g. impacts on aviation and maritime sectors, impacts on sectors related to international transport, etc.)
- Several scenarios concerning the evolution of aviation and maritime transport sectors in function of different parameters (policy option, growth, technological improvement, time horizon, fuel price, etc.) will be developed to assess the sector-based implications of the adoption of identified policy options (political decision support) during the second year of the project. During the third year, previous scenarios will be updated and additional scenarios taking into account i.e. policy measures other than climate related ones will be worked out.
- A clear synthesis of the main stakes for Belgium regarding the different integration options of aviation and maritime transport in the international, European and/or Belgian climate policy (political decision support) will be available by the end of the first and second phases of the project.

Figure 1: Tasks scheme of the ABC Impacts project.

Figure 1 : Schéma des tâches du projet ABC Impacts.



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Cycles d'essai de véhicules industriels
Méthodologie de construction à partir de données statistiques

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Résumé

L'optimisation des moteurs et des transmissions des véhicules industriels en vue de réduire leur consommation de gazole (et l'émission de CO_2) en usage réel nécessite des outils d'évaluation et de validation des solutions technologiques. En collaboration avec Renault-Trucks, l'INRETS a mis au point une méthode de construction de cycles d'essai des camions complets, adaptés aux calculs par simulation et aux essais sur banc à rouleau (faible durée). Ces cycles sont construits à partir des données statistiques de fonctionnement disponibles à bord des camions équipés en série du système Datamax/Infomax. Ils reproduisent avec précision les conditions de vitesses du camion et de régimes et couples du moteur, même pour des (centaines de) milliers de kilomètres d'utilisation du véhicule. La méthode a été validée par des calculs et des essais au banc sont en cours.

Mots-clefs : *camion, consommation de carburant, cycles d'essai, données statistiques, méthode.*

Abstract

Test cycles for industrial vehicles – determination method based on statistical data.

To meet the expectations of both society and the company's customers, Renault-Trucks launched an R&D program in 2001 on a truck for urban use called Project V2U, intended to develop a clean, fuel saving and quiet goods delivery vehicle. The optimisation of its components and functions must take into account the conditions under which trucks are used, especially regarding traffic conditions and power train operation.

To this end, INRETS and the Renault-Trucks Advanced Engineering and Complete Vehicle departments at Lyon studied different gas oil consumption assessment tools of trucks under real service conditions. The specifications

required minimising differences between the assessment and reality for average speed, statistical vehicle speed values, engine ratings and engine torques. After performing various analyses, a method for structuring test cycles using the statistical data on board the trucks was chosen. This was done by applying the Datamax/Infomax system which supplies time histograms. The method has many advantages, including the elimination of long and costly operations that are difficult to implement, such as instrumenting vehicles and collecting data in real time.

The results obtained conform to the specifications, i.e. the test cycles representing thousands of kilometres of operation in fact could only measure a few tens of kilometres, making it possible to perform tests on tests benches and very fast calculations.

In addition, the possibility of creating a sample representative of a large number of industrial vehicles operating for long periods of time, corresponding to millions of kilometres travelled, opens the way for establishing regulatory test cycles for measuring the gas oil consumption and the CO_2 emissions of full trucks. At present regulatory test cycles only concern the emissions of regulated pollutants from the engine alone.

Keys-words: truck, fuel consumption, test cycle, statistical data, method.

Introduction

L'optimisation des moteurs et des transmissions des véhicules industriels en vue de réduire leur consommation de gazole (et l'émission de CO_2) en usage réel nécessite des outils d'évaluation et de validation des solutions technologiques sur les camions complets. Cela pose aussi le problème du recueil des données de fonctionnement des véhicules et de leurs moteurs en conditions réelles d'exploitation.

A notre connaissance, il n'existe pas aujourd'hui de cycle d'essai d'un camion complet permettant de reproduire avec précision, sur une durée suffisamment courte (impératif pour un essai sur banc à rouleau), les conditions réelles de vitesses du camion et de régimes et de couples du moteur. Les cycles existants ne concernent que le moteur seul (cycles pour la mesure des émissions de polluants réglementés par exemple); ou bien ils ne reproduisent que la vitesse du camion [André et coll. (2000)] qui est imposée en fonction du temps, ce qui conduit à des cycles différents selon la charge du véhicule.

Objectifs

Cette recherche comprenait trois objectifs. Tout d'abord analyser différentes méthodes de construction d'un cycle en fonction des données disponibles de fonctionnement du camion, en tenant compte des aspects de difficulté, temps passé et coût du recueil des données, représentativité de ces données …

Après avoir retenu une méthode, le deuxième objectif consistait à rechercher les principes de construction adaptés à la nature des données de fonctionnement et permettant de répondre à un cahier des charges relatif à la

précision des résultats (écarts admissibles entre le cycle et la réalité). Enfin le troisième objectif était de développer et mettre au point la méthode (mise en œuvre et validation).

Recherche d'une méthode de construction de cycles

Deux méthodes utilisant des données issues d'enregistrements en continu à bord d'un camion ont été testées, les variables mesurées étant la vitesse du camion, le régime et le couple du moteur, et les pentes de la route. La première méthode a consisté à extraire une portion du parcours enregistré, la deuxième à effectuer, par le calcul, un bilan énergétique à la roue du véhicule puis de construire un cycle fictif, de forme trapézoïdale, présentant le même bilan.

L'analyse des résultats a montré que l'on peut obtenir une bonne approximation de la vitesse moyenne du camion et du régime moyen du moteur, mais que le couple moyen du moteur est éloigné de la réalité, principalement du fait des variations de la pente de la route à laquelle ce couple est très fortement sensible. Il faut aussi souligner que ces méthodes sont difficiles à mettre en œuvre : elles exigent des enregistrements à bord des véhicules qui conduisent à des coûts et à des durées élevés; et il faut aussi procéder à un relevé précis (1/10e de pourcent) des pentes de la route.

Une troisième méthode, qui va être présentée ici, a donc été étudiée. Elle utilise des données statistiques fournies par le système Datamax/Infomax développé par Renault-Trucks et qui équipe en série tous les camions, depuis le Midlum urbain (7500 kg, 110 kW) jusqu'au Magnum grand routier (40000 kg, 350 kW).

Description de la méthode des cycles combinés

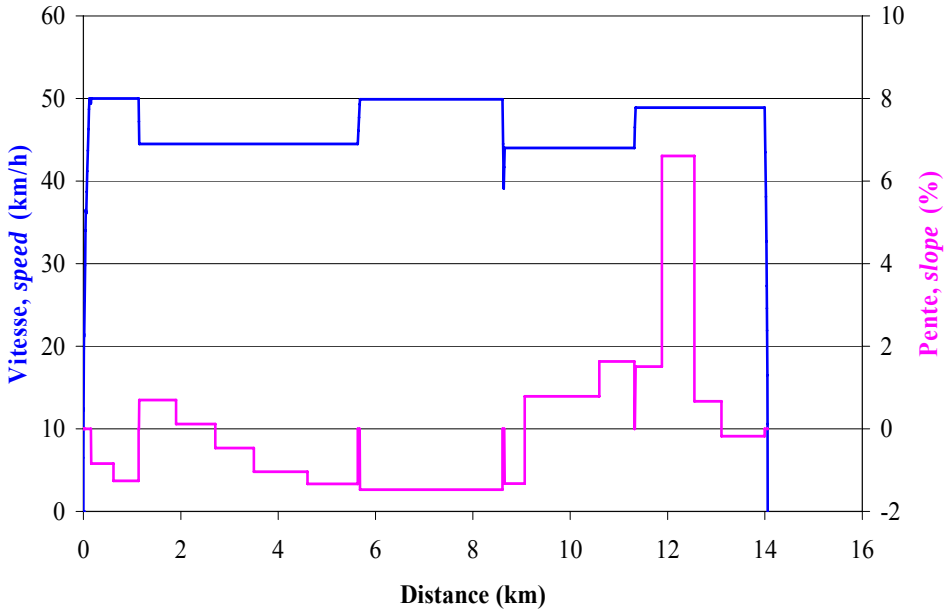
Les données de base utilisées, enregistrées par le système Datamax, sont les histogrammes temporels à deux dimensions (vitesse du camion V, régime du moteur N) et (couple du moteur C, régime du moteur N). La méthode comprend deux étapes [Roumégoux (2004)] :

construction de plusieurs cycles élémentaires reproduisant les conditions de fonctionnement des histogrammes; ces cycles sont déterminés grâce à la simulation du camion; ils comportent chacun une phase d'accélération depuis l'arrêt, plusieurs paliers à vitesses stabilisées et pentes de la route variables, et une phase de décélération jusqu'à l'arrêt (fig. 1);

recherche des combinaisons des cycles élémentaires permettant de satisfaire aux critères d'écarts maximaux entre le cycle combiné et les données Datamax; ces critères concernent la vitesse moyenne, le régime moyen et le couple moyen du moteur, et les pourcentages du temps des histogrammes à une dimension de V, N et C; les combinaisons sont constituées d'un certain nombre de répétitions de chacun des cycles élémentaires.

Figure 1 : Exemple de cycle élémentaire.

Figure 1 : An elementary cycle : vehicle speed and road slope as a function of distance.



Le cycle combiné à retenir est enfin sélectionné parmi ceux qui d'une part ont une durée minimale, d'autre part présentent les plus faibles écarts dans les histogrammes à deux dimensions.

Spécificité des cycles d'essai de véhicules industriels

A l'inverse des voitures particulières, les véhicules lourds sont très faiblement motorisés (puissance de l'ordre de 8 à 12 W/kg, soit environ le dixième de celle d'une voiture); il s'ensuit que le comportement dynamique (vitesses, accélérations) et la consommation de gazole des camions sont très sensibles à toute variation de leur poids (chargement) et des pentes de la route en particulier. Il est par conséquent exclus d'imposer la vitesse du camion en fonction du temps, comme dans le cas des voitures.

Ainsi les cycles de test utilisés aussi bien pour les calculs sur ordinateur que pour les essais sur banc à rouleau représentent-ils les vitesses à atteindre (si possible) et les pentes de la route en fonction de la distance; dans l'exemple (fig. 1) les vitesses à atteindre sont celles des paliers et les arrêts.

Mise en œuvre et validation de la méthode

Plusieurs programmes de calcul [Roumégoux (2006)] sont mis en œuvre pour appliquer les principes de cette méthode : création des cycles élémentaires par simulation du camion dans les histogrammes (logiciel

SimulVeh) à l'aide d'un écran interactif de visualisation des écarts (fig. 2), combinaisons des cycles élémentaires et création des données des cycles combinés sous la forme spécifique aux véhicules industriels.

La validation de la méthode ne peut se faire que dans des conditions bien contrôlées où toutes les variables sont connues avec précision, ce qui n'est pas le cas des camions en exploitation réelle (données Datamax). Elle est alors effectuée dans le cas d'un trajet-type, avec les étapes E suivantes :

E1 : simulation du camion sur trajet-type et calcul des histogrammes temporels (V, N) et (C, N);

E2 : détermination du cycle combiné correspondant;

E3 : simulation du camion sur le cycle combiné et E4 : essai au banc à rouleau sur le cycle combiné;

comparaison des résultats E3-E1 et E4-E1.

Figure 2 : Ecran interactif de visualisation des écarts et de construction des cycles élémentaires.

Figure 2 : Interactive screen for displaying the differences between the cycles and the data to be represented, and for creating the elementary cycles.

Exemple de cycle combiné

On donne ici un exemple de cycle combiné élaboré pour la validation de la méthode . Le trajet-type à représenter correspond à un usage mixte (ville, route, autoroute); d'une longueur de 668 km, il est parcouru par un camion de 13000 kg à la vitesse moyenne de roulage (arrêts exclus) de 55,3 km/h, soit

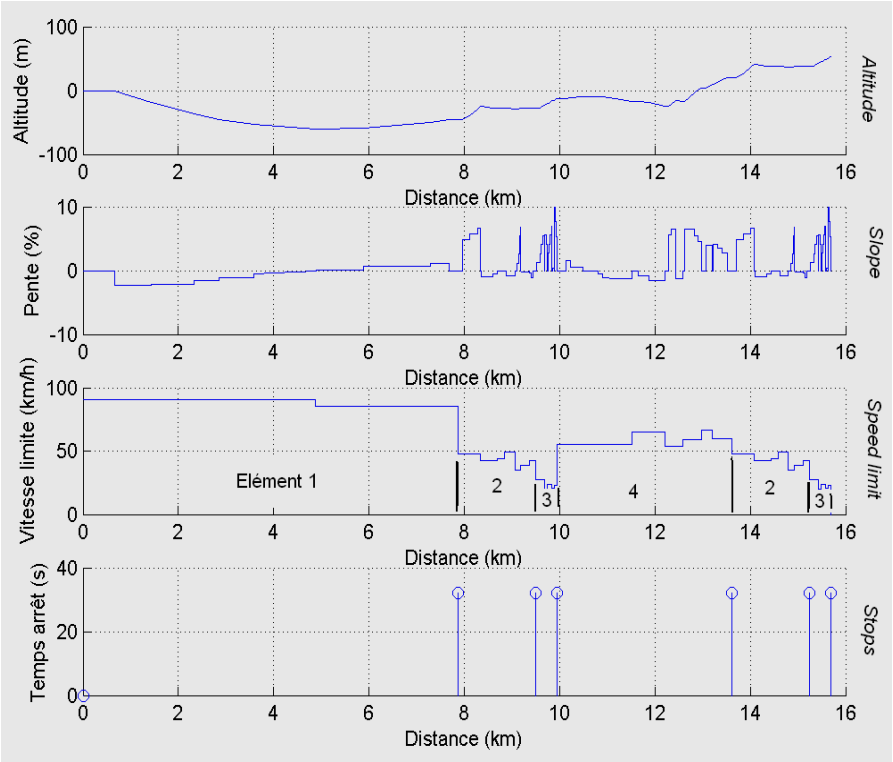
une durée de 12h 5min, beaucoup trop élevée pour un essai sur banc à rouleau.

En suivant les étapes précisées ci-dessus, un cycle combiné composé de 4 cycles élémentaires, dont deux sont répétés, a été construit (fig. 3). D'une longueur de 15,7 km, il est parcouru en seulement 17 minutes de roulage, ce qui est parfaitement compatible avec un test sur le banc à rouleau. Notons qu'il suffit de parcourir une seule fois chacun des cycles élémentaires, ce qui réduit encore la distance et la durée de l'essai.

Les différences de résultats, obtenus par simulation avec le logiciel Geode de Renault-Trucks, entre le trajet-type et le cycle combiné sont très faibles : 0,2 km/h sur la vitesse de roulage, 10 tr/min sur le régime du moteur et 20 Nm sur le couple (soit à 5 % près); par ailleurs l'écart des consommations calculées n'est que de 0,2 l/100km.

Figure 3 : Exemple de cycle combiné sous la forme spécifique aux véhicules industriels, composé de 4 cycles élémentaires (éléments 1 à 4).

Figure 3 : An example of test cycle with the specific to industrial vehicles shape, which represent a 668 km route; it includes four elementary cycles (two times the number 2 and the number 3 elements).



Conclusion

La méthode des cycles combinés a été validée pour quelques trajets-type par simulation des véhicules : elle permet de reproduire avec une bonne précision les conditions de fonctionnement des camions, tout en procurant des cycles d'essai de longueur et de durée très réduites. Les résultats des essais sur banc à rouleau sont attendus pour examiner le cas de chauffeurs réels.

L'étape suivante va consister à appliquer la méthode à des données d'usage réel portant sur de grandes durées d'utilisation (des milliers d'heures); il s'agira alors d'étudier si elle permet encore d'aboutir à des cycles de durée suffisamment réduite pour autoriser des essais sur le banc à rouleau.

Remerciements

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Impact of trip purpose on driving behaviour: case study on commuter traffic in Belgium

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Abstract

This study explores the relationship between the purpose of a trip and the vehicle exhaust emissions caused by the driving behaviour during this trip. More specifically, this research focuses on the difference in driving behaviour between commuter traffic and other traffic. The hypothesis formulated is that people driving to work produce more emissions per kilometer than drivers with other trip purposes, for instance due to a different driving behaviour. To examine this hypothesis, a methodology was developed to relate trip driving behaviour and vehicle emissions to trip purpose, and this method was applied to a small case study. This paper reports on the methodology developed for this research and presents the first results from the case study.

Keywords: ***driving behaviour, emissions, trip purpose, activity-based, GPS.***

Résumé

Cette recherche examine les relations causales entre la destination d'un tour en voiture et les émissions produites par la conduite de l'automobiliste. Plus spécifiquement, cette recherche traite des différences de conduite entre des tours de la migration pendulaire et des tours avec une autre destination. L'hypothèse formulée suggère que les personnes qui vont au travail produisent plus d'émission par kilomètre que les personnes avec une autre destination, par exemple à cause d'une conduite différente. Pour examiner cette hypothèse, une méthodologie a été développée pour relier la conduite de l'automobiliste et les émissions du véhicule à la destination d'un tour, et cette méthode a été appliquée à une étude de petite échelle. Cet article rapporte la méthodologie développée pour cette recherche et présente les premiers résultats de l'étude de cas.

Mots-clés: *conduite, émissions, destination, activity-based, GPS.*

Introduction

For the last decade, activity-based (AB) transportation models have certainly set the standard for modelling travel demand. The major idea behind AB models is that travel demand is derived from the activities that individuals and households need or wish to perform (Ettema and Timmermans, 1997). In order to summarize the most important features of AB modelling, the work of McNally (2000) is cited, who has nicely listed 5 themes which characterize the AB modelling framework:

Travel is derived from the demand for activity participation;

sequences or patterns of behaviour, and not individual trips are the relevant unit of analysis:

household and other social structures influence travel and activity behaviour;

spatial, temporal, transportation and interpersonal interdependencies constrain activity/travel behaviour;

AB approaches reflect the scheduling of activities in time and space.

AB approaches aim at predicting *which* activities are conducted, *where*, *when*, for *how long*, *with whom* and the *transport mode* involved. Obviously, data is needed for all these facets in order to develop an AB model. For this purpose an AB survey, collecting activity diary data, is conducted involving the questioning of a large number of households during two or more consecutive days. To acquire information of higher quality but still taking into account the respondent's burden, new data collecting technologies are being developed (e.g. Kochan *et al.,* 2005). Accurate information on facets like activity location and route choice, for example, can be obtained through the use of a GPS receiver.

In combination with the use of environmental models this AB approach can have important advantages for air quality purposes (Recker and Parimi, 1998; Shiftan, 2000). Macroscopic emission models, for instance, are able to convert the predicted flows of traffic into emission estimates (Beckx *et al.,* 2005). Microscopic emission models, on the other hand, are able to calculate the instantaneous vehicle emissions by using the microscopic activity data together with data from the GPS tracking device. In this way vehicle driving dynamics (the variation in average speed, acceleration and deceleration, time spent stationary,…) are taken into account when estimating vehicle exhaust emissions, resulting in a very accurate emission calculation (Beevers and Carslaw, 2005). Furthermore the use of these microscopic driving data together with the activity diary data allows to study the relationship between the driving behaviour of the respondents and the associated activity data. In this way the underlying factors of the observed driving behaviour and the associated exhaust emissions could be explained. This information can be important for policy makers aiming vehicle exhaust reduction knowing that fuel consumption

could increase up to 40% for more aggressive driving compared to normal driving dynamics (De Vlieger *et al.,* 2000).

Methodology

This section describes how the database with details on the activities and driving behaviour of people was obtained and how the data were processed.

1. Data collection

Activity data were obtained in a small scale AB data collection using self-reporting of activities and trips by respondents in a paper activity diary. A Personal Digital Assistant (PDA) with built-in GPS receiver was used to acquire information about the exact location of activities and to provide more accurate information on the reported trips (route choice, trip distance, driving speed,…). The original data set contained AB information of 32 respondents, men and women, varying in age, education, income,… They all filled in the activity diary for a period varying from two days to one week. In total 1014 trips were reported in the paper activity diaries of which 303 trips were made as a car driver.

2. Data processing

After data collection, data were organized and converted into usable formats. The activity diary data were adjusted to provide more useful information about the vehicle trips. An important step in the data processing concerned the classification of the trips according to trip purpose. Trips were classified as commuter trips when going directly to or from work, or making part of a trip to or from work. Trips with other purposes, like shopping or going out, and not making part of a commuter trip, were classified as 'other trips'. The GPS logs, consisting of second-by-second information on location, time, speed and date were downloaded from the GPS receiver. Next, these NMEA GPRMC sentences were converted into formats usable for further analysis.

The next step in the data processing was linking the activity diary data and the GPS logs, based on the trip departure and ending times. A manual check was performed to ensure that all the GPS records associated with vehicle trips were included in the analysis and, if necessary, trip timings were adjusted. After this processing procedure 235 vehicle trips were detected.

Emission modelling

Within the EU 5th framework project DECADE (2001-2003) a vehicle level simulation tool was developed for the simulation of fuel consumption and emissions for real traffic transient vehicle operation. A specific task in the project was to include a method for calculating dynamic emissions, and thereby reaching higher accuracy than traditional emission simulation modelling (Pelkmans *et al*, 2004). The final simulation tool, which is called VeTESS (Vehicle Transient Emissions simulation Software), calculates emissions and

fuel consumption made by a single vehicle during a defined 'drive-cycle'. The VeTESS emissions model uses new methods based on experimental characterization of engines and aims to provide a more realistic simulation by incorporating transient engine behaviour (Beevers and Carslaw, 2005). Together with the associated speed profiles, the actual power demands allow a detailed calculation of emissions.

VeTESS calculates the emissions per second for CO_2, CO, NO_x, HC and PM, but for the moment detailed engine maps are only available for three types of passenger cars: a Euro II LGV, a Euro III diesel car and a Euro IV petrol car. Since all the participants in the AB survey drove a diesel car and, moreover, most vehicle kilometers in Belgium are covered by diesel vehicles, this study was limited to the EURO III diesel car, described in Table 1. The other assumptions used in the model include flat terrain, 'normal' driving and gear change assumptions and no air conditioning or additional payload carried by the vehicle.

Table 1: The EURO III diesel car in the VeTESS emissions model (Beevers and Carslaw, 2005).

Tableau 1 : La voiture diesel EURO III dans le modèle d'émissions VeTESS.

Make of car	Skoda Octavia 1.9 Tdi
Engine size	1896 cm^3 diesel engine
Fuel system	Direct injection
Euro class	EURO III certified
Max. power	66 kW at 4000 rpm
Max. torque	210 Nm at 1900 rpm
Engine aspiration	Turbo + intercooler
Exhaust gas recirculation	Yes
Emissions control device	Oxidation catalyst

Speed profiles, based on the instantaneous speed data from the GPS receiver, were composed for every detected vehicle trip and used as input for the VeTESS tool. The model output consisted of second-by-second emission data, total emission data and emission factors for every trip.

1. Driving behaviour

Speed and acceleration profiles were estimated based on the data from the GPS receiver and a set of driving parameters was calculated. The driving parameters applied in this study include average speed, average positive acceleration, relative positive acceleration (RPA) and the percentage of stop time (PST) (see Table 2). RPA is calculated from the power that is needed for all vehicle accelerations in the cycle, divided by the distance driven. It gets high when the driving pattern includes a lot of high power-demand accelerations and

is found to increase exhaust emissions and fuel consumption (Ericsson, 2005). RPA is calculated as:

$\frac{1}{x}\int_0^T va^+ dt$, where T = total cycle time (s), v = speed (m/s), a^+ = positive acceleration (m/s²) and x = total distance (m).

Table 2: Driving pattern parameters for the study.

Tableau 2: Les paramètres de conduite pour cette étude.

Driving pattern parameter	Denotation	Unit
Average speed	v_{avg}	km/h
Average positive acceleration	a^+_{avg}	m/s²
Relative positive acceleration	RPA	m/s²
Percentage of stop time	PST	%

2. Analysis

The analysis aimed at answering the following question: What could be the influence of the purpose of a certain trip on the driving behaviour of its driver and/or amount of vehicle exhaust emissions caused by this trip. To answer this question, the calculated emission factors and driving parameters needed to be reunited with the information on the trip. Since the trip number was attached to every calculation, each driving pattern and emission estimate could be coded with information concerning the purpose of the trip. In this study trips were classified either as a commuter trip going to or from work, or as a trip with 'other' purpose. An analysis was then performed to find out if there was a difference between the calculated emission estimates and driving patterns of trips with a different trip purpose.

Results

This section presents the first results from the small scale survey where 32 respondents participated in an AB survey with GPS tracking technology. Both the results from the emission estimates and the driving parameters are shown for different trip purposes. In total 235 trips were analyzed.

1. Emission estimates

The emission model VeTESS calculated the emission values based on second-by-second speed measurements. Both the total amount of exhaust emissions as well as the emission factors (g/km) were calculated. Table 3 and table 4 present respectively the average total emission values and the average emission factors per trip as calculated by the emission model VeTESS. An unpaired two-sided t test was performed to check the differences between the values of different trip purposes (p-value <0.05).

Table 3: Total emissions and fuel consumption. Averages per trip and per

trip purpose.

Tableau 3 : L'émission totale et la consommation. Les moyennes par trajet et par destination.

	Distance (km)	Fuel (l)	CO_2 (g)	CO (g)	NO_x (g)	HC (g)	PM (g)
commuter	17.72	1.13	2963.95	0.60	13.97	0.12	1.48
other	8.32	0.53	1385.91	0.32	6.37	0.07	0.69
p-value	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Table 4: Emission factors and fuel consumption. Averages per trip and per trip purpose.

Tableau 4 : Les facteurs d'émission et la consommation. Les moyennes par trajet et par destination.

	Distance (km)	Fuel (l/100km)	EF CO_2 (g/km)	EF CO (g/km)	EF NO_x (g/km)	EF HC (g/km)	EF PM (g/km)
commuter	17.72	7.23	188.86	0.06	1.02	0.01	0.09
other	8.32	7.09	185.15	0.05	0.94	0.01	0.09
p-value	< 0.05	0.53	0.51	0.39	0.09	0.15	0.79

The results in table 3 show clearly that there is a difference between the total emissions from commuter trips and other trips. The total amount of emissions per commuter trip is almost twice as high comparing to the total emissions from other trips ($p<0.05$). When taking into account the distance for every trip, table 4 shows however no significant differences between the emission factors of the different polluents. The mean emission factor values for commuter trips are always equal to or higher than the values for trips with other purposes, but apparently these differences are not statistically significant.

2. Driving behaviour

Driving parameters used in this study include average speed (v_{avg}), average positive acceleration (a^+_{avg}), relative positive acceleration (RPA) and percentage of stop time (PST). Table 5 presents the calculated driving parameters for the trips in this study.

The average driving speed for commuter trips is significantly higher than the average speed for trips with other purposes ($p<0.05$). Trips going to or returning from work are driven at 39,20 km/h on average whilst other trips have a mean driving speed of 33.30 km/h. The parameters concerning the positive acceleration, a^+_{avg} and RPA, both seem to be higher for commuter trips than for other trips, but in this small scale survey this difference is not statistically significant ($p=0.10$ and $p=0.13$). The driving parameter PST is slightly higher for

other trips compared to commuter trips, but this difference is not at all significant in this survey.

Table 5: Driving parameters. Averages per trip and per trip purpose.

Tableau 5 : Les paramètres de conduite. Les moyennes par trajet et par destination.

	v_{avg} (km/h)	a^{+}_{avg}	RPA	PST
commuter	39,20	0,64	0.25	24.29
other	33,30	0,60	0.23	24.66
p-value	<0.05	0.10	0.13	0.85

Discussion

The methodology and results presented in this paper demonstrate that useful information can be obtained by enlarging an AB survey with GPS technology and linking trip information to other parameters like driving parameters and emission estimates. This approach can provide interesting information on the reasons behind the environmental pollution by traffic and is able to evaluate the impact of the driving behaviour on the vehicle exhaust emissions.

But still there are some aspects that need to be considered when applying this methodology. Firstly, for future use trip detection needs to be done automatically based on the GPS records in stead of using the trip timings of the respondents to link the data. This method will increase the accuracy of the results since the notes of trip timings by respondents aren't very accurate. Secondly, the emissions are calculated assuming only one vehicle type for all the recorded speed profiles. This assumption needs to be validated since changes in vehicle type have an impact on emission simulations. On the other hand, the use of only one vehicle type offers advantages for the analysis excluding the influence of the vehicle type. Another aspect that needs our attention deals with gear changing behaviour. When calculating the emissions, we have used the default gear changing values provided within the VeTESS model. Since gear shifting behaviour can have a great influence on the emission exhaust, this needs to be taken into consideration. If possible, future research could include an in-vehicle tool recording this information.

The first results from the small scale survey demonstrate the application of the developed methodology but real explications of the calculated values will require more data. Future research will therefore also include a large scale survey.

Conclusion

This paper demonstrates the methodology to link trip information to driving behaviour and emission estimates. This method includes the completion of an activity-based survey, collecting activity diary data, extended with a GPS

tracking technology to examine the relationship between the purpose of a trip and other parameters like the average positive acceleration or the average emission factor. Differences were found between the emission values of commuter trips and trips with other purposes, but more data are needed to acquire meaningful results. Future research will therefore include the application of the developed methodology on a large scale survey.

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Relating Swedish traffic activity data to ARTEMIS traffic situations

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Abstract

ARTEMIS is an EU model for the calculation of traffic emissions on national and regional level. The model includes 276 traffic situations, i.e. combinations of road and traffic conditions, with associated emission factors for different vehicle categories. This paper reports on a methodology for deriving the necessary traffic input data for the application of the model on a national level in Sweden. Procedures were established to distribute total vehicle mileage over: 1) urban and rural roads, 2) different road categories and 3) different traffic flow conditions, and to translate the results to the traffic situations defined in ARTEMIS. The basis for the work was: 1) two national road databases, 2) traffic simulations (SIMAIR) for test regions, 3) a GIS layer with polygons defining built-up areas and 4) ranking curves for the yearly distribution of Average Daily Traffic, ADT. Overall results for the Swedish case are presented.

Introduction

ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) is a EU model for the calculation of traffic emissions on national and regional level. It was established in 2005 as the result of the EU's 5th Framework Programme. At the end of 2004 a joint research project was started (including IVL, AVL MTC, VTI and LTH at Lund University) aimed at implementing ARTEMIS in Sweden and using it for the reporting to the UNCCC (United Nations Convention on Climate Change) in 2004, (Sjödin et al., 2006). ARTEMIS is an emission factor model based on detailed descriptions of vehicle and road categories and traffic conditions. The model includes 276 traffic situations (TS), based on a combination of road class and traffic flow conditions, see Table 1.

When modelling emissions it is naturally important to use reliable data. This article descr years 1990 to 2004 between the TS in Table 1.

Table 1: Principle for division into traffic situations (Keller et al., 2005; Andre et al., 2006)

Road type	Speed limit in rural areas (km/h)	Speed limit in urban areas (km/h)	Traffic flow conditions
Motorway - National	80 - >130	80 - 130	4 L.o.S.
Motorway - City	-	60 - 110	4 L.o.S.
Semi motorway (2+1 lanes, variable)	90, 110	-	4 L.o.S.
Main Trunk Road - National	60 - 110	70 - 110	4 L.o.S.
Trunk Road - City	-	50 - 90	4 L.o.S.
Distributor – District Connection	50 - 100	50 - 80	4 L.o.S.
- "- (with Curves)	50 - 100	-	4 L.o.S.
Local Collector	50 - 80	50, 60	4 L.o.S.
- "- (with Curves)	-	50 - 80	4 L.o.S.
Access - Residential	30 - 50	30 - 50	4 L.o.S.

Methods

The aim was to distribute national Swedish data concerning vehicle mileage between the traffic situations in the ARTEMIS model. The method of distribution and the data used are described. Calculations were performed for the years 1990, 1995, 1998, 2000 and 2004.

1. Data Used

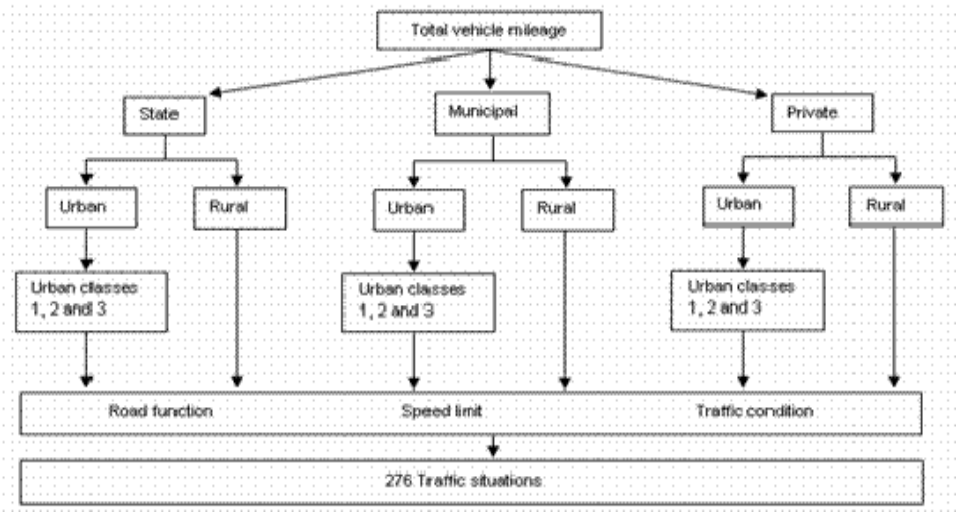
Firstly, a road database was required in which each road is associated with information about: 1) traffic flow and length, to compute the vehicle mileage, 2) road function and 3) speed limit. In Sweden, roads are owned and maintained by the state, municipalities or privately. For the state roads there is a complete and accurate GIS road database called VDB. This database is updated once a year by the Swedish Road Administration, SRA. For the municipal and private roads there is a complete digital map called the National Road Database (NVDB) in which function and speed limits are included, but the traffic flow is not given. On the basis of the vehicle mileage for the state road network, the SRA estimates the total vehicle mileage in Sweden using the Vehicle Mileage model (VM model). This model contains total mileage for each year since 1990, and is produced by The Swedish Institute for Transport and Communications Analysis (SIKA) and the Swedish National Road and Transport Research Institute (VTI) (SIKA and VTI, 2005). To estimate the traffic flow for the municipal and private roads the traffic demand model SAMPERS and the traffic model EMME/2 were used for four test regions that were chosen to represent

the distribution over road types for municipal and private roads for the whole of Sweden. Traffic was simulated on a detailed and classified road network according to NVDB To differentiate the vehicle mileage on urban and rural roads, polygons defining built-up areas were used. These polygons define the borders of built-up areas ranging from small villages to large cities Sweden, and are updated every five years.

2. Distribution of national vehicle mileage - overview

The identification of vehicle mileage with the TS in the ARTEMIS model is based on a top-down model. The total vehicle mileage was separated into the three road administration categories using the VM model. The proportion of vehicle mileage on urban and rural roads was calculated for each road administration category. The urban vehicle mileage was then divided into three classes based on the number of inhabitants. The last step before matching the Swedish road categories with the ARTEMIS traffic TS was to adjust the relation between the average daily traffic (ADT) and traffic volumes in ARTEMIS's four classes for traffic conditions, via considerations concerning the speed-flow curve for different types of roads.

Figure 1: An overview of the distribution of vehicle mileages in the top-down model.



3. The state, municipal and private road networks

Information on the distribution of vehicle mileage for the years considered was obtained from the SIKA and VTI and converted using the VM model. The vehicle mileage on state roads in the VM model is based on 80 measuring points on these roads (Björketun et al., 2005). The total vehicle mileage was found to increase from 64 310 to 74 599 million km between the years 1990 and 2004. The proportion on state roads increased from 65.8% to 67.7% while there was a corresponding decrease on municipal roads, from 30.2% to 28.4%. The

private roads were estimated to have a constant share of 4% of the total vehicle mileage during the period studied.

Due to the completeness of the information in the VDB, it was possible to recalculate the total vehicle mileage for state roads. The traffic flow in VDB is given as ADT based on the number of vehicles or on pairs of axles during a specific year. To calculate the total vehicle mileage for a certain year this ADT was enumerated by index, to represent the intended year. The index shows how the set of traffic has increased or decreased since the year it was measured (Johansson et al., 2002; Holmgren, 2004). When all links were enumerated to the intended years, the total vehicle mileage on state roads could be calculated from a bottom-up approach and compared with the top-down values in the VM model. There was a small difference between the two methods. In this study the enumeration method was used for all distributions.

4. Distribution of vehicle mileage on urban and rural roads

By using the polygons describing each built-up area, all roads could be defined as either urban or rural. Roads with their centre inside a polygon were defined as urban, and vice versa. The definition of a built-up area is: “a group of buildings normally not more than 200 metres apart, and a minimum of 200 inhabitants” (SCB, 2005). For the state road network obtained from the VDB this polygon overlay method was used for all the years of interest. The results showed an increase in vehicle mileage on state rural roads from 78.3% to 81.8% between 1990 and 2004. Due to the lack of traffic flow data on the municipal and private road network, four test regions with simulated traffic data were used to distribute mileage between urban and rural areas. The four regions studied were three counties (Stockholm, Uppsala and Östergötland County) and one municipality (the municipality of Halmstad). The same overlay method was used for these areas as for the state road network. For the municipal road network the results showed that 88.9% of the vehicle mileage was driven on urban roads, the corresponding proportion on the private road network was 25.2%. The total distribution over urban and rural roads for the different road administration categories is given in Table 2.

Table 2: The distribution of vehicle mileage for urban and rural roads in Sweden during 2004

	Urban	Rural	Total
State roads	15 %	53 %	68 %
Municipal	25 %	3 %	28 %
Private roads	1 %	3 %	4 %
Total	41 %	59%	100 %

5. Distribution of vehicle mileage between different urban areas

Urban vehicle mileage as well as the distribution over road classes and traffic conditions is likely to be related to the size of the city. The next step in the distribution model was thus to find a method of calculating the vehicle mileage

for cities with different populations. One hypothesis is that the number of TS as well as the proportion of vehicle mileage per TS varies depending on the city size i.e. its population. Due to the fact that national data for the municipal and private road network are not complete, the polygons describing the built-up areas in the four test regions were used. The 207 areas were classified into three groups based on the number of inhabitants; villages and small towns (200-49 999 inhabitants), towns and small cities (50-199 999) and large cities (>200 000) in accordance with classifications made by Vilhelmson (2000).

An equation for the vehicle mileage within a city as a function of the number of inhabitants was obtained through regression analysis, see Equation 1. The R2 value for the equation was 0.9971 including Stockholm and 0.9501 excluding Stockholm. Equation 1 was applied to distribute the urban traffic over different kinds of built-up areas, see Table 3.

Vehicle mileage = 3975.81 * Number of inhabitants Equation 1.

Table 3: The vehicle mileage in 2004, distributed over the three types of built-up areas

Type of built-up area	State roads	Municipal & private roads
Villages & small towns (200 – 49 999 inh.)	58.9%	58.1%
Towns and small cities (50 000 – 199 999 inh.)	12.5%	16.5%
Large cities (> 200 000 inh.)	28.6%	25.4%
Total	100%	100%

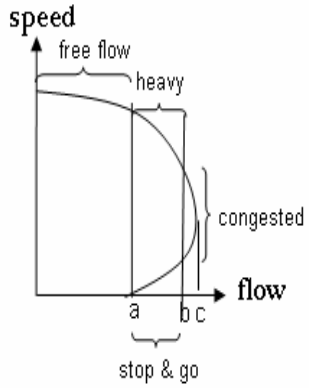
6. Functionality, speed limit and traffic condition classifications

ARTEMIS includes in total 69 road categories (including functionality and speed limit), see Table 1. Each road category is divided into four classes of traffic conditions, “level of service”, giving altogether 276 TS. The prevalence of road categories as well as their shares of total vehicle mileage varies between countries and conditions in Sweden had to be matched to those in ARTEMIS. The classifications in the two Swedish road databases (VDB and NVDB) utilised were translated into the classifications in ARTEMIS. Keys between the Swedish classification systems and ARTEMIS road categories were based on road hierarchy (national, primary, secondary, etc.), function and design (motorway, dual carriageways, single-lane roads etc.) and the prevailing speed limits. In total 33 of the ARTEMIS road categories were identified in Sweden.

To distribute the vehicle mileage on different roads over different traffic conditions, ranking curves for the yearly distribution of ADT divided on light and heavy vehicles, based on measurements of the distribution of traffic flow over the hours of a year for different road types (Björketun et al 2005, Jensen 1997), were utilised. Calculations of traffic flow and vehicle mileage at different hours (using ranking curves) for different links were performed for all state road links. These calculations were also performed for the municipal and private road links

in the test regions of the county of Östergötland, the municipality of Halmstad and the Stockholm area (for which new traffic simulations were performed to represent traffic flow in large cities). Urban and rural roads have different ranking curves and thus separate procedures were used. The result, traffic flow per lane per hour at different rang classes, was related to volume-delay functions according to Figure 2, and preliminarily classified into traffic conditions 1-3. For, 4, stop & go see below.

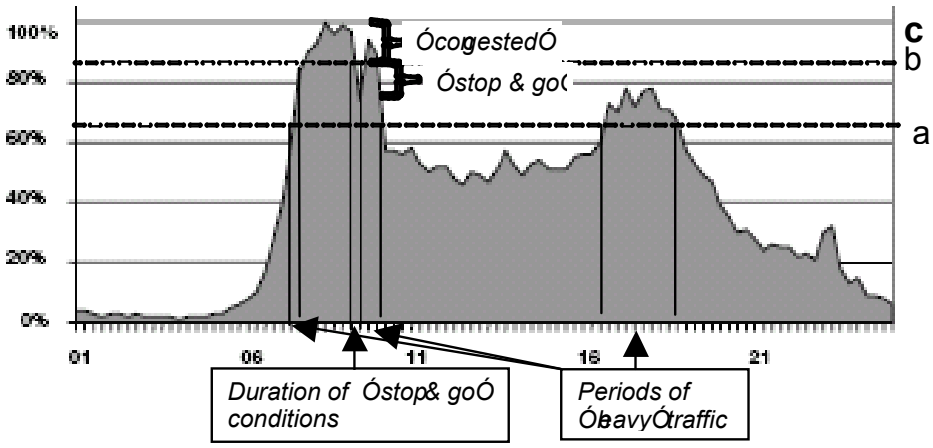
Figure 2: Principles for classifying different flows (vehicles/lane*hour) on roads links with different speed limits as ARTEMIS traffic conditions 1-3. Limits for different traffic conditions were extracted from TU71 volume delay functions (Matstoms, 2004).



Road speed limit	Capacity (c in figure veh./lane*h)	Condition 1 "Free flow" (a in figure)	Condition 2 "Heavy" (a-b)	Condition 3 "Congested" (b in figure)
90+	2000	<1300	1300-1700	≥ 1700
70	1550	<600	600-1300	≥ 1300
50-	1150	<600	600-900	≥ 900

It is not possible from traffic flow data alone to determine whether a flow between free flow (a) and congested (b), in Figure 2, is a case of demand exceeding capacity (stop & go) or if it is a lower flow (heavy). Thus it is not possible to quantify the vehicle mileage under stop & go conditions. To overcome this, two assumptions were made: stop & go would only occur on road links that had reached their capacity, c; and for these roads it was assumed that stop & go constituted a fixed share of the preliminary estimated vehicle mileage in the traffic condition "heavy". By studying flow over the day for individual congested roads, see Figure 3, it was seen that a local decrease in flow sometimes occurred within a congested period (i.e. when flow is near the capacity). This period was assumed to be a stop & go period. Thus, for links reaching their capacity the vehicle mileage under 'stop & go' conditions was estimated to be 14% of the vehicle mileage that had initially been assigned to 'heavy'. The vehicle mileage under level "heavy" conditions was decreased correspondingly on those roads. Vehicle mileage was finally summed over all road classes and traffic conditions and translated into ARTEMIS TS.

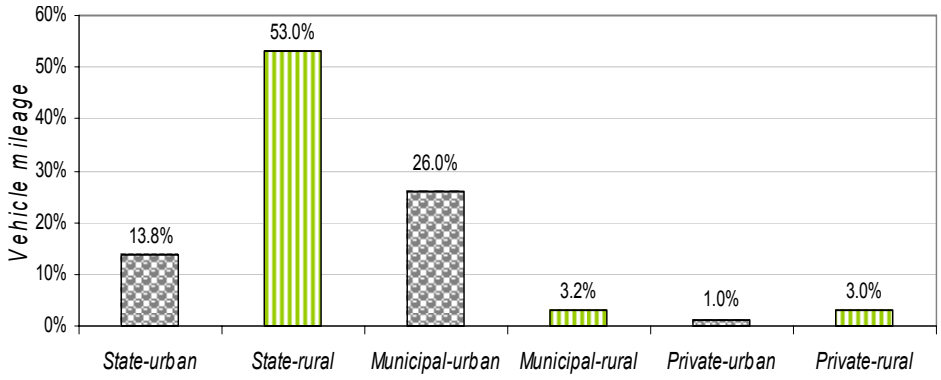
Figure 3: Principle for quantification of stop & go conditions on congested roads. a, b and c refer to Figure 2.



Traffic situations in Sweden in 2004

Concerning the different road administration categories the largest share of vehicle mileage, 53.0%, was driven on state roads in rural areas. The second largest share, 26.0%, was driven on municipal roads in urban areas, and the third on state roads in urban areas, 13.8%, see Figure 4. In total 59.2% of vehicle mileage was driven in rural areas (of which 14.6% on motorways and 44.5% not on motorways) and 40.8% in urban areas (of which 4.0% was on motorways and 36.9% not on motorways). Before this study the rural share of vehicle mileage in Sweden had been assumed to be 65% (Ringhagen, 1987).

Figure 4: Distribution of vehicle mileage in Sweden on urban and rural roads for different road administrations for the year 2004.



The result of the distribution of the total vehicle mileage over road categories and traffic conditions on urban and rural roads in Sweden showed that 85 of ARTEMIS 276 TS were found in Sweden in 2004, 45 in rural areas and 40 in

urban areas. They consisted of 33 road categories, most of them never exceeding the traffic conditions free flow (1) and heavy traffic (2). In fact, as much as 94.4% of the vehicle mileage in Sweden is performed under free flow conditions; 3.4% in heavy traffic, 2.1 % in congested traffic and as little as 0.05% under stop & go conditions. Stop & go traffic occurred only in the largest cities (>200 000 inhabitants). The ten most common TS in Sweden are presented in Table 4.

Table 4: The ten most common TS in Sweden in 2004, and their share of the total vehicle mileage

Description of traffic situation	**Vehicle mileage**
Rural / Distributor-District connection / Speed limit: 90 km/h / Free flow	21.3%
Rural / Distributor-District connection / Speed limit: 70 km/h / Free flow	11.1%
Rural / Motorway / Speed limit: 110 km/h / Free flow	10.7%
Urban / Local collector / Speed limit: 50 km/h / Free flow	9.7%
Urban / Access-Residential / Speed limit: 50 km/h / Free flow	6.6%
Urban / Distributor-District connection / Speed limit: 70 km/h / Free flow	5.9%
Rural / Local collector / Speed limit: 70 km/h / Free flow	5.7%
Urban / Distributor-District connection / Speed limit: 50 km/h / Free flow	4.8%
Urban / Access-Residential / Speed limit: 30 km/h / Free flow	2.2%
Rural / Trunk road / Speed limit: 110 km/h / Free flow	2.0%
Total	**79.9%**

Conclusions and further research

This paper presents a procedure for relating national Swedish data concerning vehicle mileage with the TS in the ARTEMIS model. Eighty-five of ARTEMIS's 276 TS were identified in Sweden in 2004. The study presents new figures concerning the distribution over urban and rural roads in Sweden i.e. 41% and 59%, respectively. Furthermore, a model for estimating the distribution of urban traffic in cities of different sizes is presented. This methodology will be developed and refined in further research when more simulated traffic data are available. New results concerning the distribution of the vehicle mileage in Sweden over traffic conditions are presented. Validation of the assumptions and methods to estimate the share of vehicle mileage at "stop & go" conditions are areas for further research. The translation between Swedish road categories and ARTEMIS categories was mainly based on the description of road

hierarchy, function and design, and speed limit. In further research the driving cycles associated with the various TS in ARTEMIS will be compared with data on real traffic driving patterns for the corresponding Swedish road categories.

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