SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY

SPSD II

AN INTEGRATED INSTRUMENT TO EVALUATE EFFECTS OF LOCAL MOBILITY PLANS ON TRAFFIC VIABILITY AND THE ENVIRONMENT

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GENERAL ISSUES

AGRO-FOOD

ENERGY

PART 1

SUSTAINABLE PRODUCTION AND CONSUMPTION PATTERNS — TRANSPORT

SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY (SPSD II)

Part 1: Sustainable production and consumption patterns

FINAL REPORT

An integrated instrument to evaluate effects of local mobility plans on traffic viability and the environment

CP/37

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1 Introduction

1.1 Context and summary

Sustainable mobility at the local level, in cities, towns or districts, requires a balance between accessibility, viability and environmental quality. Despite technological progress and strict standards for new vehicles, a balanced local traffic plan is still needed to improve the quality of life and environment in our cities and communities. Local administrations are therefore in need of an integrated instrument to check the impacts of their plans with criteria for district accessibility, viability (including road safety, pedestrian cross-over possibilities, etc...) and environmental quality (noise and air).

The Mobilee project aims to scientifically quantify the impacts on noise, air quality, dynamic exposure and traffic viability of local traffic plans. It therefore has objectives that are very similar to those of larger more prominent projects such as ISHTAR (e.g. Agostini & Negrenti, 2005).

The organisation and main goals of the project are summarized in Figure 1. A similar structure is found in this report for the readers' convenience.

The methodology that was developed is best understood as an open toolbox of models and not a ready to use software suite. Given the major goals of the project and the budgetary constraints, Mobilee did not focus on software development. Nevertheless all parts of the methodology use the same basic information (e.g. on traffic flow, vehicle types, population…). This facilitates the comparison of the results obtained for air quality, noise and viability. In addition the connections between the different models have been either automated (e.g. the inclusion of emission modules for both noise and exhaust emissions in the traffic model) or at least standardized. This enables the fast calculation of additional scenarios.

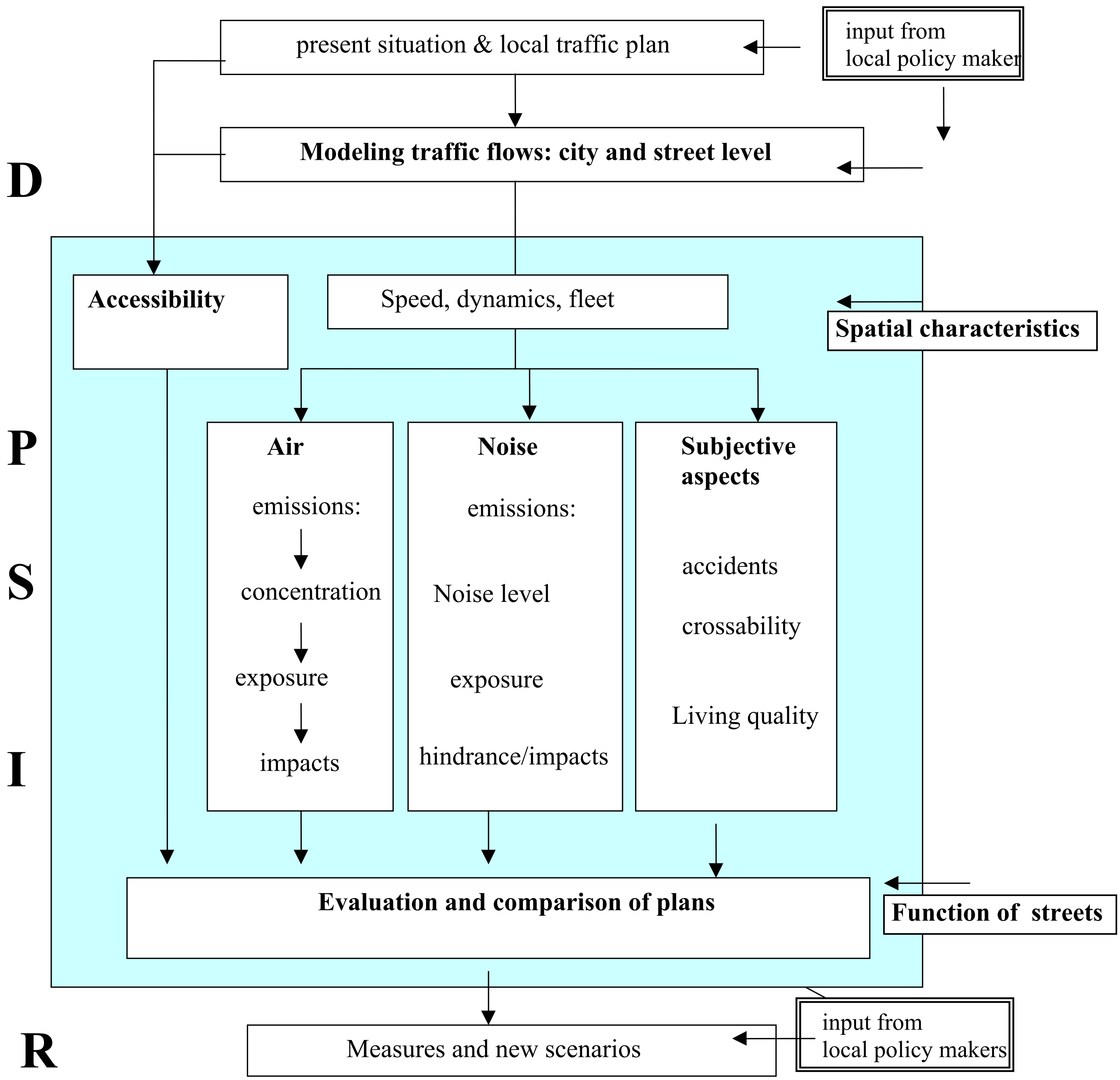


Figure 1: Organisational scheme of the Mobilee project

1.2 Overall objectives of the project

At the start of the Mobilee project, three main objectives were set:

1. To develop an integrated methodology for the evaluation of impacts of local traffic plans on accessibility, traffic viability, noise nuisance and air quality.
2. To develop and use new methods and models to evaluate all these impact categories at the district or street level and in more detail than before.
3. Provide new recommendations for local policies related to mobility, environment, road safety and urban planning.

The results on each of these issues are reported in Chapters 2, 3 and 4 respectively.

1.3 Final outcomes of the project

The major results of this project are:

- An integrated methodology for the evaluation of impacts of local traffic plans on accessibility, traffic viability, noise nuisance and air quality.
- The demonstration of this methodology for a case study in the district of Gentbrugge in the city of Ghent.
- New methods and models to evaluate all these impact categories at the district and at the street level in much more detail than before.
- A series of reports and articles that document and discuss these new approaches and their results (See Annex 5.2 Publications for publications resulting from this project).
- New recommendations for local policies related to mobility, environment, road safety and urban planning.

Other important results of the project are related to different subtasks:

- A new set of instantaneous exhaust emission functions and vehicle fleets data – more representative for local and slow traffic flows and accounting for the traffic-flow dynamic.
- A new dispersion model (based on IFDM and OSPM) that - starting with emission factors and traffic flows - can generate hourly air quality parameters at the city and street levels (in a GIS-environment), and provide details in the street canyon .
- A dispersion model that - starting from emission factors and traffic flows - can generate noise levels at street level (in a GIS-environment).
- A conversion of the results of dispersion models to health impacts. Population distribution is linked to noise and air quality levels at district level to estimate the exposure of different sections of the population.
- A methodology for the quantification of accident risks, pedestrian cross over possibilities and spatial quality of major road types.
- The creation of a database of viability indicators linked to viability levels depending on the typology and function of the district.
- Recommendations for policy makers specifying which actions lead lower and which actions lead to higher exposure of the local population.

The **scientific innovation** of Mobilee is found in different aspects of the study:

- All modules work in a specific **urban context**, and take into account the spatial characteristics of districts (broad lanes or narrow streets), the context of local traffic (volumes, dynamic speed and acceleration patterns) and the specific social functions of streets (dwelling, working and shopping). The methodology allows the calculation of indicators for a district or city as a whole, but is also capable of zooming in on specific streets.
- The **dynamic analysis** of traffic and its impacts. We no longer rely on macroscopic traffic models or Copert-like emission factors with average speeds. For use at the sub-city-level analysis we succeeded in complementing the classic approach with a microscopic traffic model to analyse the impacts of mobility plans on the dynamic behaviour of traffic flows (esp. volumes and speed/flow pattern). The methodologies for air quality, noise and pedestrian cross-over were tailored to reflect the consequences of traffic dynamics.
- A **multi-disciplinary** assessment of the different types of impacts in one consistent scheme
- **Integration of different themes;** impacts of a widely different nature such as accessibility, mobility, crossability, road safety, noise and air quality assessed in an integrated way.
- **Updated** existing models with new data and the latest social, technological (e.g. environmental standards) and scientific information.

2 Description of the scientific methodology

2.1 Selection of the case-study

2.1.1 Preconditions for selection of the case study

At the start of the Mobilee project a case study was selected to further develop and to demonstrate the integrated methodology. This case-study had to meet certain preconditions. These preconditions relate to the situation in the field (traffic, vehicles, buildings, functions) as well as to the availability of data (information about population, accident rates, traffic counts, buildings etc). In addition to the gathering of available information, a few measurements and counts were performed. The selection of the case-study focused on minimising own data collection because of budgetary constraints.

2.1.1.1 Situation in the field

In the following, a summary of the preconditions for the situation in the field is given. These were determined in the beginning of the project and mainly meant to facilitate the development of the methodology. These should *not* be regarded as preconditions that have to be met by other towns or traffic plans to allow a full or partial analysis.

- A wide variety of vehicle types: private cars, buses, delivery vans, trucks, motorized two-wheelers, tram,/trolley/ train, bikers and pedestrians;
- These vehicles all have a different impact on viability. The presence of different vehicle types is also useful to study modal shifts.
- Different speed limits (30, 50, 70) and differences in traffic circulation: smooth traffic, heavy traffic, 'stop and go';
- A combination of as many functions as possible in a short distance of each other: residential area (no through traffic, with through traffic, exposed (or not) to emissions of an important road), public transport (tram and/or bus lines), combined commerce and residential area; school environment…;
- Different types of housing: low density (open-space) development, high density development high-rise buildings;
- A large and heterogeneous (gender and age) population group. The area should be large enough so that an important part of its inhabitants stay into the defined area during a normal day.
- A strong conflict between traffic and residential functions.
- Enough possibilities to simulate realistic improvements in the traffic situation;
- Measures that result in a change in traffic circulation (prohibition for trucks, prevent people taking short cuts…);
- Measures that result in a change of the traffic situation (speed bump, one-way traffic, roundabout, road building and maintenance…).

2.1.1.2 Availability of data

The preconditions for availability of data were the following:

Data needed	Source
meteorological data	VITO, VMM, KMI
composition of the floor surface	own fieldwork
position and height of buildings	NGI file
background concentrations	measuring station VMM
composition of the vehicle fleet	local authority
detailed traffic counts	local authority
demographic data	local authority
traffic speed data	local authority
presupposed traffic measures	mobility plan, viability plan
data from a macroscopic traffic simulation model	local authority
accident rates	local authority
orientation, length and width of the street	local authority, GIS file

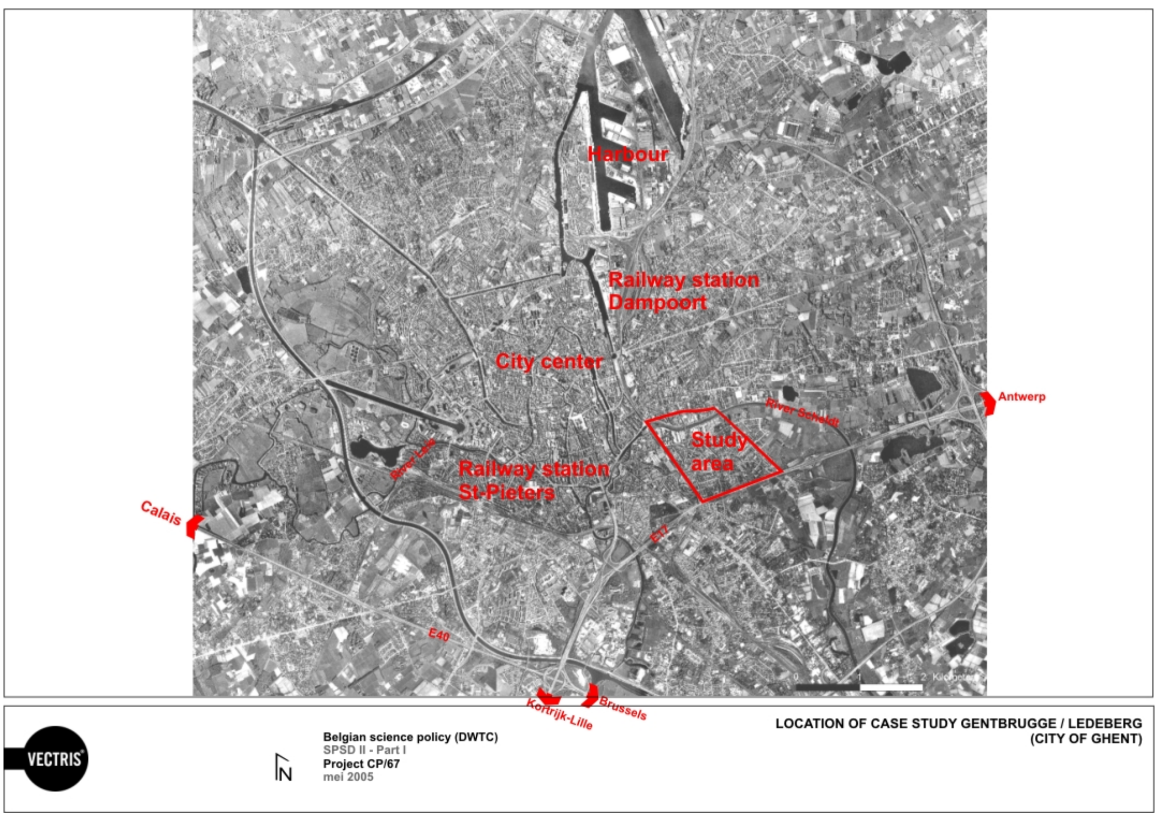


Figure 2: ***location of case study Gentbrugge / Ledeberg (city of Ghent)***

2.1.2 Selection of the case study: Gentbrugge / Ledeberg (in the city of Ghent)

Considering the preconditions mentioned earlier, it was decided to take the city of Ghent as a case study, more specific the area Gentbrugge/Ledeberg.
The study area is a typical high density 19th century neighbourhood with a mix of activities (and planned brown field development on the old industrial sites), located south east of the city centre. It is bounded and partly divided by several major infrastructures (highway E17, railway, river Scheldt…).

The study area Gentbrugge / Ledeberg was selected for different reasons (cf. preconditions):

- Few traffic works have already been executed, but a significant number of projects are ready to start. In this way we may compare the viability situation before and after the works.
- A mobility impact report (MOBER, Tritel (2002), a viability plan and a bicycle plan are available.
- Some drastic traffic works are planned: speed bumps, 30 km/h areas, change in circulation, redevelopment of the former industrial ARBED-site.
- The possibility to perform some measurements and counts still exists before the traffic works start.
- The case study includes urban area, schools, tram-, bus-, and trolley routes, a train station, approach routes and shopping streets.
- The city of Ghent already has a macroscopic traffic simulation model and a GIS-section within the mobility department.

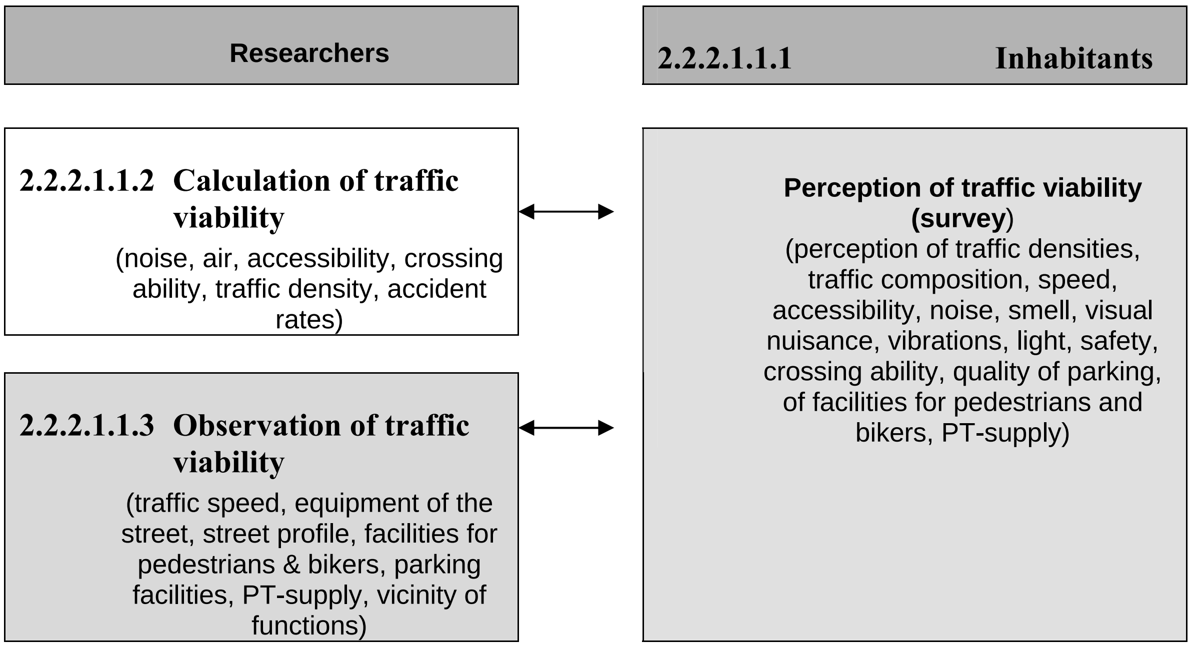
2.2 Typology

2.2.1 Subjective measures of traffic viability

Two instruments are developed: an observational survey for mobility experts to study an area of interest and a questionnaire on traffic viability for the inhabitants of that area.
In the observational survey an expert observes a street for some spatial characteristics like the profile of the street, parking arrangements, accessibility of services and so on. The questionnaire is developed to ask the inhabitants' opinions on traffic viability in their neighbourhood. There are some socio-demographic questions like age, gender, activity, composition of the family etc. Then a lot of statements concerning the impact of traffic and the traffic situation are presented to the inhabitants. We also ask them about the importance of different traffic problems.

2.2.2 Questionnaire

In 2004 we organized and processed the questionnaire amongst inhabitants of the study area. The aim was to measure the (subjective) perception of traffic viability amongst inhabitants, to figure out relative importance in perception of obstacles between different sources of nuisance and to investigate in how far the respondent profiles determine obstacle perception. The results of this questionnaire are compared with results from an observation exercise conducted in the same study area and with the results of 'objective' calculations of nuisance by each source individually. The following graph shows the interdependencies of the survey of inhabitants with other research parts of the MOBILEE-study.



The research team opted for a questionnaire amongst a small stratified sample of 120 residents in a selected study area. The instrument constructed was a structured questionnaire form with multiple choice questions.

2.2.2.2 Sampling methodology and contacting method

The study area for the survey and observation exercise was delineated to 4 streets of the complete study area of the study being (1) Kerkstraat, (2) Robert Rinskopflaan, (3) Brusselsesteenweg and (4) Kliniekstraat. The aim was to reach a group of 120 respondents, with approx. 30 respondents per street. In order to reach this response, a sample of 240 people was selected, stratified by the following characteristics: 60 persons per street, 50% m/v, age distribution 25% between 15-30, 50% between 30-60, 25% older than 60 years old.

In September/October 2003, all 240 persons were informed by mail and invited to an information meeting in Gentbrugge. Respondents could fill out the questionnaire form on the meeting or afterwards. A remuneration of 10€ was offered to the participants.

2.2.2.3 Instrument: a written questionnaire form

The written questionnaire was made up of three blocks of questions.
A first block consisted of questions asking for the respondent's perception of mobility and traffic viability. Different aspects of traffic (such as accessibility, road safety and quality of facilities for road users (parking, footpaths, cycle tracks, etc.) were looked upon. Also different sources of nuisance such as noise, air, light, visual obstacles were treated. A five point scale was used to describe the degree of nuisance.

In a second block, the relative importance of the different sources of nuisance were asked about. A four point scale was used here: very important, rather important, rather unimportant, not important.

In a third block, some general questions were asked regarding the respondent's socio-economic profile (street, sex, age, type of living, household form, activities, ..) and his/her experiences with nuisance in the past (accidents, special glazing because of street noises, ...). A copy of the questionnaire is taken up in annex 5.10.2. The survey data were processed and analyzed with the statistical software package SPSS.

2.2.3 Observation survey

Parallel with a questionnaire among the residents, an observation exercise was conducted. A checklist was constructed and a traffic expert visited the study area to observe and measure the traffic situation and to make an estimation of the nuisance to the residents caused by the observed traffic situation. The purpose of this observation was to confront the 'opinion' of the traffic expert with the opinion of the residents. The observation checklist is taken up in the annex 5.10.1. The following issues were considered in the observation exercise:

- an overall typology was made for each street, measuring the hierarchical role of each street (unlocking, one/two-way traffic, main/secondary approach road, centre/periphery/transition; a transverse section was made of each street measuring the width of traffic lanes, foot and cycle paths, greenbelts, etc
- a detailed description was given (1) of the facilities for bikers, pedestrians and car drivers (2) of the street profile (obstacles, activities along the road) and assessed in terms of safety and maximum admitted speed regime.
- PT-timetables were consulted to assess the PT-supply; accessibility towards different public services were measured using average distances

2.3 Description of scenarios

In the study area of Gentbrugge, traffic flows are simulated for different scenarios. To simulate traffic flows, the micro-simulation model Paramics Quadstone (2004) is used. In this model, individual drivers and vehicles are dealt with separately. The driver- and vehicle characteristics at time t + Δt are calculated according to their characteristics at time t. Driving behaviours, vehicle accelerations, etc, … are modelled in a detailed way, which is important in order to accurately model noise and emissions produced by vehicles. Macroscopic traffic models do not take into account these parameters.

First of all, the road network needs to be defined in the Paramics simulation model. After that, the traffic demand is brought into the model. For each interval of time, new traffic demands are imported as Origin-Destination matrices, introducing a certain level of dynamics into the model.

In the Mobilee project, three scenarios are simulated: the 'current situation', where the 2002 network is combined with the 2002 OD-matrices, 'scenario 1', where the 2010 network is combined with the 2002 OD-matrices, and finally 'scenario 2', where the 2010 network is combined with the 2010 OD-matrices. Scenario 2 represents the situation in the future including the redevelopment of the former industrial zones, whereas scenario 1 is included to isolate and evaluate the influence of the changed network infrastructure.

Compared to the 2002 network, the most important changes in the 2010 network are the following:

a) Speed limits drop from 50 (70) km/h to 30 (50) km/h.
b) In 12 one-way streets, the driving direction turns around.
c) On 6 intersections, the road-surface is raised ('plateaus'), to reduce the speed.
d) The 'Land Van Rode Avenue' (LVR Avenue), an important avenue that leads to the highway, is downsized from 2 X 2 lanes to 2 X 1 lanes.

Besides all that, the network is extended with 2 new sites that will be developed in 2010: Arbed-North and Arbed-South (see Figure 11).

These 2 new sites in the Gentbrugge study area, which are now under construction, will also generate an extra amount of traffic. The 2010 OD-matrices add this extra amount to the 2002 OD-matrices. Productions and attractions to the Arbed-sites are determined by the future activities on these sites. Data about these future activities are found in a study by TRITEL on the mobility effects of the 2 sites (the Mober study, Tritel (2002)). In this study, predictions on the future developments are made, and productions and attractions are derived. An example shows how this is done:

133 private houses are assumed to be developed in 2010 in the Arbed-North site. A mean value of 2.2 persons per family is assumed, as well as a trip rate of 2.7 persons a day, 70% of which are made by car, while there are 1.3 passengers per car. These assumptions lead to 133 x 2.2 x 2.7 x 0.7 x 1/1.3 = 425 productions and attractions by car each day, due to the development of the private houses.
For a complete and detailed overview of the predicted productions and attractions, we refer to the Mober study (Tritel, 2002). The total amount of traffic generated by the 2 sites is presented in Table 2.

Table 1: amount of traffic generated by the 2 Arbed sites

GENERATED TRAFFIC (pae/h)		Morning rush hour	Evening rush hour	Other hour
		180	89	85
		85	193	85
		265	**282**	**170**
		207	106	57
		52	260	57
		259	**366**	**114**

Traffic is simulated in the different scenarios by releasing the different OD-matrices to the different networks, as described above. In the scenarios for the future, the changed network and the changed traffic demand could result in a redistribution of traffic flows. Travellers might change their routes. To capture this effect, the macroscopic model of the city of Gent is used, since the micro-simulation model Paramics does not sufficiently take this effect into account.

2.4 Definition of common vehicle types

On basis of the needs of the project partners, modelling the traffic flows, calculating the tail-pipe or calculating the noise emissions, a common categorization of the vehicle types is set up. This harmonization was required as each partner is used to work with a specific way of characterizing the vehicle fleet within his field. Factors that needed to be taken into account were ease of integration, availability of data and expandability.
After careful consideration the vehicles were divided into following categories, see Table 3. Each of these vehicle types were directly used as individual types in the micro simulation model. This means in practice that for each of these vehicle types a distinctive origin-destination matrix was derived.

Table 3

Main type	Petrol	Diesel	LPG	Electric	Hybrid	Natural Gas
Passenger car	<70 kW 70 kW - 100 kW >100 kW	<75 kW >75 kW	<65kW 65 kW - 90 kW >90 kW	X		
Minibus	X	X	X	X		
Light van	X	X	X	X		
Heavy duty (Freight)		3,5 t – 7,5 t 7,5 t – 16 t 16 t – 32 t 32 t – 40 t				

Heavy duty		Coach	Trolley	X
(Person)		City bus		
Motorcycles	<50cc			
	>50cc			
Bicycle				

The project team chose to make distinction between different sizes of passenger cars and lorries, because the difference in power and weight has an impact on the driving behaviour. Taking these differences into account resulted in a more realistic modelling of the traffic flows.

A distinction between different fuel types was needed for the purpose of air and noise pollution modelling. These emissions are strongly dependent on the propulsion technology of the vehicle.

Alternative modes and/or fuels were also included, such as natural gas powered urban busses, enabling to simulate the effect of policy measures leading to a higher penetration into the traffic of these vehicles. Bicycles were included as well. Although they have no emissions, they can have an impact on the traffic flows.

For the sake of the determination of the emission factors, both for emissions to the air as for noise pollution, a further subdivision in vehicle standards was necessary. A common subdivision was used to weight the different emission factors: one set to characterize the vehicle fleet composition in 2003; another for the vehicle fleet composition of 2010. Defining vehicle types on the level of emission standards was not desirable, as this would adversely influence the workability and the accuracy of the traffic flow micro simulation.

2.5 Traffic micro simulation

2.5.1 Micro-simulation model Paramics

The traffic model Paramics is used for the modelling of traffic flows in this study.
Paramics is a microscopic simulation model. Let's take a look at the input for this model:

- First, we put in the infrastructure, this means the configuration of the road-network, as well as the priority rules, the speed limits, etc…
- Secondly, we bring in the demand of traffic. The demand of traffic defines for each possible route between a certain point of origin and a certain point of destination, the amount of vehicles that try to reach their destination via this particular route. For each interval of time, for example for each 15 minutes, a new demand of traffic is imported in the model. Consequently, the demand of traffic is time-dependent and a dynamic model is born.
- Thirdly, we bring in the properties of the vehicles and those of their drivers. The type of the vehicle, as well as the reaction time of the drivers, influences significantly the behaviour of the vehicles. This is taken into account by the micro-simulation model.

On the basis of this input, the model assesses the movements of each vehicle. Microscopic models, such as Paramics, consider each vehicle separately.
The period of simulation is divided into small intervals, for example intervals with a length of 1 second. At every time step, the model assesses the new position, velocity and acceleration of each vehicle, as a function of the previous position, velocity and acceleration and also as a function of the traffic situation on that particular moment.

In the micro-simulation model Paramics, vehicles take into account a series of side conditions:

- Interaction with other vehicles
- Arrangements of traffic-lights
- Priority rules
- Speed limits
- Lanes for busses
- Etc…

After the assessments, the model shows the simulated traffic flows. The user-friendly nature and the numerous parameters of this microscopic model allow for a realistic and detailed representation of the traffic system.

These details, such as driving behaviours, vehicle accelerations, etc, … are important in order to accurately model noise and emissions produced by vehicles. Macroscopic traffic models do not take into account these parameters

2.5.2 Estimation of OD-matrices

The traffic demand was brought into the model using Origin-Destination Matrices. For each possible route between a certain zone of origin and a certain zone of destination, these OD Matrices define the amount of vehicles that try to reach their destination via this particular route.

In order to generate OD Matrices resulting in realistically simulated traffic flows, as they present-day occur in the study area, correct traffic data were necessary. A little overview of the traffic data we used in this study is given below:

- Different simulations with the macroscopic traffic model of the city of Ghent gave a rough image of the origins and destinations of vehicles on the major roads passing through the network, during the morning and evening rush-hour. For these periods, the number of vehicles passing per hour on the major roads were also calculated using this model.
- On two locations within the study area, traffic counts were done by the Roads and Traffic Administration of the Flemish Community (AWV), using loop detectors. For a period of a couple of weeks, the number of vehicles passing per hour was counted continuously.
- During the same period, manual counts were done at seven other points during the morning and evening rush-hour. The number of vehicles passing was counted per quarter of an hour, making a distinction between different vehicle categories.

- The public transport company 'De Lijn' provided us with the timetables of busses, trams and trolleys, which were also checked in situ.

By combination and interpolation of the gathered data, OD Matrices were constructed for the whole study area. Since new OD Matrices are imported each quarter of an hour, a certain level of dynamics is introduced into the model.

An iterative process was used to match the model link flow intensities to the counted intensities in practice. Table 5 shows the results for the morning commute (7am – 9 am).

Table 4: **Comparison between counted and modelled link intensities**

	Counted intensities pcu/u	Modelled intensities pcu/u	deviation (%)
Link counts, June 2002			
E.Blockstraat t.h.v. brug over Schelde			
direction Gentbrugge	473	491	3.8
direction Sint-Amandsberg	478	522	9.2
Braemkasteelstr. t.h.v. brug onder E17			
direction Keiberg	210	225	7.1
direction Meersemdries	369	330	10.6
Burvenichstr.(tss Oude Br.weg en spoorweg)			
direction Brusselsesteenweg	422	439	4
direction spoorweg	152	167	9.9
Kerkstraat (tss Van Ooststraat en Bassijnstr)			
direction spoorweg	86	95	10.5
direction Brusselsesteenweg	61	64	4.9
Link counts from LIN, february 2003			
Brusselsesteenweg tss Land Van Rodelaan en spoorweg			
direction Gent	1020	1112	9
direction Aalst	730	676	7.4
Brusselsesteenweg tussen Burvenichstraat en Dallierestraat			
direction Gent	435	483	11
direction Aalst	492	549	11.6
Link intensities calculated with the macroscopic model of Gent, 2001			
Brusselsesteenweg tss Land Van Rodelaan en Steenvoordelaan			
direction Gent	948	995	5
direction Aalst	682	624	8.5
Brussesesteenweg tussen Dallierestraat en L. Van Houttestraat			
direction Gent	444	481	8.3
direction Aalst	474	509	7.4
Brusselsesteenweg tussen L. Van Houttestraat en Posthoornstr			
direction Gent	481	452	6
direction Aalst	767	747	2.6
Brusselsesteenweg tussen Posthoornstraat en Schelde			
direction Gent	612	642	4.9
direction Aalst	683	696	1.9
Land Van Rodelaan tss Brusselsesteenweg en Spoorweg			
direction spoorweg	510	480	5.9
direction Brusselsesteenweg	661	656	0.8

Table 4 shows that the iterative matching process resulted in a fine correspondence between the above-mentioned intensities: deviations almost never exceeded 10%. We conclude that the OD-estimations produce quite realistic flow in different links.

2.5.3 Simulations and Calibration

First, the road network of the study area in Gentbrugge was constructed in the micro-simulation model Paramics. The network consists of about 150 nodes and 300 links.

Secondly, the traffic demand was brought into the model using Origin-Destination matrices, as explained higher.

Finally, a number of vehicle characteristics - being the basis on which the vehicle park is divided into different vehicle categories - such as vehicle length, top speed, maximum acceleration and deceleration, and a number of driver characteristics, such as the mean driver reaction time, were also introduced in the simulation model. They represent the typical vehicle park and driver behaviour in the study area.

After bringing these data into Paramics, the model computes the positions and speeds (among others) of all vehicles at all times.

To guarantee a realistic representation of the traffic system, the microscopic model needs to be calibrated. Paramics contains a number of simulation parameters that determine the simulation progress. The model is calibrated by adjusting these parameters such that traffic streams in the model correspond to traffic streams in reality. There are many parameters that determine the simulation progress, but in this study, we only use two of them: the mean driver reaction time (MDRT) and the mean target headway (MTH). The smaller the values of these parameters, the smoother the circulation flow and the higher the capacity. Theoretically, even only one parameter would be enough to calibrate the simulation model. The two chosen parameters have a great influence on the simulation progress, making the calibration process easier.

To equalize the network capacity in the model to its capacity in practice, we set the values of the MDRT and the MTH both to 0.8 seconds. This way, the mean square deviation equals 1.9%.

We conclude that a calibrated micro-simulation model is able to accurately assess the network traffic flows.

2.6 Noise

2.6.1 General methodology

The impact of traffic noise on the local viability of a neighbourhood can be considerable. Noise maps are generally considered to be an ideal tool to visualize the effect and accentuate the impact of mobility plans. For comparability of results, standardized methods are developed. During the same period as Mobilee was running, two important and far larger initiatives were taken in this respect at the European level: HARMONOISE and IMAGINE. To guarantee comparability, the tools developed in the context of

Mobilee were pro-actively streamlined with these European initiatives. Amongst others, this had a consequence that new vehicle emission curves (including speed and acceleration dependence) were included in the Mobilee toolbox during 2004 as these data became available at the EU level.

However, the focus on harmonized and comparable noise maps is slightly different than the focus on local viability. In the latter case, the goal is to predict the effect as accurate as possible. Generally speaking, in urban environment, a few aspects of the noise climate (or soundscape) other than the average noise level are known to have an impact on the quality of the living environment and health: temporal fluctuation of the noise level caused by loud vehicles or local traffic management (e.g. traffic lights); the presence of a quiet side at the dwelling; the noise climate in the wider environment of the dwelling… These additional factors are however characterized by less well-known dose-effect relationships and by a rather difficult relation between the traffic characteristics and suitable noise indicators such as noise level distributions over time. This is one of the reasons why, from the start, we decided to include a detailed assessment of uncertainty in the proposed procedures.

In Mobilee, aggregation is an important issue. Noise calculations therefore start from the same GIS-based data, the same vehicle categories, the same road descriptors etc. as the calculation of the other aspects of viability. This can be seen as a common assessment of the *driving forces* for all aspects. The modelling of the *pressure* on the urban environment, which in the case of noise is caused by the vehicle noise emissions, will be presented in section 2.6.2. For this, an emission plug-in for the Paramics micro-simulation traffic model was developed, which is also used to assess the other types of emission considered in this project. The *state* of the urban soundscape is subsequently modelled using a sound mapping model. A literature study has been made of the current national and international standards. The propagation model needed to be solid, well documented and suitable for urban areas. Not only large areas but also smaller neighbourhoods should be able to be investigated, so the model must also be able to take care of high-resolution simulation. To allow for scenarios to be modelled, a full decoupling of emission and propagation was found advantageous. In that manner the propagation can be kept constant while the emission changes from scenario to scenario. The noise mapping model is presented in section 2.6.3. Finally, in section 0 a detailed *impact* analysis will be given.

2.6.2 Sound emission

2.6.2.1 Emission factors

For vehicle emissions, the HARMONOISE model is used [1]. This mathematical noise emission model associates with each vehicle two sound sources, which can be located at different heights depending on the vehicle type, and roughly represent the emission due to tire-road noise and propulsion noise. Each source consists of a tertsband spectrum with centre frequencies ranging from 25 Hz to 10 kHz. The noise sources are a function of vehicle parameters, such as vehicle type, speed and acceleration, as well as of road parameters, such as surface type, age, wetness and temperature. The directivity of the driving vehicle is also taken into account. Because the HARMONOISE vehicle category division mainly is focused on noise properties, a suitable mapping was made to the Mobilee vehicle classification.

2.6.2.2 Detailed analysis based on micro-simulation

In Mobilee, detailed analyses of the pressure by road traffic on the environment is based on micro-simulation of the traffic flows. In such a simulation, vehicles are simulated individually; positions, speeds and accelerations as well as the simulation time are discretized. The Paramics micro-model used in Mobilee allows users to write plug-ins, consisting of a dynamic link library bundling a set of call-backs, each called at defined points in the micro-simulation. This makes it possible to extend and refine the micro-simulation model, but also to gather detailed vehicle data during simulation.

Several decisions were made to be able to do the emission and propagation calculation of local traffic situations, which are mainly considered in the Mobilee project, in a reasonable amount of time and with a reasonable amount of computing resources. First of all, a viewport is set, which consists of a polygonal part of the network around the area for which one wants to know the noise immission. Only vehicles inside this viewport will be taken into account. At each time step, positional data of each vehicle inside the viewport is gathered, together with all data needed to construct the HARMONOISE noise sources associated to the vehicle.

Subsequently, the sources associated with each vehicle are mapped on a set of emission points. The source data can be aggregated to instantaneous emission of the traffic stream in two ways. The first and less computationally intensive method is to grid the roads and aggregate emission within each grid cell. It is possible that sources coming from different vehicles are mapped to the same cell, so the directional information can not be taken into account using this aggregation method. It was observed during year 2 of the project that this was accurate enough to get a general idea of noise levels at sufficient distance but not to describe noise peaks in detail. A more accurate model was introduced for cars within shorter range of the observer. Cars within small distance (e.g. 100 m) are traced as individual point sources. This area has to be limited, because of its clear disadvantage when it comes to propagation calculations. The described idea is visualized in Figure 3.

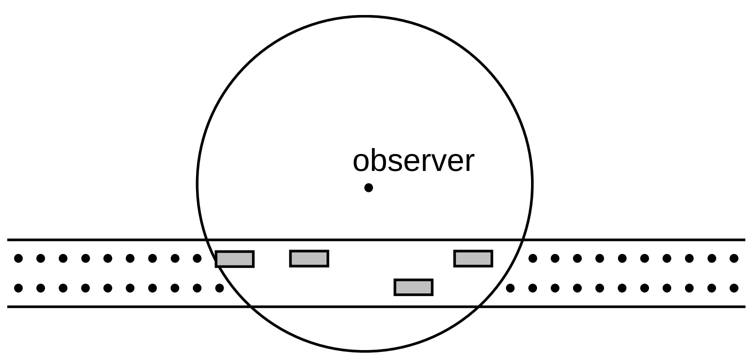


Figure 3 – Aggregation from vehicle noise sources to emission points.

2.6.2.3 Correction factors for characteristic situations

This detailed analysis based on micro-simulation is important because it allows to really assess the effect of local traffic management decisions that are part of a mobility plan. Moreover they form an ideal basis for including effects of noise that are more noise-peak related than average level related. Unfortunately micro-simulation and time varying emission calculation of large areas of cities can be computationally very expensive, can require huge setup times, or can be even impossible due to lack of data. Therefore, for larger areas or for assessment with limited resources, a model that is not much more complex than existing emission models needs to be built to predict time varying sound behaviour. It should allow bypassing the micro-simulation of traffic flows.

The methodology for building this model was decided upon after careful consideration of alternatives. This model is based on simulating traffic flows for characteristic situations and storing the emission results of these simulations as exemplars. The model then needs to compare the given environmental settings of the street with the settings of the given characteristic situations. Fuzzy Rule Base systems and Fuzzy Neural Networks are used for this purpose because they are suitable for modelling very general complex interactions while retaining an easy interpretable set of rules.

The generalised emission model still needs input data that is not always available. Default and most likely values will need to be derived from statistics. These input parameters, like the speed distribution of the traffic, also depend on other available geographical properties.

2.6.3 Noise mapping model

2.6.3.1 Urban sound propagation

Once a set of – possibly time varying – vehicle noise emissions are available, noise immission at a set of observers can be calculated using a propagation model, which needs to be specially tuned for time varying sources. Several calculation schemes are available like boundary elements, volume elements, radiant exchange, ray tracing, beam tracing and more. Considering the scale of the region to be simulated and the frequencies of interest in the road noise spectrum, only a few methods are applicable. These methods can be categorised as ray-based methods. This bias towards ray-based methods is also noticeable in national and international standards. Furthermore in urban area multiple reflection and diffraction become important. Although most standard models allow for multiple reflection and diffraction the computational burden is often very high.

Several implementation flavours of the ray-tracing techniques are known. The technique chosen in Mobilee takes advantage of the densely occluded environment to accelerate the path tracing. Diffraction is an integral part of the tracing method. It was decided to construct a beam tracing model to generate paths between the emission points and the receivers. The technique used is object precise polygonal beam tracing [2]. A beam consists of a group of rays, coherent in space (following about the same path) and bounded by the objects in the simulation area. The most important advantages of the beam tracing approach in comparison with ray tracing is that no receivers are missed by the infinitesimal small rays constituting the beams, and that diffraction is modelled efficiently, which is important in high shielded regions like urban areas. The simulation can either use a 2.5D or a 3D representation of the world. The former is the least expensive in computation resources and time, the latter is the most accurate.

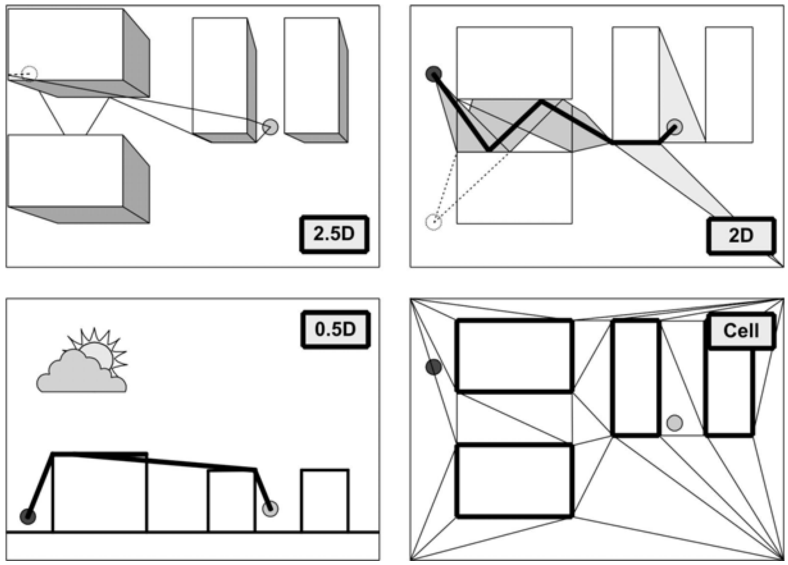


Figure 4 – Beam tracing through a 2.5D environment. The emission point is shown as a dark grey circle, the receiver as a light grey circle.

A 2.5D representation of the world consists of a terrain model with super-positioned blocks representing the buildings, as shown in Figure 4(2.5D). When looked at from above, the world is seen as a number of polygons in a plane. Standing inside the world, all walls are upright and all roofs are flat. The path generation itself is split into two parts. First a set of beams is traced through the geometric network in 2D using the footprints of the houses as objects, shown in Figure 4(2D). The shaded areas in this figure represent a subset of the bundles. Secondly, paths are constructed between all emission points and all receiver within reasonable distance of each other, and the different diffraction and reflection points in a vertical section are computed, as shown in Figure 4(0.5D). When a 3D representation of the world is chosen, splitting the tracing problem in two sub-problems is no longer required.

While the beams propagate through the geometrical environment, they reflect and diffract on boundaries, so each beam must have a local view on the environment to efficiently perform this tracing. A convenient approach consists in using a convex cell subdivision of the environment. Within each convex cell, a beam then has full visibility by construction. Thus, only interactions of a beam with a cell boundary have to be described. The cell boundary can be a wall of the real world environment or a portal, which is a virtual, transparent boundary placed during the convex cell division. Figure 4(Cell) shows a convex cell division where each cell has exactly three boundaries, also called a triangulation. The constrained Delaunay triangulation scheme is used in the framework of the Mobilee project, which preserves the original boundaries (walls of buildings) and has among all triangulation schemes the largest internal angle for all triangles, which is important for numeric stability of the implementation. Using a triangulation has the advantage over a complex polygonalization that operations on the beams are easy to formalize and to implement. The disadvantage is that more beams need to be traced.

Once a beam is constructed and a receiver is detected inside it, the path between the emission point and the receiver is generated. The stack of beams is unwound and at each real boundary the points of interest (reflection and diffraction points) are computed on the fly. On modern pc's (2 GHz) rates of 800,000 paths/s are achieved for the simplest configuration down to 200,000 paths/s when multiple reflections and diffractions are allowed, which is more than an order of magnitude faster than the actual attenuation computation following it. Diffuse reflections are not taken into account in the model. These can not be implemented optimally using a beam tracing technique; radiosity methods are more suited for this. A hybrid model would ask for considerably more computing time and resources.

The attenuation model used is based on the ISO 9613 model [3], and has been extended with diffraction along vertical walls according to the Nord 2000 model [4]. This model allows taking into account geometric divergence, atmospheric attenuation, ground effects and meteo effects (moderate downward refraction according to ISO 9613).

Finally, the immission at the receiver points is calculated by multiplying the emission with the attenuation coefficients. Two scenarios are possible, based on the emission point configuration (see Section 2.6.2.2). When exact source positions are used as emission points, the whole propagation calculation (path generation and attenuation calculation) has to be performed at each time step. When a fixed grid of emission points is used, the propagation is simulated only once, and the attenuation between each emission point - receiver pair is stored. This way, it is possible to rapidly compute immission for a series of time steps. The drawback of this second methodology is that it requires more memory because there are more emission points, and thus more paths between emission points and receivers.

Figure 5 gives an overview of the complete time-varying noise immission model developed in the framework of Mobilee.

The integrated process is complicated by the fact that geo-referenced information (roads, buildings, land-use) is likely to come from several different sources. This often leads to small spatial mismatch that can have large consequences when the data is combined in a noise level calculation. Care must be taken for pre-processing of geo-referenced data. Part of the possible problem is circumvented by automatic tuning to conform to the input standards.

Figure 5 gives an overview of the complete time-varying noise immission model developed in the framework of Mobilee.

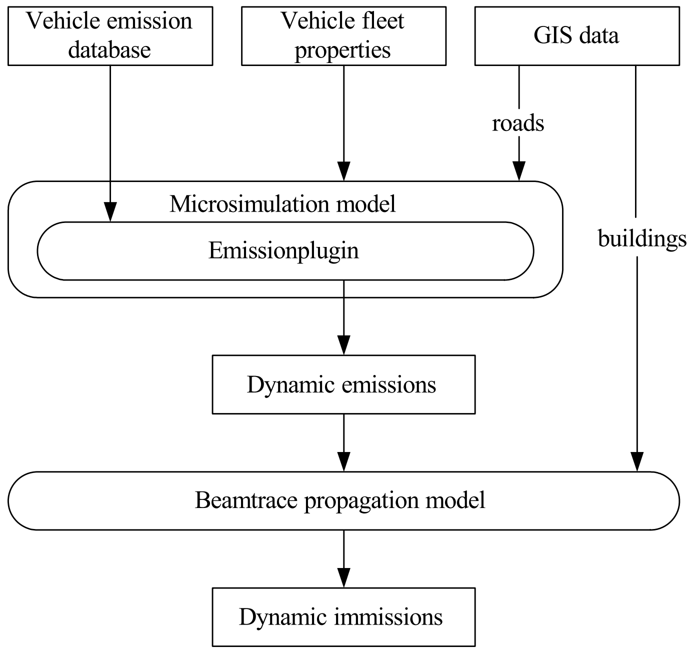


Figure 5 – Methodology outline.

2.6.3.2 Uncertainty in noise mapping

Overview

Noise mapping is a tool that is of increasing importance in policy support and decision making. Gathering the data needed and preparing the data has become one of the most important problems in current noise mapping. Data is lacking or is of poor quality, causing the noise maps to loose credibility. When noise maps are used in a legal context it is even more important to provide correct results and indicate a founded uncertainty on the result.

The imprecision that pops up in a noise mapping project has several origins. Due to the many parties involved in providing data, differences in format, encoding, and geo-mapping are a first source of error and uncertainty. Even for well-defined data sets, small differences in projection of geo-referenced data may cause problems that are difficult to solve automatically. Roads may be extracted from construction plans and houses from processing satellite images or aerial photographs causing small differences in projections. As a consequence roads may be in buildings or too close to façades leading to overestimated exposure. Traffic models are also often based on virtual links between cities without using the actual roads between them. The projection of the final modelling results onto the real roads is an important source of emission uncertainty.

All real-world information is tainted by uncertainty to a certain degree. In many noise mapping applications this imperfection is silently ignored. The imprecision of results may nevertheless lead to faulty conclusions and should therefore be clearly taken into account. Two types of uncertainty can be discriminated. *Soft uncertainties* are uncertainties that can be quantified or estimated. An example is the uncertainty about the ground reflection of an open area. The exact reflection may not be known but based on the distribution of the types soil in urban open areas a distribution of possible reflection coefficients can be computed. Also when ground reflection is extracted from satellite imagery a rough estimate of the ground impedance can be made which causes a soft uncertainty on it. *Hard uncertainties* [5] occur when even the range of possible outcomes is unknown. An example is missing geometry. The effects on reflection and diffraction can not be described by a distribution. Soft uncertainties are however the most prevalent in noise mapping.

Uncertainty can also be split up between model and data uncertainty. Model uncertainty specifies that a model is only a reflection of reality and may and will miss some features that can have an impact on the accuracy of the result. Data uncertainty relates to imprecise or lacking input data.

Uncertainty emerges at several places in the noise mapping tool chain. The Mobilee tool chain roughly follows the DPSIR (Driving Forces, Pressure, State, Impact and Response) chain model often used in environmental impact modelling. At the start of the chain, we find traffic intensities and speed distributions. They are often only measured on large access roads and highways at a limited number of locations for practical or economical reasons. Traffic models of various kinds can be employed to fill in the missing data. They can however magnify imprecision in the measurements used to calibrate the traffic model.

Road traffic noise emissions are based on standardized models like the Nord 2000 or the Harmonoise model in Mobilee. Although the error on these models is in general quite low for streams of traffic, detailed traffic data is necessary to operate within a 1 dB margin. Ignoring speed and/or acceleration can easily add up to 5 dB errors in traffic interchange areas.

Propagation models are probably the most important and best known source of uncertainty in noise mapping. The models approximate propagation through a non-uniform atmosphere and the interaction with objects of complicated form and detail very roughly. The resulting model uncertainty in general increases with propagation distance and number of interactions with buildings and other obstacles. Although approximate, these models are complex and require huge amounts of data, geometric or other. For large-scale noise mapping, the required detailed data is often lacking and forms the most important source of uncertainty. Data about local meteorological conditions is frequently missing.

In noise mapping there is also an important geometric problem to be solved which can lead to rather strong uncertainties. Engineering models used for noise mapping, such as the Mobilee tool, are ray based and hence use some kind of ray path constructor. The impact of having imprecise geometry for the buildings and infrastructure can be large. Receivers can come into the line of sight of important sources due to slight changes in geometry. The use of Fresnel zones can limit this effect but at a great cost in computing time and algorithmic complexity. The algorithm used to construct paths also has an impact on accuracy. Sweeping the space seen from the receiver by shooting rays could lead to missed sources. Better, but often slower, techniques make sure that no source-receiver-paths are missed up to a given number of reflections and diffractions. Obviously the number of reflections and diffractions used to find paths plays a role in the final accuracy. In general, it is hard to estimate the loss of accuracy due to geometric data imprecision.

Techniques

Using the technique of extended numbers, the problem of numerical uncertainty in the noise mapping process can be solved. Two flavours of extended numbers were considered: probabilistic numbers and fuzzy numbers. A probabilistic number is given by a mapping of the real axis to the closed interval [0,1] given that the integral over the real axis is exactly 1 corresponding to the normalisation of a probability distribution. Operations on probabilistic numbers are defined in terms of the cumulative distribution of the underlying probability distribution. The probability distribution of the new probabilistic number is then obtained by derivation. A fuzzy number is defined by a mapping of the real axis to he closed interval [0,1] given that the supremum of the image is 1. The mapping is also called a possibility distribution [6]. Operations on fuzzy numbers are based on the extension principle that allows extending mathematical operations on crisp numbers to operations on fuzzy numbers.

Both types of extended numbers work with underlying distributions. Representing distributions by a large number of samples, results in easy implementation of operators but also in slow calculations and huge memory usage. A piecewise linear approximation of the underlying distribution allows to perform fast computations while being memory space efficient. When the underlying distributions are convex some important simplifications can be made in the computation schemes leading to significant improvements in speed. Specifically, the calculus on the fuzzy numbers collapses to the calculus on intervals.

Measuring uncertainty

There is no single numerical definition of uncertainty. Uncertainty can be measured in several ways in both frameworks. A common measure of uncertainty is the extent (often called support) of the distribution. The width of the extent is a first indication of the total uncertainty present in the computation at a given position. When theoretical distributions that extend over the whole real axis, are used, this measure is of no use. Taking the bandwidth of the distribution as a measure of uncertainty is often a better idea. The bandwidth is the width of the distribution where it has 0.5 probability or possibility. Skewness of the uncertainty is measured by subtracting the most likely value (also called the mode) respectively defined as the value with the highest probability/possibility from the expected value, the average of the distribution under consideration.

The shape of the distribution is measured by the entropy. Low entropy is an indication of sharp shaped distributions. The sharper the distribution, the less uncertainty is present in the computation. In the limit case the distribution collapses to a single crisp value indicating absolute certainty. The opposite is maximum entropy where all values of the domain have an equal probability/possibility. Entropy is measured for probability distributions using the Shannon entropy [7]. Measuring entropy in the possibilistic framework is less straightforward; the method of Klir can be used [8]. Although both methods measure information content their absolute values are not comparable. An increase of the Shannon entropy will however also dictate an increase in the Klir entropy.

Direct quantitative comparison of uncertainty measures between the two frameworks is in general impossible.

Architecture

The extended numbers can be put to use at several places in the Mobilee noise impact assessment tool. The first option is to wrap an existing noise mapping architecture in a higher/macro level uncertainty module. This module performs a number of simulations and sweeps the parameter space. For each sample of the parameter space a new noise map simulation is performed. Although this is conceptually and practically the easiest solution some problems occurs. The relation between input and output may be non monotonic which prevents simulation of only two sample points on an input variable to gather the desired output sensitivity. If correlation between input variables has a significant effect on the output then the number of simulations grows exponential in the number of input variables. Each input variable's output sensitivity has to be computed in function of the other variables.

A better option is to handle the uncertainty at a micro level. Operations on regular floating point numbers are replaced by their extended counter part. The complete noise mapping tool is transformed. For the end users point of view, there is no visible change except for the input that the tool expects. This may still be exact, crisp, numbers but now uncertainty distributions are also accepted. Just like a regular noise mapping process, the tool is run once to compute the noise map. During this computation the extended numbers are used. The final result is a noise map based on most likely values together with a map containing an estimate of the precision of the result at each location.

2.6.4 Detailed impact analysis

In Mobilee, no epidemiological studies are performed. Dose effect relationships for noise impact are gathered from literature, guidelines of WHO, overview reports compiled by other researchers, and previous know-how of INTEC. The following effects are considered in Mobilee:

- Population averaged noise annoyance (referred to as potential noise annoyance): from the beginning of the project it was clear that this would be based on generally accepted annoyance-L_{dn} (or more modern annoyance-L_{den}) curves.
- Noise annoyance by smaller subgroups: personal characteristics of the exposed group can influence annoyance. Noise sensitivity is the most well-known stable personality trait that has an effect on annoyance. Unfortunately it is difficult to derive it from demographic data. Age is already more accessible. Other factors can be included if they are known.
- Annoyance corrected for noise level fluctuation: eventfulness of the noise climate can have an influence on perceived annoyance. Data on this effect are scarce. Modelling based on hypotheses on the process between exposure and annoyance that were found in literature, backed-up by some experimental work were recently performed by INTEC to shed some light.
- Sleep disturbance: Sleep disturbance has many different facets. The strongest form of disturbance results in remembered awakenings. These can be assessed in social

surveys and, at least for road traffic, dosage effect relationships have been deducted. It is this type of sleep disturbance that we propose to be integrated in the aggregated viability indicator for obvious reasons.

- Health effects: The best proven health effects of noise (ischemic heart disease, depression…) have been linked to sleep deprivation and thus night time exposure. The sleep disturbance in this case can be substantially weaker: changes in sleep phases, motility, and hormonal changes.

Estimating these health effects numerically and presenting them in a map gives clear insight in the effects of mobility plans. However, one still has to determine one additional factor: what is an acceptable effect. This means that societal preferences somehow have to be included. This decision is clearly not crisp. There is at least a broad grey area. To account for this, the concept of fuzzy noise limits is introduced. This results in areas being labelled very good (quiet), some areas very bad (noisy), some acceptable but with a large transition area between them.

2.7 Air quality

2.7.1 Emission factors

2.7.1.1 Dynamic tail-pipe emissions

Based on the output of the traffic flow model PARAMICS the tail-pipe emissions of the vehicles for Mobilee are calculated. This output details for every simulated vehicle its position within the modelled network, its instantaneous speed and acceleration

Different methodologies were considered for the calculation of the emissions.

- The first dataset consists of the emission functions of MEET/COPERT, relating for a specific type of vehicle its speed to the emitted quantities of various pollutants. As Paramics provides the speed for every vehicle, the tail-pipe emissions of that vehicle could be calculated.
  These emission functions are however designed for macroscopic emission estimation purposes. The minimum spatial resolution is 1 km x 1 km and the minimum temporal resolution is 1 hour. This project requested a finer level of emission estimation. As a consequence, the use of MEET/COPERT emission functions was not longer considered in the Mobilee project.

- As a second dataset, the use of the emission factors of the 'Handbook of Emission factors for Road Transport' (HBEFA / MICET) was planned. They give for a specific type of vehicle emission factors for a list of well defined traffic situations. These situations are characterised by a average speed and average acceleration. The minimum spatial resolution is a street section, which is finer than the minimum spatial resolution of the MEET/COPERT emission functions.

  However, this level was found not to be detailed enough as well. The use of the emission factors does not allow obtain a variation of emissions along the street section. One may expect higher emissions at intersections, not only because of the higher density of the traffic, but especially because of the high amount of idling or acceleration vehicles at these locations.

A second objection against the use of the Handbook emission factors was its structure. It namely consists of a matrix of emission factors, whereas MEET/COPERT consists of emission functions. The effort of integrating the former was higher than the integration of the latter.

As a result, an alternative, project specific approach was looked for.

Figure 6 below demonstrates the difference between the three methodologies mentioned above.

- The grey line is the exhaust of CO_2, given in g/s, measured on urban bus A.
- The green line is the simulated CO_2 exhaust, using the correlation between instantaneous speed, acceleration and CO_2 emission derived from urban bus B. Although the green line tends to underestimate the overall CO_2 emission of bus A, the emission profile is simulated quite well. These differences can be attributed to the specific consumption profile of the different vehicles.
- The dots represent the emissions, using the macroscopic emission functions COPERTIII in a microscopic way. One can see that this unintended use the methodology is not able to allocate the emissions where they are observed in reality. The emissions are underestimated when accelerating and overestimated when decelerating and no emissions are obtained when the vehicle is idling.
- The connected blue crosses represent the emission results when using the Handbook emission factors, in a way they are not designed for. The mismatches with the observed emissions are similar with those observed when using the COPERT functions.

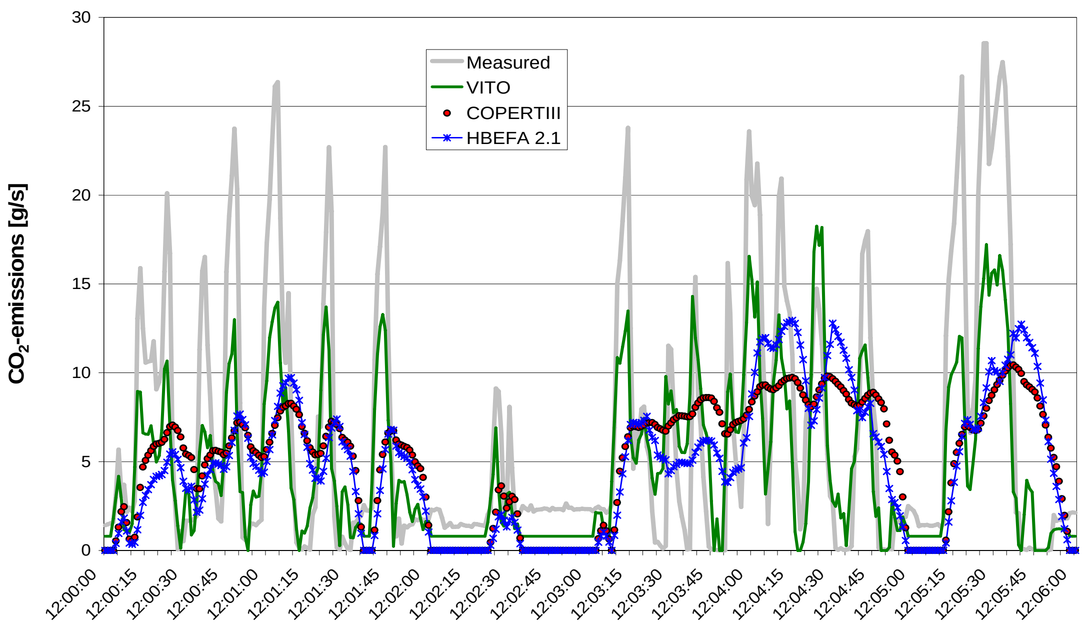


Figure 6 Example of instantaneous emission values (g/s) obtained through different models compared to measurements

The project specific emission functions were included in a module which was inserted in PARAMICS. In that way, traffic emissions for the neighbourhood studied, are calculated simultaneously when carrying out the traffic flow simulations.

Besides the intrinsic uncertainty associated with the specificities of the dataset and the statistical uncertainty of the regression it should be noted that the accuracy of the emissions depends heavily on the ability of the micro simulation model to predict the acceleration of vehicles correctly. This type of model is in the best case (cfr. In Mobilee) validated for reproduction of flows and speed distributions on a number of links, but there is no validation of acceleration (Discussion with Robert Joumard, INRETS, 2005).

2.7.1.2 Non-exhaust emissions

The emission factors detailed in paragraph 2.7.1.1 cover only those pollutants emitted from the tail-pipe. The question can therefore be raised if other sources of pollutants (especially for PM) such as brakes and tires or even resuspended road dust should be included? In the PODOI project "EXTERNAL ENVIRONMENTAL COSTS OF TRANSPORT IN BELGIUM" (Int Panis et al, 2000) it was concluded from limited runs of the American MVEI7G model that although potentially important in the PM10 range for petrol cars, the total emission in the PM2.5 range for the Belgian fleet (including a large share of diesels) was relatively small. In addition the data found proved to be old (e.g. based on asbestos containing brake pads) and not reliable.

Many more studies have been performed during the last 5 years, with most of the important reports being published only during the last months (e.g. from the European PARTICULATES project and from the German Lohmeyer group).

Average values from brake and tire wear range between 9 mg/vkm and 57 mg/vkm for petrol cars with normal tires and between 16 – 70 mg/vkm for trucks (all in PM10). Nevertheless Düring (pers. comm. June 2005) stresses that these emissions are heavily dependent on the traffic situation (rather than on speed alone) and that the existing methods (EPA, Düring, 2002) are not reliable. The modified EPA-method recently proposed by the Lohmeyer group was revoked and tentatively replaced by an INFRAS based approach. An emission model able to describe the location of the emissions (presumably concentrated on intersections, sharp bends, etc.) does not exist.

When looking on the most recently proposed values it is still clear that these are much lower than the exhaust emissions of diesel cars and can safely be neglected. On the other hand including average non-exhaust emission values on top of instantaneous emission factors for the exhaust would blur the resolution that the Mobilee model currently achieves. Finally it needs to be stressed that no evidence at all is available that PM10 from these sources (e.g. metallic brake dust) can be attributed with the same health impacts as combustion particles. Doing so would be highly speculative but could be done for sensitivity analysis of the results in petrol or LPG dominated fleets.

2.7.2 Atmospheric modelling

2.7.2.1 Points of view

In the context of this integrated instrument, the air quality model can be looked at from two viewpoints:

- as a black box, that takes in emission data, meteorological data, street maps and building frontage data, and that produces air pollutant concentration data;
- as a software package consisting of mathematical formulae to calculate atmospheric dispersion.

The black box view is interesting, for it allows focusing on the input data, including the visualization and quality control of input data and output.

The software package viewpoint will focus on the internal organization of the formulae and on the data structures used to represent the input data and the resulting computed air quality.

The contact point between both views is the user interface for data entry and control of actions.

There are two very particular aspects for the atmospheric modelling as required in this integrated instrument:

- part of the emission data is in the form of very large data files, produced by the traffic micro simulation model Paramics. During the development of the instrument, these raw data required extensive processing, including quality control, before they can be used as input to the air quality model. (Other emission data are: cold start emissions, and emissions from other sources than traffic (residential heating, green houses, industry.));
- there are two kind of receptors, that is, places for which the air quality is to be calculated:
  - receptors in the street canyon, which are located on the street network and which have to cover (part) of the street network in fine spatial resolution. Each such receptor requires a complete description of the street canyon configuration and emission as seen from this very same receptor;
  - receptors outside the street canyon, which are located on a regular grid with fine (10 meter or so) grid mesh spacing

The following sections describe the most important methodologies (data structures and computational schemes) developed for the air quality modelling part of the integrated instrument. Technical details are given in the Annex 5.11 'Van Paramics naar IFDM' (in Dutch).

2.7.2.2 The air quality models

For the integrated instrument, a Fortran program has been written that combines the IFDM bi-Gaussian plume dispersion algorithm for point, line and area sources over urban, rural and industrial regions, and the OSPM parameterization for dispersion within a street canyon.

A. IFDM

The IFDM model is used to calculate the impact of emissions outside the street-canyon at roof top level, and at receptors that are not located within street canyons.

IFDM (Bultynck and Malet, 1972; Cosemans e.a.,1992) has been conceived and developed at the Belgian Nuclear Research Institute SCK/CEN between 1960 and 1980. It is currently maintained by VITO, Mol, who, in the 1990's, ported it from IBM mainframe to Personal PC and developed a user interface for the model. Most environmental consultant agencies in Belgium have taken a license to use the IFDM model for routine permit granting applications and environmental impact assessments[1]. The applicability of the model to accurately model pollutant transport and dispersion over Western Europe flat terrain has been verified on many occasions (Cosemans e.a., 1982; Olesen, 1995) by comparison of modelled with measured pollutant concentrations.

For this integrated instrument, the IFDM model accepts line source emissions in the following format per input-record (Table 5):

Table 5: Structure of an IFDM input record for a line source

'LijnMobile' "mg/d/m" X0 Y0 X1 Y1 emission 24 values

where:

- 'LijnMobile': is a key word, telling this record describes a line source;
- "mg/d/m": are the units of the subsequent emission data;
- X0, Y0: are the co-ordinates (km) of one end of the line source;
- C1, Y1: are the co-ordinates (km) of the other end of the line source;
- emission: daily emission;

24 values: one value for each hour of the day (0-1h, ... 23-24h local time); the values have to be proportional to the emission during the respective hours.

[1] http://www.vito.be/english/environment/environmentalstudy9.htm

B. OSPM

OSPM[2] is a practical street pollution model, developed by the National Environmental Research Institute (NERI), Department of Atmospheric Environment. The OSPM model is a recent model, still under improvement as new experimental data become available. The OSPM-version used in this integrated instrument was obtained from NERI in April 2003.

The OSPM model is intended to calculate an 1-hour averaged concentration for the Leeward site and for the Windward site at the specified location in the street canyon (Figure 7: Dispersion in the street canyon (OSPM)).

In the IFDM_OSPM Fortran program format, the data that specify the OSPM-receptor and the nearby street canyon (geometry + traffic) data, form a set of 14 records. Table 6 gives a description of such a set[3].

Table 6: set of IFDM-OSPM input records to describe a OSPM-street canyon receptor and the nearby street canyon geometry and traffic data.

Rec number	Keyword	Further contents of record (all co-ordinates in km, accurate to 10 cm).
1	"x_y_recep"	Xr YR: co-ordinates of point in street canyon
2	"LijnMobile"	IFDM Line source record (see Table 5) equivalent line source for street canyon
3	"nnp"	24 values, number of small vehicles per hour
4	"nnt"	24 values, number of heavy duty vehicles per hour
5	"vp"	24 values, average speed of small vehicles (km/h)
6	"vt"	24 values, average speed of small vehicles (km/h)
7		Xr,Yr, XY_begin and xy_end street canyon, ORDER: North-East, South-West
8		height (m), width () of street canyon, length (m) of street canyon projected on North-East and length (m) of street canyon projected on South-West, orientation (°) of street canyon according to OSPM convention (all in meter).
9		Number of wind sectors with different building height
10		for each sector: begin (°) (in clock wise order) _ dd_l
11		for each sector: end (°) _ dd_u
12		for each sector: building height (m)
13		height (m) of receptor above the ground
14		X Y X Y co-ordinates of receptors at respectively the North-East side and the South-West side of the street

[2] (http://www2.dmu.dk/1_Viden/2_miljoe-tilstand/3_luft/4_spredningsmodeller/5_ospm/5_description/default_en.asp)

[3] There is some redundancy in Table 5 between the information in records 1, 2, 7, 8 and 9. This redundancy is useful for easy program verification, this as well for the data generating program, as for the IFDM-OSPM Fortran program. It is important that the receptors at the South-West side and North-East side of the street are always labeled correctly.

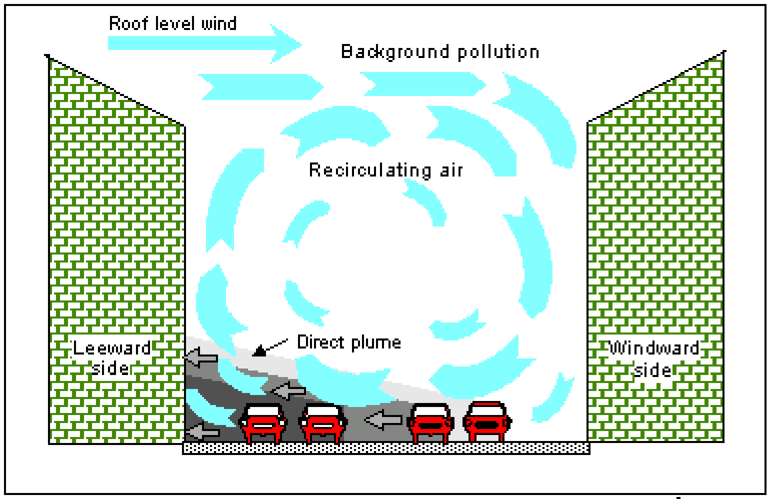


Figure 7: Dispersion in the street canyon (OSPM)

C. The IFDM-OSPM Fortran program

The integration of both IFDM and OSPM in one Fortran program is outlined below. The important advantage of integrating both models is that the existing user interface for IFDM that takes care not only of model input, but also of the management of input data, computations and modelling results, can be used in the integrated tool. In the next paragraph, the integration of both models is sketched in a rather high level 'flow chart' style.

Computations for one year of meteorological data

For each receptor in the street canyon

a. Read receptor X,Y and OSPM street canyon description at this receptor
   + (geometry + hourly traffic-data & emission data)
   + corresponding line source segment (CLSS)
b. Compute time series due to all sources inside & outside canyon
c. Output time series of computed concentrations for this receptor:
   i. time series of roof top concentration RTC (i)
   ii. time series of hourly concentration on NE side conc_NE (i)
   iii. time series of hourly concentration on SW side conc_SW (i)

Compute time series due to all sources inside & outside canyon =

For each hour (i) of year

a. Read meteorological data for that hour
b. Calculate the concentrations on the:
   i. Roof Top Concentration: RTC(i)
   ii. North-East Side concentration: conc_NE(i)
   iii. South-West Side concentration: conc_SW(i)

Calculate concentrations for meteorological conditions of one hour =

1) call OSPM_algorithm for receptor/canyon/meteorological situation

   ➔ NE-side concentration for that hour: ***NE_c***
   ➔ SW-side concentration for that hour: ***SW_c***

2) call IFDM algorithms for Concentration due to all Point, Line and Area Sources
   ➔ **C_p_a_l**

3) Compute Concentration due to Line Source CLSS
   ➔ **C_CLSS**

   i. Roof top concentration ***RTC*** due to all PAL sources in emission inventory
   except for these that define the OSPM street canyon for this receptor:
   RtC **= C_p_a_l - C_CLSS**

   ii.

   iii. concentration on NE side: conc_NE(i) = ***NE_c*** + ***RtC***
   concentration on SW side: conc_SW(i) = ***SW_c*** + ***RtC***

Note: source strengths are also time dependent (daily/weekly cycles, outside temperature dependency (space heating) ...)

Output time series of computed concentrations for this receptor

1) Write time series of hourly concentrations for post-processing
2) Compute year average and percentiles of hourly concentrations
3) Compute time series of daily concentrations
4) Compute percentiles of daily concentrations
1) Compute other things, such as:
   - ➪ average of the concentrations at 1 o'clock
   - ➪ average of the concentrations at 2 o'clock
   - ➪ ....
   - ➪ average of the concentrations at 12 o'clock
   - ➪ ....
   - ➪ average of the concentrations at 24 o'clock

C.1. Post processing

Currently, post processing of the model output is needed in certain cases.

NO_2/Ozone

needed:
time series of measured hourly ozone and background NO_x (NO and NO_2);
time series of computed NO_x-concentrations.

Action: to compute hour by hour the NO_2-NO-O_3 photo-chemical equilibrium.

Note: this can be integrated in the IFDM-OSPM Fortran Program. The meteorological data file used should then also contain the hourly background ozone and NO_x data, as measured by the Flemish Environmental Agency VMM and to be obtained from IRCEL/CELINE.

Background pollution

For past situations, background pollution data can come from air quality monitoring in rural sites or from a regional model. For future emission scenario's, background concentrations have to come from a regional model. As the impact of all local emissions can be calculated with IFDM, the regional model must not take these local emissions into account. The impact of remote sources will vary little or not over the region, so the hourly background value could be added to the hourly meteorological records.

Cross roads

Two crossing streets define 4 receptors (A, B, C, D) at their intersection point (Figure 8). The North-East and South-West sides of the respective streets contribute to the 4 receptors as indicated in Table 6. Take care that rooftop concentration is added only once.

Notes.

1. For averages, this cross road concentration can be obtained by adding the average values as indicated in Table 3 (minus the rooftop concentration). For percentiles, this must be done on the time series of computed hourly values; the percentiles are to be computed from the resulting time series of summed values).
2. In principle, this could be implemented in the IFDM-OSPM Fortran program by providing an input record with keyword "Cross road" followed by 2 sets of IFDM-OSPM input records as defined in Table 6.
3. However, crossroads are currently not supported by the input-data-generator (See later in this chapter).
4. Many crossroads in the Gent-Brugge test area have a more complex geometry as sketched in Figure 8.
5. The method described here was discussed with Ruwin Berkowicz of NERI, the developer of OSPM.

Figure 8

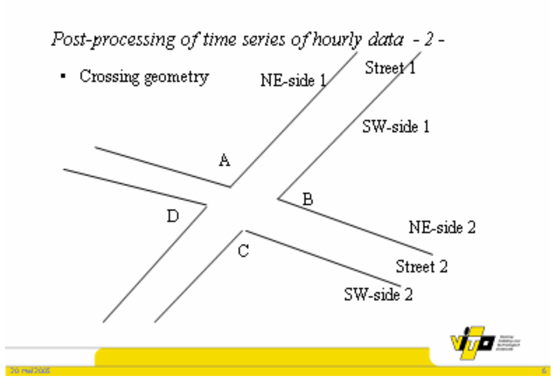


Table 7

Receptor	street **1**		street **2**	
	NE	**SW**	**NE**	**SW**
A	←		←	
B		←	←	
C		←		←
D	←			←

C.2. Integration with existing IFDM user interface

The existing IFDM user interface maintains a set of files – mostly in ASCII– that contain –or that describe – data in order to manage input data, computations and modelling results.

A IFDM computation is always performed for a particular combination of input data files (meteorological data, source data, receptor data, model options).

The user must give a 8-letter name[4] to this combination. The different result files, created during this computation, are identified by names composed of this 8 letter name and various 'file extensions' and 'path names.'

Practically, this means that the IFDM-model knows the name, given by the user, to the computations it is carrying out.

The trick is, that we let the IFDM-OSPM Fortran program do all the work the normal IFDM code normally does. Suppose the computation was given the name '03_PM_Br', as a short mnemonic for: PM calculations for the year 2003 in the Brusselsesteenweg Then the IFDM-OSPM Fortran program will check whether, apart from all the traditional IFDM input files, there does exist a file called .\1718\03_PM_Br.CANYON.

If this CANYON-file exists, it must contain a set of input records such as in Table 6. If so:

- ➪ the IFDM and OSPM computations will be carried out for each receptor defined in this file;
- ➪ extra result files with concentrations (average, percentiles) on the South-West side of the street, on the North-East side, on rooftop level, and so on will be produced;
- ➪ this output is in a format ready for input into a GIS or other evaluation/visualization software that makes part of this integrated instrument.

In order to complete the integration of the IFDM-OSPM Fortran program into the integrated tool, all that is needed is an INPUT-DATA-GENERATOR that transforms the data from other disciplines (cold start emissions, traffic emissions from the PARAMICS traffic micro-simulation model, building frontage data) for a selected subset of the region into IFDM-OSPM input data as described by Table 6.

4 The 8-letter filename, a limit coming from the DOS operating system in use when the UI was programmed. A file under DOS is identified by a Path-name, a file name (8 letters at most) and the file extension.

2.7.2.3 The input data generator

A. Overview

The IFDM-OSPM input data (Table 6) are quite complex in structure. All information needed to construct the input is already stored in the computer. Hence, it is logical to write a program that, for a given receptor point, computes the geometry and emissions situation in a street canyon as seen from that particular point in the street canyon. Once this program has been made for an arbitrary point in a street canyon, it is quit simple to write a program that, for a given street (or segment of a street), 'walks' along that street, generating the co-ordinates for an receptor every 10 of 15 meters. Once written, this program needs little extension to handle all the streets in a certain part of the region under study, such as the environment of the Brusselsesteenweg , the Kliniekstraat, or any other city quarter one wants to study with the integrated tool.

Practically, this input data generator needs 3 kinds of inputs:

- ⇨ Traffic (hourly averages of emission & speed and number of light & heavy duty cars), data present in the output of the Paramics micro simulation model;
- ⇨ Building frontage data, store as connected line segments (provided by the city of Gent);
- ⇨ The set of streets where receptors are to be placed, which can be created by any digitizer.

There are two output files to be generated:

- ⇨ for the entire region, simulated by Paramics: line sources for IFDM (Table 5);
- ⇨ for the selected sub region: IFDM-OSPM- street-canyon data (Table 2) per receptor.

The Paramics output, transferred from Ugent to VITO, is in the form of large XML-files, about 1.2 Gigabyte per emission scenario simulated. The files contain, per hour, for each vehicle category, accumulated values of number of cars, their speed, emission and acceleration summed per square meter of road surface, as observed with an sampling frequency of 1 (or 0.5) second.

The Paramics output data are first transformed into quantities expressed per meter along the street axes covering the region (Figure 9a). In the street axes network, line segments belonging to the same physical street must be connected. Cold start emissions are brought under a similar format. So we end up with two kind of geo-referenced data:

- ➢ emission and traffic data along the street axes network;
- ➢ building frontage and building data that describe the geometrical aspects of the street canyons (Figure 9b).

Having all this, the automatic generation of IFDM-OSPM input records is relatively easy[5].

Figure 9

Figure a: The street axes network covering the Paramics simulation region

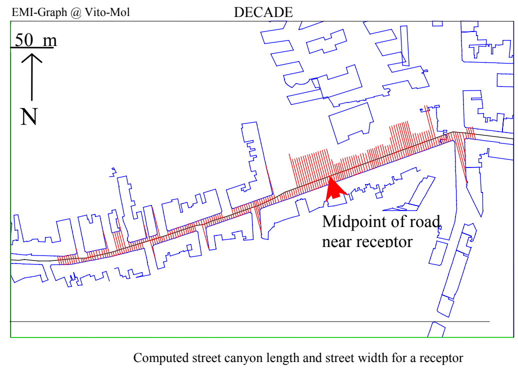


Figure b: Automatic computation of street canyon data. Given detail: maximum length and width

2.7.3 Exposure analysis

Mobilee was set out to derive a methodology for exposure assessment. To prepare for a detailed exposure assessment both detailed emission patterns and concentration fields have been developed. Within the scope and objectives of Mobilee we had to take into account two limitations for exposure assessment for the case study:

- no additional measurements of pollutant concentrations were available to establish differences in different micro-environments. The use of literature data provides a proxy for the exposure in the case study.
- the dynamical pattern of people has to be derived from existing activity patterns, without further examination of time-activity patterns through questionnaires. This had as a consequence that no information on influx and outflux of people across the boundaries of the area was known. Although the methodology is capable of handling this, we chose for exposure scenarios, with predefined activity patterns, rather than for real and dynamic exposure patterns in the case study, to avoid creating a false sense of accuracy for the case study.

The exposure assessment uses a GIS based approach, where traffic related concentration-increments derived from the dispersion model are intersected with population data. Next the concentrations are used to derive indoor concentrations in buildings and cars to establish the total traffic related air pollution exposure of people in the area. When taking into account the time activity pattern of the population, a time dependant exposure pattern is then derived. Without applicable time-activity data, time-activity scenarios are used to study the difference in exposure due to different behaviour. The approach resembles the

[5] The geometry computations are relatively complex as they must deal with all kind of discontinuities in the building fronts. This problem was solved in an earlier project (Decade).

methodology used by Gulliver and Briggs (2005) and is schematically given in the figure below. In the next paragraphs we discuss the methodology to derive traffic related outdoor exposure indicators, and the relation to indoor exposure.

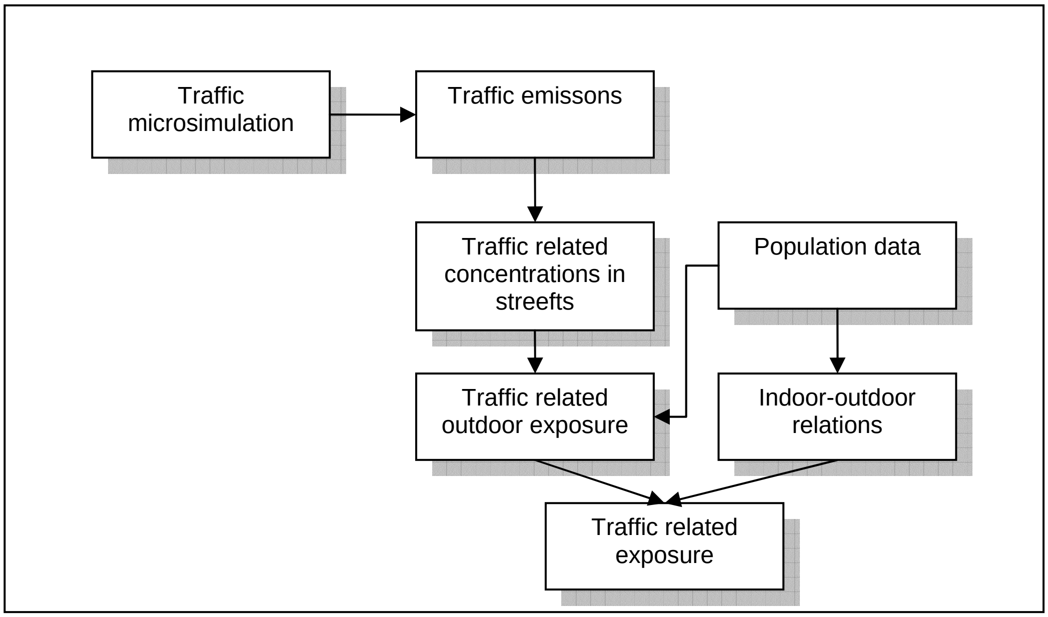


Figure 10 Schematic representation of our approach to exposure

2.7.3.1 Exposure at street level

We used PM2.5 and NO_2 to test the methodology to estimate the exposure of the total residential population. 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 region.

It was further envisaged that the changes in the population of the different street segments would be calculated from the Origin-Destination (O-D) matrix that describes the number of people leaving or arriving at each street segment. Analysis of the data revealed however that the number of people arriving and leaving was almost exactly the same. The O-D matrix does describe the resulting traffic flows in an accurate way, but apparently was not designed to model the movement of populations. To account for the people in traffic, and to study the different aspects of the new industrial sites we have completed the existing population maps with information from the local mobility plan and from the development plan for the industrial site.

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. Privacy laws do not allow for further detail. Then the residential population was multiplied with the concentrations above rooftops to calculate the population-weighted exposure to $PM_{2.5}$ and NO_2. When using the calculated concentrations for the canyons the exposure level was higher but the conclusions (increase, decrease between scenarios) within the street segments did not change very much (see maps in annexes 5.4 and 5.6). The calculation was done for the four scenarios (current, business as usual (BAU) and the two plan scenarios: scenario1, a mobility plan without redevelopment of the industrial site and scenario2, a mobility plan with redevelopment). The change between the current and the BAU scenario was calculated to estimate the impact of EU legislation. Then, the BAU and plan scenarios (with the mobility plan, and with redevelopment in the second scenario) were compared to make an estimation of the impact of the mobility plan and the redevelopment plan. In addition, different location types (e.g. combined residential and commerce area comparing to residential area only) were compared.

In addition to exposure of people staying in the street segments, exposure to drivers and their passengers (1.3 persons per car) in a certain street segment was calculated with a traffic count map and time being exposed based on street length and average vehicle speed. The time most cars and heavy duty vehicles were present in a certain street segment was only a few seconds.

2.7.3.2 Methodologies for indoor exposure

Outdoor air pollution penetrates in indoor environments, adding further to the exposure of people to traffic related air pollution. The exposure to pollutants indoor (residential) is function of the concentration outdoor and the penetration level or filtering level of the building, the sources indoor, the chemical adsorption indoors and the ventilation rate.. To determine the fraction of the indoor exposure that relates to outdoor pollution the infiltration factor or indoor-outdoor relationship is needed. This unitless fraction takes into account the fraction that penetrates indoor and is available for exposure (taking into account deposition or adsorption). For the infiltration efficiency we assume the following relationship between concentrations indoor (Cin) and outdoor (Cout) (see also, Wallace, 1996, Allen et al., 2003 and Yeh et al., 2002):

$$\frac{C_{in}}{C_{out}} = \frac{Pa}{a+k} = F \qquad (1)$$

The penetration factor P is the dimensionless fraction of the pollutant in ambient air that penetrates into the indoor environment. A is the air exchange rate, and k the deposition or adsorption rate. In his review Wallace (1996) concludes that the penetration factor is 1 for gases and close to one for PM_{10} and $PM_{2.5}$. This is confirmed by Allen et al (2003) for $PM_{2.5}$. Ranges of deposition rates have been reported in Wallace (1996) and He et al. (2005) and compared with other studies. Allen et al. (2003) report additional results. The influence of outdoor concentrations C_a (µg/m³) on exposure in indoor environments is thus described as

E_{indoor}= F x C_{out} x T_{indoor}

Where E_{indoor}, the exposure (in µg/m³.s) is a function of the time spent in the indoor environment and a penetrated fraction of C_a, F being the indoor/outdoor (I/O) relationship for a certain pollutant and indoor environment. F can be measured, using tracer gas techniques or simultaneous indoor/outdoor measurements. Here we use selected results from a literature review for Mobilee. We believe that these data give satisfying results, but more research is needed to create a database of input/output factors for typical residences, schools and office buildings in Belgium.

NO_2: I/O factors for homes, schools and other indoor environments

Poupard et al. (2005) demonstrate convincingly in a two week measurement experiment that the I/O relationship for different schools in France is between 0.87 and 1 for NO_2. The result is also robust to changes in air-tightness of the building (varying from low to high permeability), outdoor concentrations, and occupancy of the class. In residences in Switzerland where no smoking or cooking occurred, Monn et al. (1997) find an I/O factor of 0.4 to 0.7.

$PM_{2.5}$: I/O factors for homes, schools and other indoor environments

Both in the Expolis study (Hanninen et al., 2004) and in North American PTEAM study (Ozkaynak et al., 1996; Yeh et al., 2002) the I/O relation for $PM_{2.5}$ varies between 0.5 and 0.7. Kruize et al. use distribution of 0.4 to 0.7 in the Netherlands (Kruize et al., 2003).

This is further corroborated by Monn et al. (1997) who find an I/O relation for PM_{10} of about 0.7 (0.5 – 1), and of 0.54 for $PM_{2.5}$ in Swiss homes without gas cooking smoking or human activity, indicating that this is due to outdoor infiltration only.

2.7.4 Impact analysis

2.7.4.1 New information from recent epidemiological research

There is ample evidence that air pollution is an important risk factor in aggravating or inducing severe health effects and premature mortality. Combustion related particles are a suspected contribution to these health effects, and proximity and exposure to traffic more suspected than others.

Two large scale prospective cohort studies attracted increased attention to particulate matter air pollution. Both the Harvard Six Cities study (Dockery et al, 1993), and the American Cancer Society study (Pope et al, 1995 and 2002) provide strong evidence for the effect of chronic (long-term) exposure to $PM_{2.5}$ on premature mortality in the general population. Even at low concentrations, the risk posed by ambient $PM_{2.5}$ seems comparable to passive smoking risks. Since then several time-series studies in Europe and the US (Katsouyanni et al., 2001; Samet et al., 2000) have gathered more information on the effect of acute (short-term) exposures to particulate matter (expressed as PM_{10} or as black smoke) on mortality. Epidemiological studies have also shown that respiratory diseases are influenced by or even that the incidence of diseases increases with increasing ambient concentrations of particulate matter (Atkinson, 2001; Le Tertre et al. 2002; Abbey et al., 1995). These morbidity effects, even of very minor respiratory symptoms (Medina et al.1997; Ostro, 1987) contribute to the conviction that particulate matter air pollution is a driver of disease and leads to premature mortality. It now seems plausible that particulate air pollution is causing these health effects, but important questions remain about the exact mechanism of causation, and about the sources contributing to the health impact.

Intervention studies clearly demonstrate the role of air pollution in reducing health impacts. In Dublin, Ireland Clancy et al. (2002) demonstrate that a drastic reduction of black smoke and SO_2 concentrations as a consequence of a law banning the use of coal in the city of Dublin from 1 September 1990 on, lead to reduced mortality rates after the ban. In Utah Valley (US), a strike at the local steel mill, had a remarkable beneficial effect on the health of the local population. Arden C. Pope (1996) reports that the industrial air pollution in the valley 1) decreased lung function; 2) increased incidence of respiratory symptoms; 3) increased school absenteeism; 4) increased respiratory hospital admissions; 5) increased mortality, especially respiratory and cardiovascular mortality; and 6) possibly increased lung cancer.

Within the many studies that relate air pollution to health some studies point to traffic as the main culprit. In a recent overview the WHO summarizes the available evidence of the role of transport in the air pollution and health debate (WHO, 2005). The evidence of traffic related premature mortality is indirect. Some studies single out transport from ambient air pollution studies like the Harvard Six Cities study through modelling and source apportionment techniques (Schwartz et al., 2002). Other studies use exposure proxies like the distance to roads or traffic density. Hoek et al. (2002) found an increased risk to cardiopulmonary mortality for people living close to major roads, in addition to urban black smoke or NO2 concentrations. For morbidity there is more empirical and direct evidence. Respiratory diseases, increased severity of existing respiratory conditions (exacerbation of asthma), effects on cardiovascular diseased people are mentioned in literature to be associated with black smoke, different particle fractions and NO2. Panel studies provide the best information, especially when using additional measured data (e.g. Janssen et al. 2003).

NO2 is in this context probably not the main causing factor, but it remains an important effect modifier (see also Katsouyanni et al., 2001) and contributor to the formation of secondary aerosols and to tropospheric ozone.

2.7.4.2 Health impact Assessment: Exposure of population subgroups to airborne pollutants & Application of health-impact functions

The Mobilee project built on this epidemiological evidence and focused on a detailed analysis of traffic movements, emissions and dispersion, and dynamics of the population. The objective of the health impact assessment work package was to develop and apply a methodology to deal with dynamic exposure to traffic-related air pollution on a local scale in cities. Here we describe the methodology, and how the application to the results for the area of Gentbrugge is treated.

Health impact assessment

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 et al. 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

In air pollution studies where the relation between health effect(y) and pollutant ($PM_{2.5}$) is log-linear, the outcome is described as:

$$y = B.\exp(\beta.PM_{2.5})$$

B being the incidence or prevalence of the disease in absence of air pollution. The relative risk for an increase in $PM_{2.5}$ is:

$$RR = \exp(\beta.\Delta PM_{2.5}) = y/B$$

A change in the number of attributable cases, Δy, as a consequence of a change in air pollution $\Delta PM_{2.5}$ is expressed as:

$$\Delta y = y_0.(\exp(\beta.\Delta PM_{2.5}) - 1) = (y_0/B)(y-B) \qquad (1)$$

with y_0 the initial number of cases, before the change in air pollution. In cases where no health threshold is used $\Delta PM_{2.5}$ is off course the concentration and y_0 is equal to B, and therefore unknown (there is always air pollution). We can rewrite equation (1) as:

$$\Delta y = -y.(\exp(-\beta.PM_{2.5}) - 1) = y-B = y-y_0$$

y is the total number of cases coinciding with concentration $PM_{2.5}$. In case of a threshold T a similar formulation can be written:

$$\Delta y = y_0.(\exp(\beta.(PM_{2.5} - T)) - 1)$$

or

$$\Delta y = -y.(\exp(-\beta.(PM_{2.5} - T)) - 1)$$

if $PM_{2.5} > T$ µg/m³. y_0 is now the number of cases when $PM_{2.5}$ is below T. For the purpose of incremental traffic related air pollution a discussion of a threshold is less important however. In ExternE marginal changes in air pollution are being considered, and than a first order linear approach is applicable:

$$\Delta y = y_0.(\exp(\beta.\Delta PM_{2.5}) - 1) \approx y_0.\beta.\Delta PM_{2.5}$$

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 et al., 2001). In the original study the relative risk is associated with PM_{10}, whereas we apply this risk to $PM_{2.5}$. This is plausible in an urban environment, where traffic contributes for more than 60% to the overall PM_{10} concentrations, but it also adds an extra uncertainty to the results. However the relative change of the morbidity impact when going from 2003 to 2010 is not 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.

For mortality impacts an identical approach is proposed by Künzli et al (2000).It now seems 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 USA.

A critical reflection on application of the current epidemiological knowledge.

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 et al., 2000) or on a city-wide scale (Medina et al. 2004). In those studies ambient air pollution concentrations, measured by central site monitoring stations, were used as the suitable indicator of exposure. 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. 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 et al., 2004). Therefore a tentative impact assessment based on concentration-response functions derived from central site monitoring stations is possible resulting in an assessment of impacts on a population level, without a detailed analysis per street or street segment. This is the current practice and has been applied e.g. in ExternE for the calculation of external costs of transport (Int Panis et al., 2004).

It was intended in Mobilee to go a step further into developing indicators on health on a very local level, informing local stakeholders either directly or after aggregation. Intra-urban comparison between streets or between groups of people is the level of detail that is required than. Where we foresaw in 2001 that new information would be available (without doing an epidemiological study ourselves) at the end of the project to use in this kind of detailed impact assessment, it is now clear that still more research is needed. For example Forsberg and colleagues (2005) note that *"Obviously there is a striking need to introduce more specific exposure variables and a higher geographical resolution in epidemiology as well as in health impact assessments."*

The same message is formulated by the WHO (2005) as

"*Most of the studies measured air pollution at a single site and made no distinction between spatial variation in levels of traffic-related air pollution or exposure"* and

"*All this information identifies the hazard sufficiently, but is still too inconsistent to derive a well-based exposure–response function, which is needed to quantify precisely the adverse effects of transport-related air pollution. The epidemiological studies available used different exposure and outcome indicators, which limits the possibility of comparing their results quantitatively and estimating a common risk function, as has been done for studies of ambient air pollution".* The Mobilee methodology will work at its finest resolution for health impacts when these quantifiable risk functions come available. Similar projects in Europe are faced with the same constraints, and use exposure as the impact indicator.

Moreover we work on a very local scale, a suburb of the city of Ghent, with about 15 000 inhabitants. We have detailed the exposure up to a resolution of 25 m, and have distinguished between segments of streets, assigning 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 obvious that source specific impacts of air pollution and benefits of policy measures should be available. 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. In other words, more research is still needed. It is a matter of defining the necessary and detailed exposure-response functions in order to use models like Mobilee adequately.

2.8 Analysis of traffic safety and crossability

2.8.1 Traffic safety

The analysis of accidents is based on data of the city of Gent of accidents in the period 2000 - 2002.The analysis is based on the number of casualties. Then, this number has been made relative by dividing by the length of the segment. Accidents in a segment are assigned to the street segment, accidents on a crossing are assigned to the both streets (but the score is then divided by two). These results are projected in a map in Annex 5.7.

2.8.2 Crossability

The crossability is the average delay time for crossing a street. It is affected the traffic flow (time between vehicles), the width of the street and the average speed of crossing pedestrians. The crossability is calculated using the dynamic traffic model, for the present situation as well as for the possible future scenarios. These results are projected on a map in Annex 5.7.

3 Detailed description of the results

3.1 Demarcation and description of the selected case-study area in Ghent

A map showing the demarcation of the case study area can be found in annex 5.7

The case study is divided in four areas:

- The high density area of the Gentbrugge neighbourhood (part of the 19^{th} century belt): bounded by the river Scheldt in the North, the railway in the West, the highway "E17" in the South and E. Blockstraat, Kerkstraat, E. Hielstraat and Braemkasteelstraat in the East.
- The old ARBED-sites (north and south) were brownfield development is planned
- The "Brusselsesteenweg": incoming urban axis with different functions
- The area between the Brusselsesteenweg , the river Scheldt, the railway and the E17: medium to high density residential area (Sas- en Bassijnwijk – Flora)

3.2 Definition of selected typologies

In view of assessing the viability and environmental quality of a municipality, a city, a city quarter or a specific location, we need to make a distinction between different types of areas with their own traffic characteristics, spatial and environment characteristics and viability levels. Depending on the type of situation, other viability levels will be defined and certain indicators will carry more weight than others. The goal is to end up with an environment capacity matrix that, depending on the type of situation, will describe indicators that define the viability and the environmental quality of the area.

Different factors have an influence on the behaviour and expectation level towards viability of users of (the sides of) the roads (as a public space):
1. Hierarchical level of the city / town / neighbourhood / village (due to the presence of functions and amenities,…)
2. Relative geographical location: location of the road in the broader urban network of the city / town / neighbourhood / village
3. Amenities on the side of the road
4. Morphological structure of the road
5. function of the road in traffic network

The three last criteria can be incorporated in a classification of road types. Without the pretension of making the ultimate classification we distinguish the following types of roads and environments:

type 1: important shopping road: main concentration of functions and amenities; limited function in traffic network: relieved by other parallel structures

type 2: major incoming urban axis / urban boulevard: mixed use, high density, lots of traffic (> 20.000 vehicles/day), important function in public transport,

type 3: through road: road with regional function going through the centre of a village / town / urban district

- subtype 3a: narrow street type (< 12 m)
- subtype 3b: normal street type (12 – 17 to 20 m)
- subtype 3c: broad street / boulevard type (> 17 to 20 m): relative independent functioning of both sides, large units, rows of trees,…

type 4: inter local road: road connecting different centres: concentration of functions and amenities in the centres special attention nearby schools,…

type 5: opening up road: collecting traffic from residential (subtype 5a) or non-residential (subtype 5b) area towards major roads

type 6: local street in residential area (woonstraat)

In certain occasions the general type is strongly influenced by the presence of a specific / dominating amenity (hospital, sports stadium,…).

Investigated streets in the study area
Brusselsesteenweg: type 2
Kerkstraat: type 4
Rinskoflaan: type 5
Kliniekstraat: type 6 – special item: presence of hospital (one of the two entrees)

3.3 Resident's Perception of Traffic Viability versus Expert Observations and Calculations

3.3.1 Results of questionnaire

We selected 120 persons to fill in the questionnaire (30 persons * 4 streets). 94 persons responded.

- Almost half of the respondents don't feel safe in traffic.
- 63% of the respondents have put double-glazing in their houses or intend to do so because of noise nuisance.

- There is a difference in reachability on foot for a number of services between the 4 streets. This is due to location characteristics and not to the perception of distance in accordance to age.
- Although Brusselsesteenweg is a traffic intensive street, people are not that negative about viability. They do confirm that a lot of accidents with vulnerable road users happen.
- In 3 of the 4 streets people agree that the infrastructure invites drivers to speed.

We asked the respondents if they are hampered by traffic viability problems. We calculated the ranking of viability problems from most hampering to least hampering:

1. noise from road transport
2. vibrations from traffic
3. bad smell from exhaust gases
4. noise from trains
5. smog
6. illumination of the roads
7. illumination from the cars
8. noise from air traffic.

Besides we asked the respondents how important different traffic viability problems are. We calculated the ranking from most important to least important:

1. too high speeds of the motorised traffic
2. unsafety for vulnerable road users
3. exhaust gases are harmful for health and environment
4. amount of traffic
5. noise of the traffic
6. low reachability by a lack of public transport
7. bad smell from exhaust fumes
8. bad reachability by congestion.

3.3.2 Results of expert observation survey

3.3.2.1 Accessibility on the basis of the observation research

Traffic intensities

In the observation card the traffic planner described the four streets as follows: the Brusselsesteenweg is a main approach road, the Kliniekstraat and Kerkstraat are one way residential streets, the Rinskopflaan was described as 'opening-up road'. All four streets are situated in a centre area. The observation research clearly confirms the pressure from traffic on the viability in the Brusselsesteenweg. The perception research gives extra information through the question of perception of freight transport in the street. Kliniekstraat and Kerkstraat are both one-way residential streets but the composition of traffic in the Kliniekstraat results in more nuisance for the inhabitants. The Kliniekstraat has to deal with, according to the inhabitants, relatively more freight transport.

Facilities for the soft road users

When we look at the description of cycle paths in the four streets (through the observation), the results of the perception research are partly obvious: the Brusselsesteenweg is after all the only of the four streets where a cycle path is installed. Interesting is that when one asks for the safety of the cyclist, the cycle path in the Brusselsesteenweg – compared to the 'suggestion' line for bicycle traffic in opposite direction (in the Kliniekstraat) and the complete absence of cycling facilities in Kliniekstraat and Rinskopflaan – is not safer (no statistic significant difference).
Concerning the status and width of footpaths no differences in perception were expected: each of the four streets has at both sides of the street a footpath of min. 1,5 meter width (cfr. observation card)

Parking facilities

The judgement of the expert in the observation card about the parking possibilities in the four streets of the study area is milder than the survey: although in the Kliniekstraat and the Kerkstraat parking places are only installed on one side of the street, in none of the four streets on the moment of the observation parking problems (double/wild parking, …) were determined.

Traffic safety

The analysis of accidents is based on data of the city of Gent of accidents in the period 2000 - 2002. The analysis is based on the number of casualties. The casualties are integrated in a index, where a casualty counts as 1, and someone who died as 5. To make the results comparable, the index is divided by the street length; if this is not done, the index is influenced by the street-length (the longer the street, the more casualties).

The Brusselsesteenweg is by far the most dangerous street (table 7). The index of the Kliniekstraat is also more than 1. The Rinskopflaan and the Kerkstraat have about the same level of traffic safety.

Table 8

	casualties	deceased	index	street length (m)	index
Brusselsesteenweg	73	1	78	1886	4,135737
Rinskopflaan	3		3	563	0,53286
Kerkstraat	6		6	964	0,622407
Kliniekstraat	4		4	375	1,066667

Crossability: objective calculation of crossing of each of the four streets of the study area

Based on the intensity of the traffic, the street width and the crossing speed, the average waiting time can be measured in the traffic model. This calculation gives the next results:

- Brusselsesteenweg: between 13 and 92 seconds (depending on the design of the street)
- Rinskopflaan: between 3 and 4 seconds
- Kerkstraat: 2 seconds
- Kliniekstraat: 1 second

In general, the crossability is considered as very good if the average waiting time is lower than 5 seconds. This is the case for all streets, except the Brusselsesteenweg, where the average waiting time is at least 13 seconds, and in general more. So for this street, the crossability is very bad.

Presence public transport: comparison with the offer according to the time schedules

There are several lines of public transport that serve the area:

- tramway
- trolley
- bus
- train

The frequency depends on the type of line (Table 9)

Table 9

max. waiting time in min.	service weekday peak hours	min. service weekday	Saturday	Sunday
tramway 2 lines	7	15	7 - 10	12
tramway 1 line	15	30	15 - 30	25
trolley	7	15	7 - 15	12 - 15
local bus	15	30	15 - 30	30
train	60	60	120	120

This way, it is possible to make a hierarchy in public transport lines, based on the frequency (from high frequency to low frequency):

- tramway 2 lines
- trolley
- tramway 1 line
- local bus
- train

In most of the public transport stops, there are several types of lines available. Based on this model, it is possible to make a hierarchy of the several stops, based on the availability of lines (Table 10, Figure in Annex 5.7)

Table 10

level	lines
1	tramway 2 lines + local bus
2	trolley + local bus
3	tramway 2 lines
4	trolley
5	tramway 1 line
6	local bus
7	train

For each street, the minimum and the maximum walking distances for each level will be determined (
Table 11). If the closest stop is a higher-level stop, then the distances to lower-level stops are not calculated anymore, because this makes no sense anymore (people will not walk further for lower-level facilities). An exception is made for the train station, which is categorised as level 7. This connection is unimportant on a local level, but it can be more important on a higher level for more long-distant travels.

Table 11

meters	Brusselsesteenweg		Rinskopflaan		Kerkstraat		Kliniekstraat	
level	min	max	min	max	min	max	min	max
1	0	750	550	850	925	1300	550	925
2	-	-	450	750	300	1000	250	575
3	0	250	-	-	425	1300	-	-
4	-	-	-	-	100	750	0	400
5	-	-	50	600	-	-	-	-
6	-	-	-	-	-	-	-	-
7	550	1300	0	300	775	1175	300	650

The Brusselsesteenweg has the highest level of public transport. This street has the only stops of level 1, with 2 tramlines and a local bus. The maximum walking distance to reach a stop of this level is 750 meters. There is also a stop of level 3 (2 lines of the tramway). In this street, everybody has public transport (at least 2 lines of the tramway) within a walking distance of 250 meters. The distance to the train station is between 550 and 1300 meters.

The Rinskopflaan is situated in the middle of the region with the level 1 and the level 2 stops. The consequence is that there is a big offer in public transport within a walking distance between 500 and 850 meter. The closest stop (level 5) is at a minimum distance of 50 meter. The train station is situated in this street.

The Kerkstraat is a long street, so the variance in distances is big. This street is far away from the stops of level 1, but a stop of level 2 is at minimum 300 meters. For everybody in this street, the stop of level 2 is closer than the stop of level 1. The closest stop is a stop of level 4 (trolley), within a walking distance between 100 and 750 meters. The walking distance to the station is between 775 and 1175 meters.

Kliniekstraat is closer to the cluster of level 2 than to the cluster of level 1. At the end of the street is a stop of level 4 (trolley). The distance to the train station is between 300 and 650 meters.

The Brusselsesteenweg has the best ranking concerning public transport because of the availability of 2 tramways, and in some parts an additional local bus line. In a second place, the Kliniekstraat is easy to reach because of the trolley, and also the local bus line is not so far away. The Rinskopflaan is in a region between important clusters of public transport, so the closest stop of high-level public transport (level 1 or 2), is at least at 450 meters. This is the highest minimum distance. For the Kerkstraat, it is more difficult to go to conclusions; because of the length of this street, the variance in walking distance is quite high.

3.3.3 Similarities and differences between results of both methods

Concerning traffic intensities the results of the nuisance survey are clearly in line with the observation card: the perceived traffic intensities is in accordance with the road categorisation to which the concerned road belongs to: the Brusselsesteenweg has obviously more traffic to deal with. The perception research results nevertheless in extra information on the composition of traffic: although three out of four investigated streets are 'residential streets', the traffic in the Kliniekstraat causes more nuisance because of the stronger presence of freight transport. Concerning the facilities for the vulnerable road user, we notice that…

The hierarchical evaluation of the accessibility by public transport by the expert corresponds to the opinion of the inhabitants: Brusselsesteenweg (best accessible) scores best. Kerkstraat, which lies partly in between the good accessible places has a moderate score. The presence of a railway station in the Rinskoflaan, although only useful for the external accessibility, has a positive effect on the opinion on public transport (underestimated by the expert).

There 's a great correspondence in the Brusselsesteenweg between the calculated low crossibility (average waiting time mainly exceeds 15s) and the bad score of the inhabitants. In streets that are easier to cross (Rinskoflaan, Kliniekstraat and Kerkstraat all have very short average waiting times: < 4s) the opinion of the inhabitants is more charitable. Remarkable is that people are less positive in the Rinskoflaan and Kliniekstraat where there in (a sensation of) more traffic than in the Kerkstraat.

3.4 Differences in flows and congestion for different scenario's

3.4.1 Current situation (2002 network & 2002 OD-matrices)

The simulation of the current simulation shows some minor delays in the busiest periods of the day for vehicles driving on to the Brusselsesteenweg (see Figure 11). However, the queues don't grow very long, and they do not cause secondary effects like congestion spillback. These phenomena were also observed in the field. In the current situation, the traffic circulation is smooth.

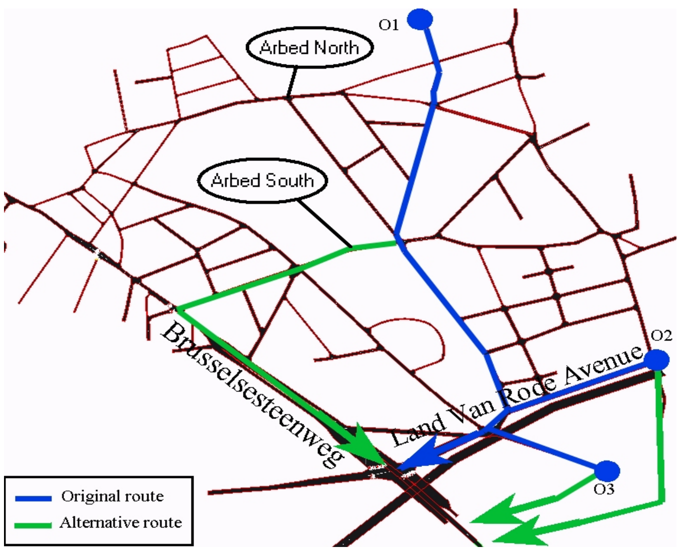


Figure 11: Arbed North site, Arbed South site, Brusselsesteenweg, Land Van Rode Avenue, origins O1, O2 and O3, original routes and alternative routes.

3.4.2 2010 network & 2002 OD-matrices

If travellers would take the exact same routes to reach their destination as they do in the current situation, they would face a considerable amount of congestion on the Land Van Rode Avenue (LVR Avenue, see figure 1). The LVR Avenue mainly collects traffic from the three origins depicted in figure 1 (O1, O2 and O3). In scenario 1, the LVR Avenue is downsized from 2 x 2 lanes to 2 x 1 lanes, and now traffic demand exceeds the Avenues capacity in the busiest moments of the day. Consequently, a queue develops and this queue spills back in the network. As a secondary effect, other network links are getting congested as well.

This situation would occur if all travellers took the same routes as they do in the current situation.

The macroscopic model of the city of Gent shows however that travellers change routes due to the smaller capacity of the LVR Avenue. A number of travellers (this number depends on the time of day) will reach the destination via the alternative routes depicted in Figure 11. This redistribution of traffic keeps the LVR Avenue from being highly

congested. In the busiest periods of the day, travellers sometimes may have to wait for two cycles to cross traffic lights on the LVR Avenue, but congestion stays limited and there are no secondary effects (such as the spilling back of congestion).
In scenario 1, the traffic circulation is less smooth compared to the current situation, but the congestion stays limited.

3.4.3 2010 network & 2010 OD-matrices

The extra amount of traffic in the 2010 OD-matrices compared to the 2002 OD-matrices is presented in Table 2.

The simulations for the future scenarios show a somewhat heavier loaded network, but the overall picture stays the same: the intersections dealing with the highest travel demands are a bit congested in the busiest moments of the day, but travellers never have to wait for more then two cycles before crossing an intersection and the relatively small queues don't cause secondary effects.

3.5 Noise

3.5.1 Validation and results of micro-modelling

The tool for obtaining noise emission both from micro simulation and from average traffic streams has been developed and tested during the first years of the project. In 2004, the constants used in the harmonized European road traffic noise emission model became available, and were immediately included in the Mobilee tool, as already mentioned. This involved splitting the vehicle noise source into two separate contributions, the engine noise and the rolling noise. In addition, the tool was improved for road surface (including age of the surface and difference between dry and wet) and horizontal directivity of the source was taken into account.

Two types of noise validation of the Mobilee toolbox on the case study network of Gentbrugge were performed. The first validation, which was carried out in 2003, consisted of a set of conventional noise measurements in the study area, and a comparison with the noise levels simulated with the Mobilee tool. The comparison included average level, noise level distribution and noise level power spectrum [1]. The second and more innovating validation was carried out in 2005, and consisted of a set of rides in the case study area. Instantaneous speed, acceleration and noise emission were compared. Both validation rounds will be discussed in the next sections.

3.5.1.1 Conventional noise measurements

On the 5th of June 2003, during the evening rush-hour, sound measurements were done at the 6 observer points shown in Figure 12. Using a B&K 2260 Investigator with a B&K 4189 free-field microphone mounted at a height of 1.2 m and at a distance of 1.2 m from the edge of the road, time series of $L_{Aeq,1s}$ values were measured, for a period of 15 minutes. Simultaneously, the number of vehicles passing by was counted. The results of these counts are shown in Table 12, together with the number of vehicles obtained from 5 different simulation runs. These numbers illustrate the variation between different runs caused by the random processes involved in the traffic simulation Mostly they are quite small. Overall for the evening rush-hour, the simulated number of vehicles differs by at most about 25% from the actual counts, which is small enough to have no significant effect on equivalent noise levels. Measured $L_{Aeq,15m}$ values and statistical noise levels are shown in Table 13.

Traffic simulation and emission calculation at the evening rush-hour of the case study using the Mobilee tool resulted in a 15 minute time series of vehicle emissions. For reasons of efficiency, the propagation calculation was done for each observer point separately, and was in itself also divided into three parts. For the vehicles within the range of 150 m of the observer in question, exact positions of the sources were used. This covered about 10-20 vehicles each time step. The beam trace model was set to account for a maximum of 4 reflections and 1 edge diffraction. To make propagation calculations feasible and efficient for the traffic at larger distance, a grid of emission points was used with a spacing of 5 m. Emission of the traffic on the E17 highway was taken into account separately. A grid with a spacing of 5 m was also used here, but during beam trace only propagation in the vertical plane connecting source and receiver (diffraction over the buildings) was included. The noise barriers were not taken into account.

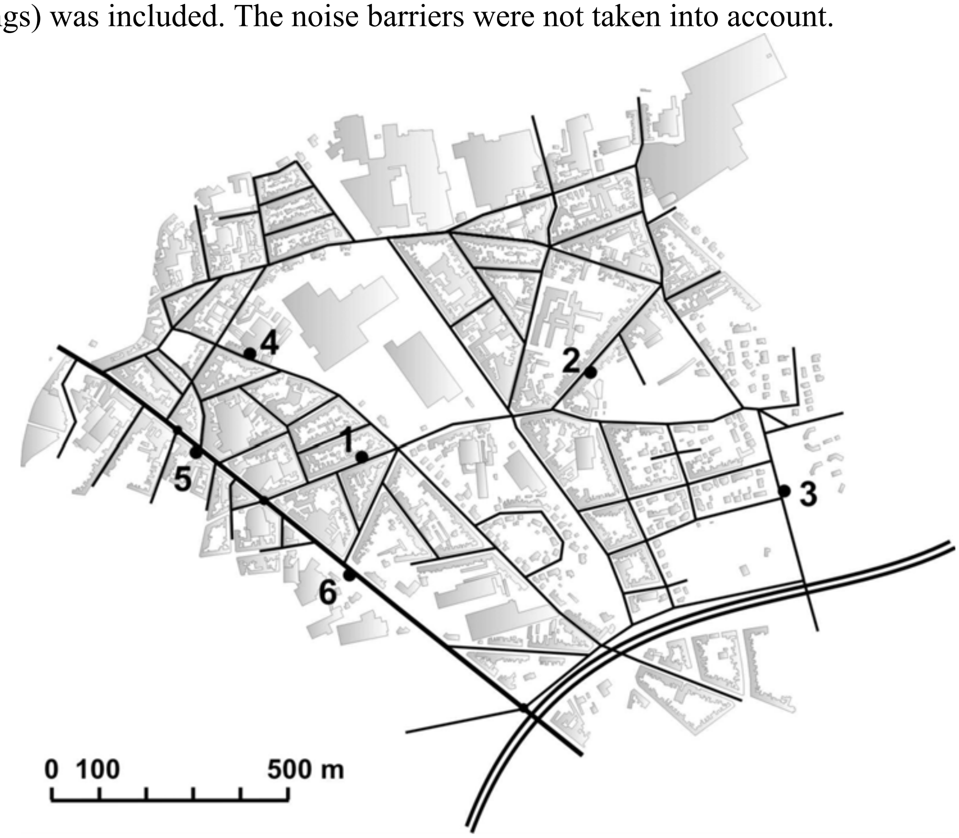


Figure 12 – View of the case study area of Gentbrugge with 6 observer points shown as a dot at the measurement side of the road.

Table 12 – Vehicle counts at the 6 observer points and results of different simulation runs. For points 1 to 4, vehicles were counted along the measurement side of the road (a), and in the opposite travelling direction (b). The counts are each for a duration of 15 minutes, and include all vehicle types under consideration. The mean value is also given, together with its deviation from the measurement.

Point	Measurement	Run 1	Run 2	Run 3	Run 4	Run 5	Mean	Deviation
1(a)	46	39	36	46	38	38	39.4	-14.3%
1(b)	64	72	62	77	67	77	71.0	+10.9%
2(a)	27	36	33	35	30	33	33.4	+23.7%
2(b)	9	7	8	10	8	9	8.4	-6.7%
3(a)	67	79	80	78	72	84	78.6	+17.3%
3(b)	62	57	61	59	61	64	60.4	-2.6%
4(a)	31	23	33	31	29	28	28.8	-7.1%
4(b)	27	26	28	25	27	23	25.8	-4.4%
5(a)	246	208	160	205	216	197	197.2	-19.8%
6(a)	286	280	255	281	298	266	276.0	-3.5%

Table 13 – Measurements and simulations – statistical levels for a period of 15 minutes. The simulated values are for one simulation run only.

Point	Measurement					Simulation			
	L_{Aeq}	L_5	L_{50}	L_{95}		L_{Aeq}	L_5	L_{50}	L_{95}
	70.4	76.7	63.5	49.3		67.5	74.3	60.9	50.3
	64.4	70.1	53.5	43.6		65.6	73.5	51.4	34.0
	67.2	73.4	58.6	49.7		66.2	73.5	58.8	49.9
	66.0	72.5	56.2	41.4		66.2	74.2	51.7	34.9
	73.0	78.3	69.9	62.3		71.3	75.3	68.9	56.6
	73.8	77.6	71.6	60.6		73.7	77.7	70.1	62.1

Finally, a time series of $L_{Aeq,1s}$ immission values was calculated at each observer point. Because of the probabilistic nature of traffic micro-modelling, simulated and measured time-series are not equal, but about the same dynamic pattern seemed to arise; the duration and the magnitude of the events are also comparable.

Figure 13 shows the statistical and cumulative level distributions at the 6 observer points, both for the measurements and simulations. For the $L_{Aeq,15m}$, L_5 and L_{50} values, the deviation between simulation and measurement is on the average within 3 dB(A), as can be seen in Table 13. The deviation in L_{95} is more striking for points 2, 4 and 5. The streets in which point 2 and 4 were situated are both streets with low traffic. Between the passing by of vehicles, the simulated level drops to unrealistically low values of 30 dB(A) and less for this suburban area. The noise coming from other sources such as wind, birds, pedestrians and cyclists, planes at high altitude, ventilation and cooling systems causes the level not to drop so low in reality. The noise coming from the E17 highway has, because of the distance, no effect on the noise immission levels at these points in our simulation. The road at the fifth observation point carries a high amount of traffic, but because of the presence of a lot of shops in the neighbourhood, also a lot of pedestrians are passing by at the evening rush-hour.

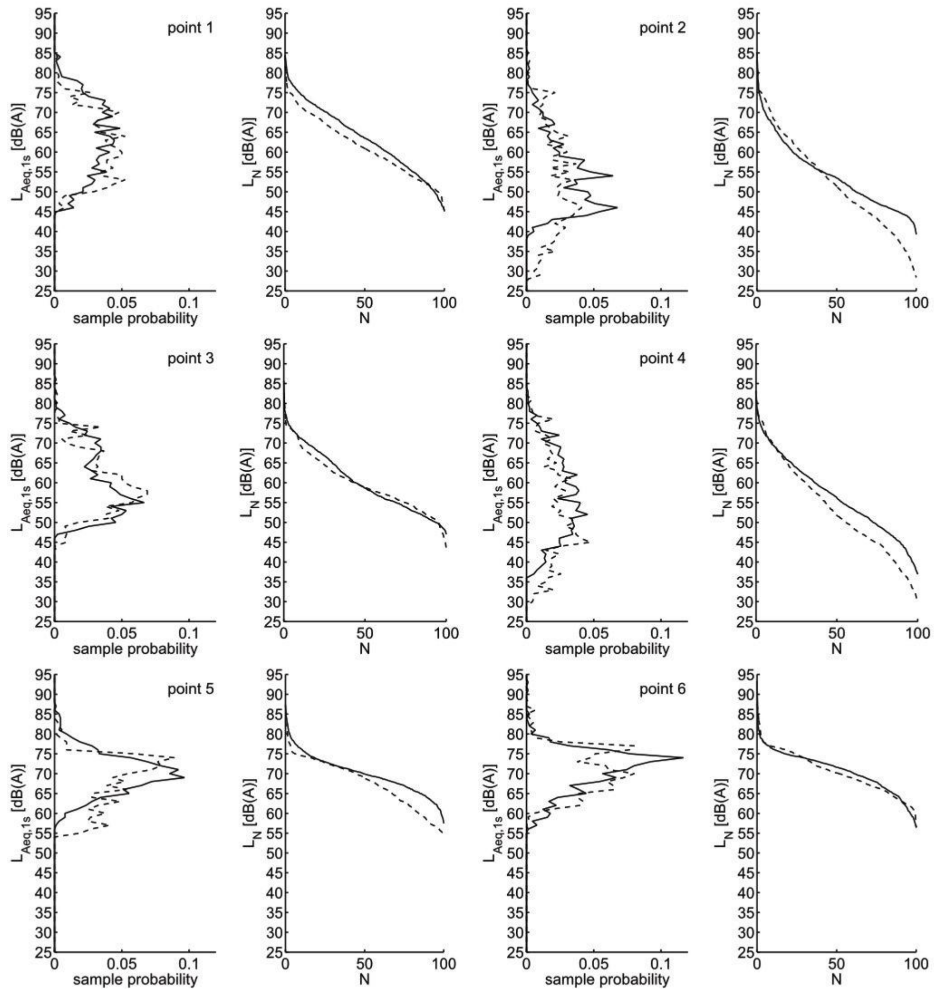


Figure 13 – Statistical and cumulative level distributions at the 6 observer points. The measurements are in solid lines, the simulations in dashed lines.

3.5.1.2 Validation using rides in the case study area

The second set of validations consisted of a number of rides through the case study area. For this, a normal car was equipped with a speed meter and a GPS, which logged the instantaneous velocity and position of the car each second of the ride. Acceleration data was calculated afterwards from the speed data. Two different trajectories through the network were chosen, as shown in Figure 14. The first trajectory represents the local traffic that has its destination in the study area. The second trajectory represents the sneak traffic through the area, from and to the city of Ghent. Both trajectories were driven two times, once with a normal driving style, and once with an aggressive driving style.

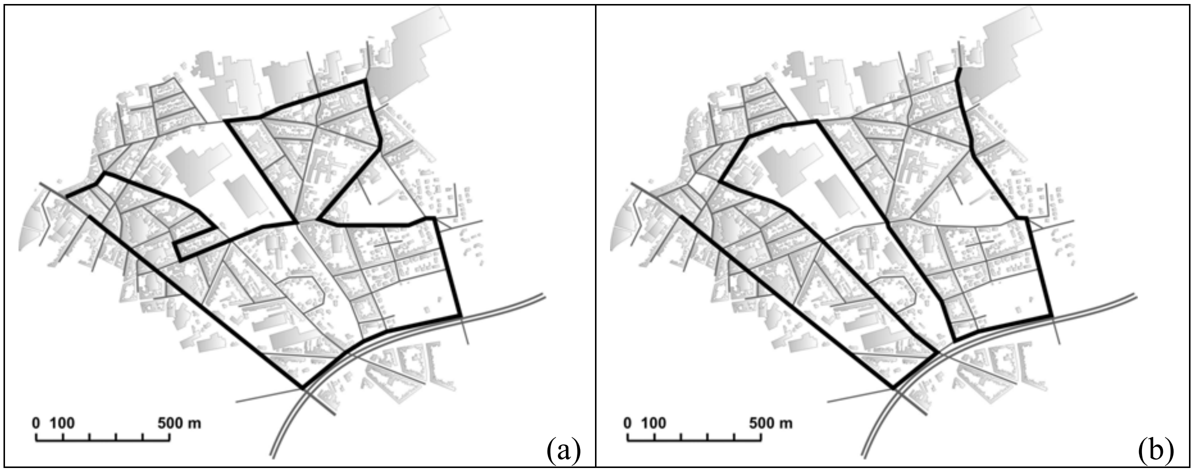


Figure 14 – Selected rides through the case study area. (a) Local destination traffic; (b) sneak traffic.

Using the case study micro simulation model, the speed and acceleration data for all car vehicles driving at some moment along one of both paths was gathered (current situation network). Vehicle emission values were then calculated both for the rides and for the simulation, using the Mobilee toolbox. The emission time series of the car during the ride at various places along the path was compared with the emission of all simulated cars that pass on the same places along the path. For the roads were 70 km/h is allowed, the ride emission is most of the times within the limits predicted by the Mobilee toolbox. For the more urban stretches of road, were only 50 km/h is allowed, several low level peaks are observed during the ride, which are not predicted by the Mobilee toolbox. These can be explained by the fact that the car during the ride had to slow down for an obstacle, such as a person crossing the street, a car parking, or because a parked car is blocking part of the street, and one has to slow down for an oncoming car. These situations are not simulated by a micro model.

A way to aggregate and represent the data is to analyse what level will be predicted by the micro simulation, at all places along the paths where the ride emission had a certain level. In Figure 15, the emission data is given on a categorical scale. One can see that, for low levels on roads were 50 km/h is allowed, on average the simulated emission values are too high, but the ride emission values are still within the limit values which are predicted by the Mobilee toolbox. The slope of the mean simulated values is less steep than it should be. This could mean that the path of a car driving in an urban area will be more interrupted in reality than in micro simulation. For the roads were 70 km/h is allowed, one would expect less sporadic obstacles, but more jams, which are simulated by the Mobilee toolbox. The simulation mean predicts the ride emission better for the higher levels on these roads.

When one looks at the emission of the car considering the whole ride, one can compare the different driving styles. It was found that on the average the emission level is about 2.5 dB higher for the aggressive driving style compared to normal driving. Accounting for the shorter duration of the ride on a path when driving aggressively, it was found that the total emission can still be more than 1 dB higher compared to a normal driving style.

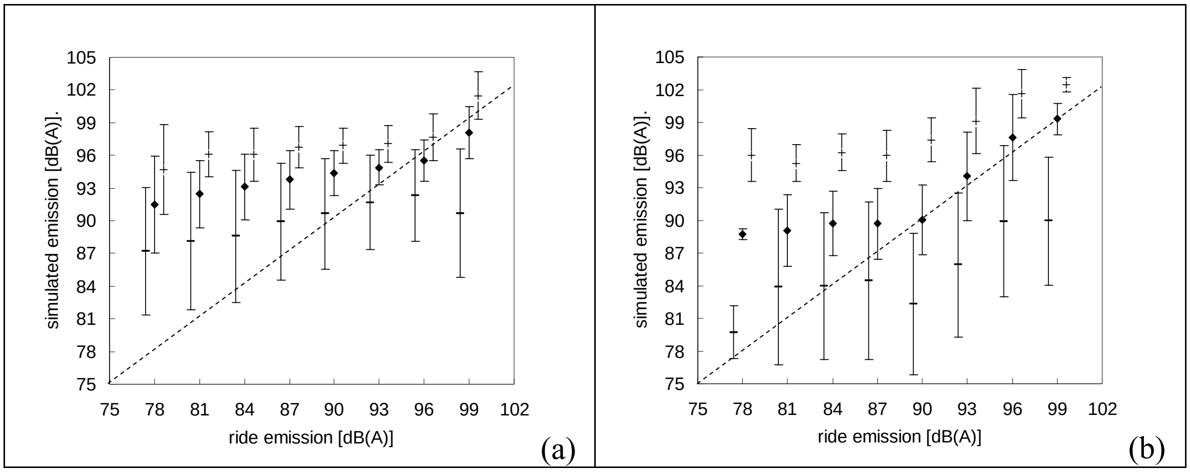


Figure 15 – Predicted level versus ride emission level on a categorical scale, for (a) the roads were 50 km/h is allowed and (b) were 70 km/h is allowed. The markers give the mean value of (♦) the mean predicted emission level, (+) the maximum predicted emission level, (-) the minimum predicted emission level. Standard error bars are also shown.

3.5.2 Conclusions for macroscopic traffic modelling

Micro-simulation of traffic flow was proven to be a powerful tool for assessing the impact of local mobility plans and quantifying the impact of local action plans against noise. However, at a larger geographic scale or when budget is limited, this approach is not feasible. For these cases macroscopic traffic models and/or a limited number of traffic counts is the only feasible alternative. Often no detailed information on speed and acceleration of the vehicles is available. It is common practice to use the allowed speed as the speed for each vehicle. To improve on these assumptions, Mobilee drew some conclusions for good practice in cases where only macroscopic traffic modelling is feasible.

3.5.2.1 Junctions

Near junctions, real vehicle speeds are often quite different from the allowed speed and the effect of acceleration on noise emission can hardly be neglected. Standard calculation methods such as the "Nederlandse rekenmethode 2002[6]" include a correction for crossings managed by traffic lights of e.g. $1.4+0.001p-0.01a$ with p the percentage of heavy vehicles and a the distance to the centre of the crossing. This correction has to be taken into account to a distance of 150m. The German standard method RLS90 suggests a correction that decreases with distance and is at most 3 dB(A) within 40 m from the crossing. It was however pointed out that the correction depends on allowed speed and driving style – which may in turn be influenced by the general surroundings of the crossing[7].

[6] REKEN- EN MEETVOORSCHRIFT WEGVERKEERSLAWAAI 2002, Minister van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Nederland
[7] G. Watts, Harmonoise prediction model for road traffic noise, project report PPR034, UG473

It is clear that assumptions on driving speed and acceleration near a crossing may eventually lead to similar corrections on noise emission levels.

In Mobilee we used the micro-simulation model to learn more about detailed noise dynamics close to junctions (keeping in mind that the micro-simulation model results depend on assumptions on driving behaviour put into the model). Two sets of simulations were considered. The first set consisted of a collection of prototype junctions (and speed humps) with different priority rules. A speed hump resulted in a reduction in noise level of typically 2 to 3 dB(A) in a small area around the obstacle (neglecting noise produced by loose cargo when a truck passes the hump). For roundabouts, a general decrease in noise level growing to 4 dB(A) at 50m from the roundabout was observed. The situation for traffic lights was less clear so no general rule could be extracted. In general, the approach was rather sensitive to changes in traffic model parameters.

The second set of simulations aimed at creating a real traffic context and was based on the case study in Gentbrugge. From Figure 16 it can be seen that using allowed speed underestimates noise levels near the most important junctions that are managed using traffic lights, is underestimated by up to 5 dB(A) (lower middle and left lower area). It is also noticeable that for the lower level roads in the centre of the map, there is no systematic under- or overestimation of noise levels near the small junctions. It is rather difficult to derive general guidelines in that case. Note that the blue colour in the centre is due to an average vehicle speed slightly over the speed limit in this area.

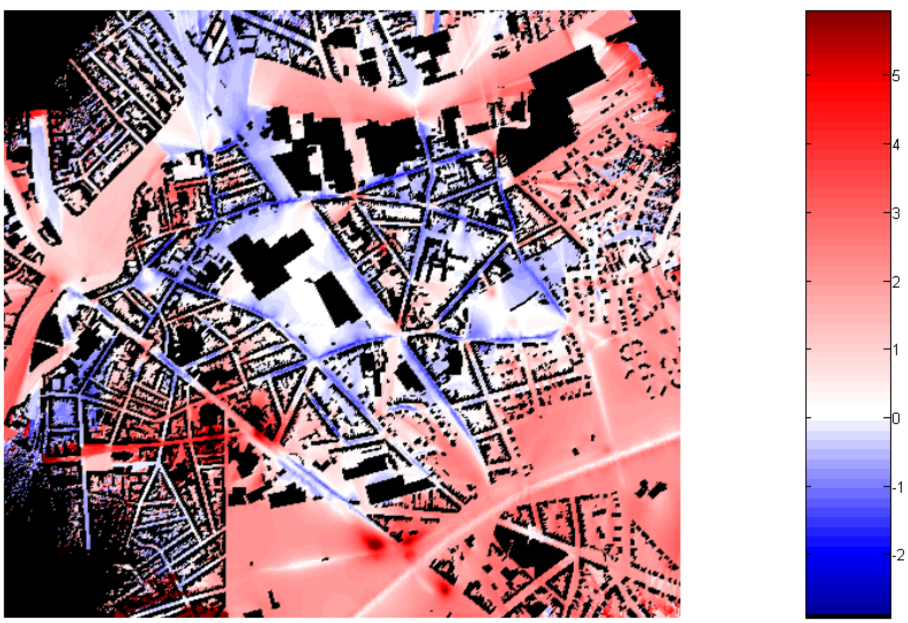


Figure 16 - Difference between road traffic noise simulated using micro-simulation and road traffic noise map based on allowed vehicle speed (in dB(A)).

3.5.2.2 Vehicle velocity from road typology

As mentioned in the methodological part of this report, a first approach considered for improving the correspondence between real vehicle speed and modelled vehicle speed, consisted in using a rather large database of reference situations using fuzzy rule bases or fuzzy neural networks to extract speed distributions based on road characteristics. Unfortunately, it turned out that almost no suitable measured vehicle speeds were available for feeding this database. Thus the categorization of the road had to be limited to a few general categories (taken from the Streetnet database). Using this categorization worked reasonably well for roads outside agglomerations, but in the urban area considered in the case study, the noise emission of the mayor road was overestimated by up to 10 dB(A). The obvious reason is the reduced speed in the built-up area approaching the city of Gent. For the highway and the local roads the error remained within 5 dB(A). In general, it thus seems appropriate to keep use the speed limit as a first approximation for the real vehicle speed if no micro-simulation model or measurement are available.

3.5.2.3 Fleet composition

Noise emissions of road vehicles are limited by European product norms. The noise emission test is however known to be not very representative for real driving conditions. Moreover, vehicle types are approved for the European market, not individual vehicles. Once in operation, noise emission of road vehicles can increase due to malfunction or deliberate tampering with mufflers or tires. To discover trends in emission of individual vehicles, we nevertheless studied type approval levels of vehicles sold in Flanders[8]. The procedure involved collecting statistics on the number of vehicles sold of each type (data Febiac), linking the available types to the homologation types and averaging out. The result is shown in Figure 17. There is no general trend towards lower noise emission which is not unexpected considering that noise emission limits have not become stricter recently. Small changes in average car emission can be attributed to the popularity of particular brands in a particular year. More detailed analyses shows that there is at most 2 dB(A) variation in noise emission amongst popular cars. Therefore it is expected that including more detailed composition of the fleet will not improve traffic noise prediction. The obvious exception is public transport. A decision to use a particular make of vehicle by the company operating busses and trams can influence noise emission in some low-traffic streets considerably. There the only option for improvement is to include the emission of the type of vehicles used in the study area.

[8] MIRA-T, hoofdstuk Lawaai

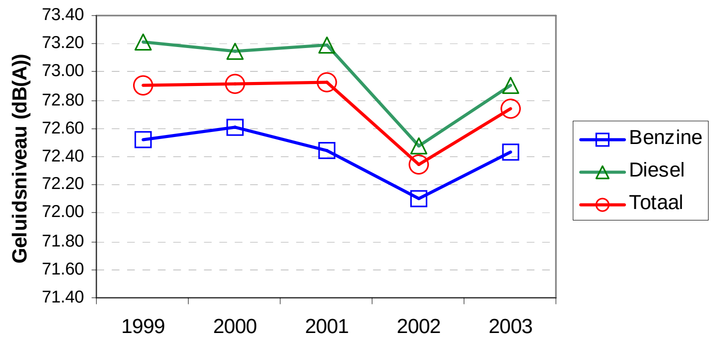


Figure 17 – Average noise level at 7 m for newly sold vehicles (cars and small vans) in reference years.

3.5.3 Noise immission

3.5.3.1 Noise immission results

Figure 1 in Annex 5.8 shows a $L_{Aeq,1h}$ noise map of the study area for the morning rush-hour, calculated using the Mobilee toolbox. The map shows the current situation. When compared with maps for both scenarios, it is found that the noise level in the larger part of the study area drops with about 1 to 3 dB(A), but in some areas the noise level rises 1 to 2 dB(A), notably in the neighbourhood of the two former Arbed zones that will be redeveloped, and in the northern part of the Brusselsesteenweg. Scenario 2 is found to result in noise immission levels about 1 dB higher than scenario 1, for the larger part of the case study network.

3.5.3.2 Uncertainty and low quality data

In the section on methodology two techniques were explained to introduce detailed treatment of uncertainty in the noise mapping process. Figure 18 show both techniques applied to a small part of the case study area. Different aspects of uncertainty are considered:

- *Source placement uncertainty*: Because often the exact position of the road is not known in street canyons, a maximum displacement of 3 m is taken into account. This translates into an uncertainty in the direct neighbourhood of the sources but the effect diminishes rapidly with distance to the source.
- *Uncertainty of the ground effect*: The ISO 9613 ground model is used where the G parameter is only known within a Gaussian distribution with mean of 0.2 and standard deviation 0.01. The relative importance of the ground effect at longer distances means that the uncertainty will also grow with distance for this effect.
- *Reflection coefficient of the façade*: The reflection coefficient is expressed as a real relative impedance. The relative impedance used is 1/17 with a standard deviation of 0.005, corresponding to a mean perpendicular absorption coefficient of 0.8. The use of impedances allows the uncertainty to depend on the angle of coincidence of the incoming ray.
- *Model uncertainty*: The propagation model is only accurate for short distances. Longer distances show an increasing spread between model and measurements. This

is partly due to instable meteo conditions. The uncertainty on the level takes a Gaussian shape with standard deviation linearly increasing from 0 to 2.5 dB at 1.5 km path length.

Other aspects of uncertainty are available in the Mobilee tool but were not used in the example:

- *Discretization uncertainty*: The model uses point sources, whereas line sources may be a more accurate approximation of reality. Typically the space between two successive point sources is kept around 10 m. Because the distance to the façade is also of that order, some uncertainty arises about the real façade levels. Close to the point sources the noise level is slightly overestimated, while between two point sources the noise level is slightly underestimated.
- *Source emission uncertainty*: The power spectrum may not be known exact due to the traffic data used to estimate the emission.

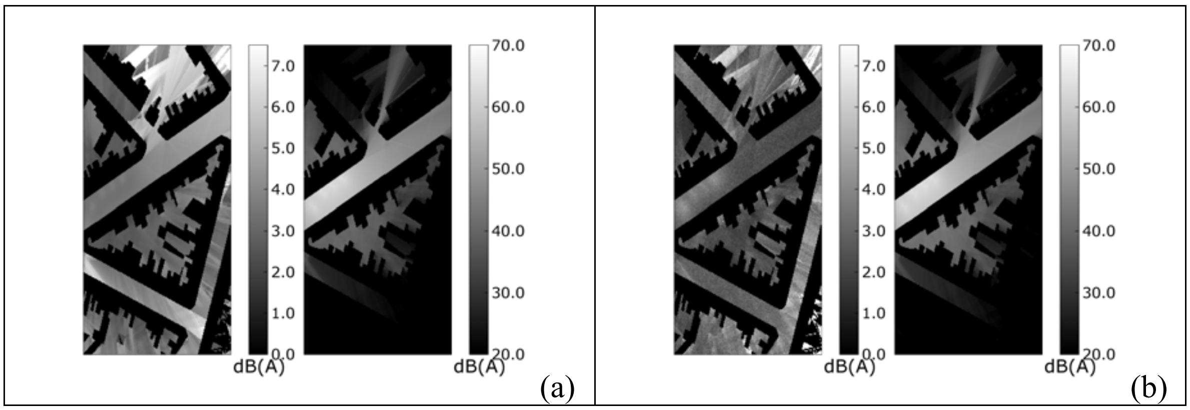


Figure 18 – Uncertainty (left) and averaged value (right) for (a) the fuzzy approach and (b) the Monte Carlo approach.

The fuzzy approach uses possibility distributions with 8 control points and a linear interpolation between them. The computation of the noise map with the fuzzy approach takes about 5 times longer than the computation of a single sample of the Monte Carlo approach. However, in the fuzzy approach 8 times more information is processed. The use of interval calculus assures that the computation time increases linearly with the chosen level of discretization of the uncertainty on the input variables. For real world environments this factor drops typically to around 3.

For the Monte Carlo approach, 200 runs were used to sample the uncertainty on the input variables. From Figure 18 it is clear that the averaged value from the Monte Carlo approach and the most likely value from the fuzzy approach match very closely. The uncertainty measure used in all figures is the support of the respective distributions. The figures show the general tendency of the Monte Carlo approach to flatten out the uncertainty. In areas where no single factor of uncertainty is dominant, the Monte Carlo approach smoothens the picture while the fuzzy approach takes the worst-case value.

The uncertainty computed by the Monte Carlo approach contains more noise, which is to be expected from a random sampling technique. The noise is not present in the averaged value. Taking the averaged value instead of the most likely value in the probabilistic approach is done for computational reasons. To estimate the most likely value in a probability distribution some analysis of the distribution is needed, while the average is easy to compute. The average will be the most likely value for convex distributions where the average is equal to the median value.

3.5.3.3 Detailed analysis of specific geometries and meteo simulation

The Mobilee toolbox has been compared with the more detailed model based on Finite-Difference-Time-Domain (FDTD) discretization of the Linearized-Euler-Equations. From literature it is known that an easy access to a quiet place, for example a backyard, in noisy areas reduces the percentage of highly annoyed residents [2]. As the centres of large cities can be seen as an ensemble of street canyons, the particular focus here was on the modelling of noise levels at the quiet side of a house facing a street canyon. The influence of meteorological conditions and the roughness of the façades were investigated. The computational effort required for FDTD simulations is large, but this is partly overcome by using a coupled 2D FDTD-PE (Parabolic equation) model, which has shown to drastically limit the computing time and memory usage [3]. Calculation times were further reduced by assuming that the source and the receiver canyon are geometrical identical.

Figure 19 shows the setup for the calculations. In the source canyon, FDTD calculations are performed. Staggered-in-space calculations are combined with the prediction-step staggered-in-time (PSIT) approach to evaluate the moving-medium sound propagation equations [4]. Perfectly matched layers are used to simulate an unbounded atmosphere. At short distance from the canyon edge, time signals are recorded on a vertical array to generate starting functions for the PE method. Next, a transition from the time domain to the frequency domain is performed by means of FFT. Finally, the Green's Function PE method is used to calculate sound propagation up to a receiver at the symmetry plane, for a number of frequencies. The latter uses the effective sound speed approach.
Symmetry (see Figure 19) and reciprocity allows approximating the transfer function from the source to the receiver by two times the transfer function from the source towards a point on the symmetry plane, at a limited height. Using this approach, reflection on the rigid roof is counted twice, so 6 dB must be subtracted from the doubled sound pressure levels at the symmetry plane.

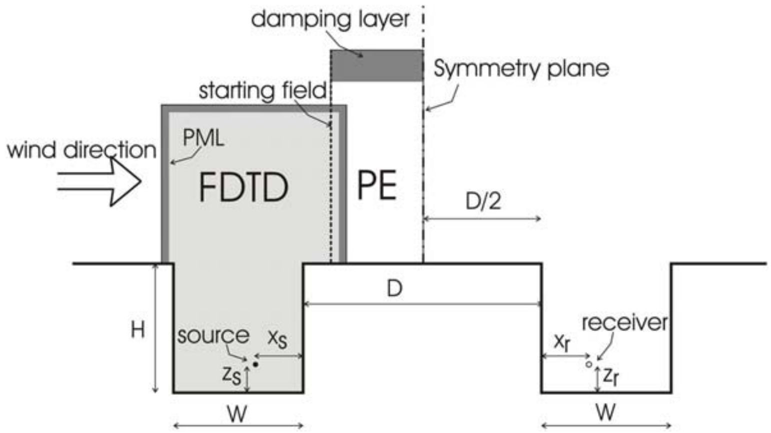


Figure 19 – Setup of the coupled FDTD-PE model used for the street canyon parameter study.

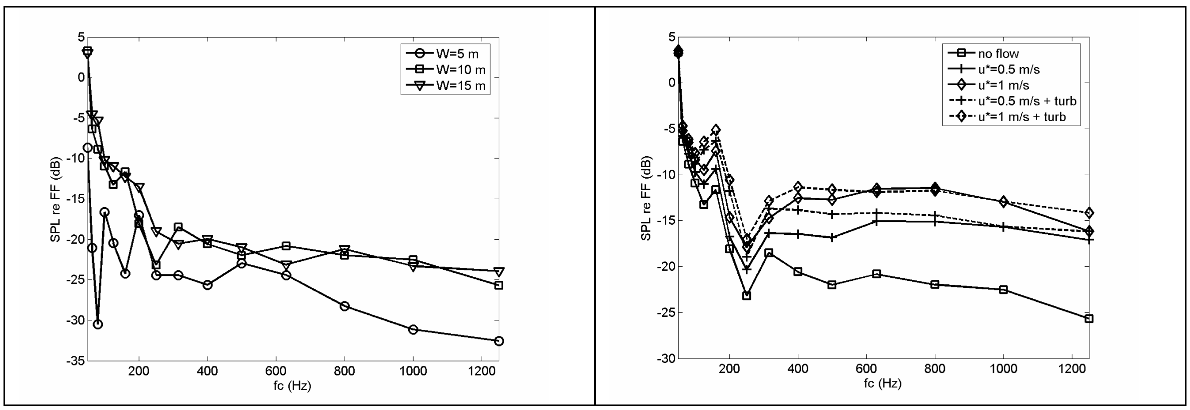


Figure 20 – Sound level relative to the free field, in 1/3 octave bands, (left) for different widths of the canyons in a non-moving atmosphere and (right) in a non-moving, in a refracting non-turbulent and in a refracting turbulent atmosphere. In case of the refracting atmosphere, two wind speed profiles are used. The façades are flat.

The effect of canyon width is shown in Figure 20(left). The shielding increases with increasing frequency. For very low frequencies, almost no shielding is observed. The shielding of very narrow canyons is large. With increasing canyon width, the relative sound pressure levels in the receiver canyon increase. When the width of the canyon exceeds its height (starting from W=10 m in our example), the sound pressure levels become more or less constant.

To assess the influence of a moving atmosphere, the flow field near the canyon geometry is calculated with the CFD software tool Fluent [5]. A logarithmic inflow profile is used, which corresponds to downwind sound propagation from the source canyon to the receiver canyon. It can be seen from Figure 20(right) that the wind effect is large. The downwind refraction encountered in open field is enhanced by the so-called building-induced refraction of sound, which is more or less similar to the screen-induced refraction of sound by wind. Downwind refraction becomes more pronounced with increasing frequency and with increasing wind speed. A decrease in shielding compared to a non-moving atmosphere of about 10 dB is observed when u* = 1 m/s, for the frequency bands that are important for traffic noise. It is clear that the effect of wind can not be neglected in these situations. The wind field above a city is usually highly turbulent. A simulation, including both refraction and turbulence is performed. Temperature turbulence is not accounted for. It is found that the wind effect increases slightly when the turbulent atmosphere is accounted for. The main effect of the wind is however caused by downwind refraction.

The importance of diffuse reflection in urban environments is well-known. A commonly used method to account for diffuse reflection is assuming that a certain amount of energy is transferred from the specular (coherent) field to the diffuse field with each reflection. The scattering coefficient quantifies this transfer. This approach assumes that façades scatter randomly from every point. In reality however, diffusing elements are well-localized. In the FDTD simulation, diffuse reflection is explicitly modelled by making surfaces irregular. Recesses and protrusions due to windows and window sills are modelled near the façade, together with a rough wall, as shown in detail in Figure 21(left). The windows itself and the window sills are modelled as rigid, while the rest of the façade has a normalized real impedance of 10.

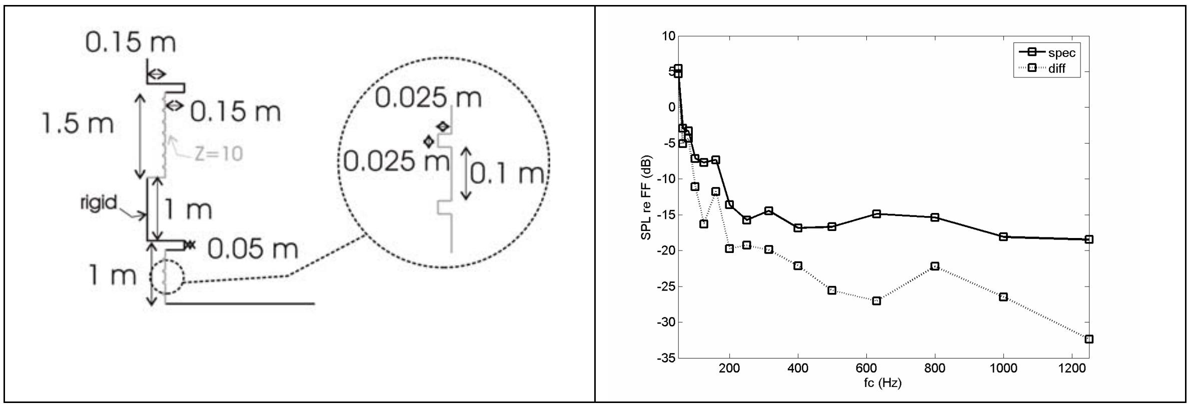


Figure 21 – (left) Part of the diffusely reflecting façade that is modelled. (right) Sound level relative to the free field, in 1/3 octave bands, in a non-moving atmosphere. The (partly) diffusely reflecting façade is compared to an equivalent flat façade with the same impedances.

In Figure 21(right), the effect of such a profiled façade is compared to a completely flat façade, with the same impedances, for sound propagation from the source to the receiver canyon. The positive effect of diffuse reflection is important and increases with frequency in our example. It needs to be mentioned that scattering is only modelled in upward and downward direction, since 2D simulations are performed.

To conclude, refraction by wind and diffuse reflection are important and therefore need to be taken into account when accurately predicting sound levels in highly shielded urban areas. The problem of accurately calculating the effect of traffic on noise levels in quiet urban areas is recognized by many researchers but an accurate and fast solution has not yet been discovered.

3.5.4 Exposure and impact

3.5.4.1 Number of people exposed to different noise levels

In Figure 22 the number of people are shown for varying $L_{Aeq,1h}$ noise exposure level, for the current situation as well as for both scenarios. For this, the data for all streets within the study area were aggregated. It can be seen that in the current situation the largest group of people is exposed to noise levels at the façade varying from 55 to 65 dB(A). In both scenarios the number of people not exposed to noise levels over 60 dB(A) significantly increases which is generally assumed to be positive with respect to mental health and general well-being. The number of people exposed to very high levels, over 65 or even over 70 dB(A) during the day remains constant.

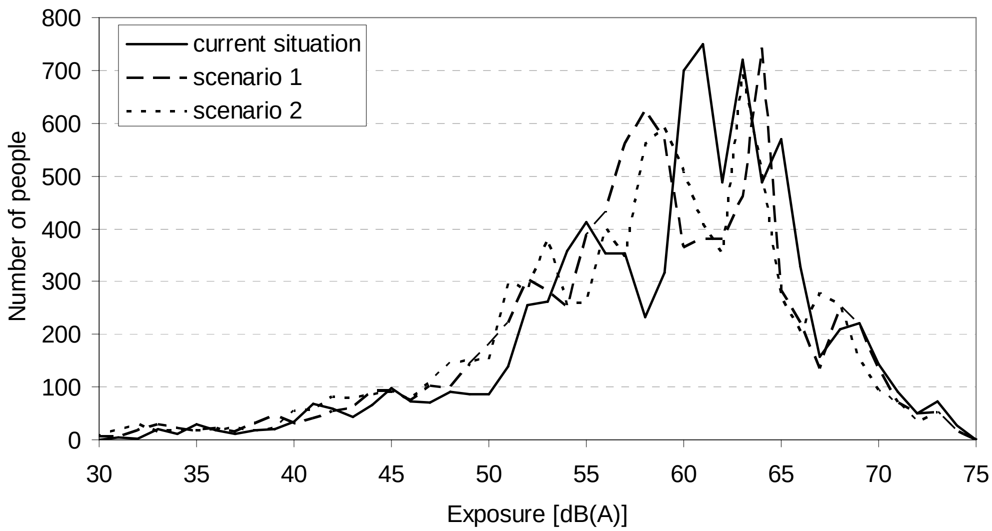


Figure 22 – Histogram of the number of people exposed to certain $L_{Aeq,1h}$ levels during the morning rush-hour. The exposure is aggregated in 1 dB categories.

3.5.4.2 Number of people potentially annoyed

Using the number of people exposed to different noise levels, the fraction of highly annoyed people was calculated on a street basis using commonly used dose-response relationships [6]. The result can be seen in Figure 2 in Annex 5.8. The fraction of the population potentially highly annoyed by traffic noise is lower than 20%, for most of the case study area, except for the Brusselsesteenweg and the Land Van Rodelaan. Figures 3 and 4 in Annex 5.8 show the change in fraction of highly annoyed people, caused by both scenarios studied. Overall there is a small decrease in potential high annoyance, except for the roads that lead from the southern highway E17 to the redeveloped Arbed sites (Robert Rinskopflaan and Leo Tertzweillaan).

3.6 Air quality & exposure

3.6.1 New dynamic emission functions

As described in 2.7.1.1 project specific emission functions were derived based on on-the-road-emission measurements, carried out by VITO. During these experiments are the vehicle's instantaneous speed, acceleration and emissions of CO, CO_2, NO_x, PM and NMVOC recorded. A correlation between the instantaneous speed and acceleration and

the emissions was looked for in the course of this project. This was done for each of the vehicle types taken into account in this project.
These emission functions were finally integrated in PARAMICS, enabling to calculate the vehicles' emissions in the same run at which their movement is simulated.

The figure below shows the validation of the model of a particular type of vehicle (passenger car, 0 – 1.4 l cylinder content, Euro3 homologated) by comparing it with the emission results. Although the correlation between measured and modelled seems quite poor, the model is able to locate the emissions at the correct time (and hence place).

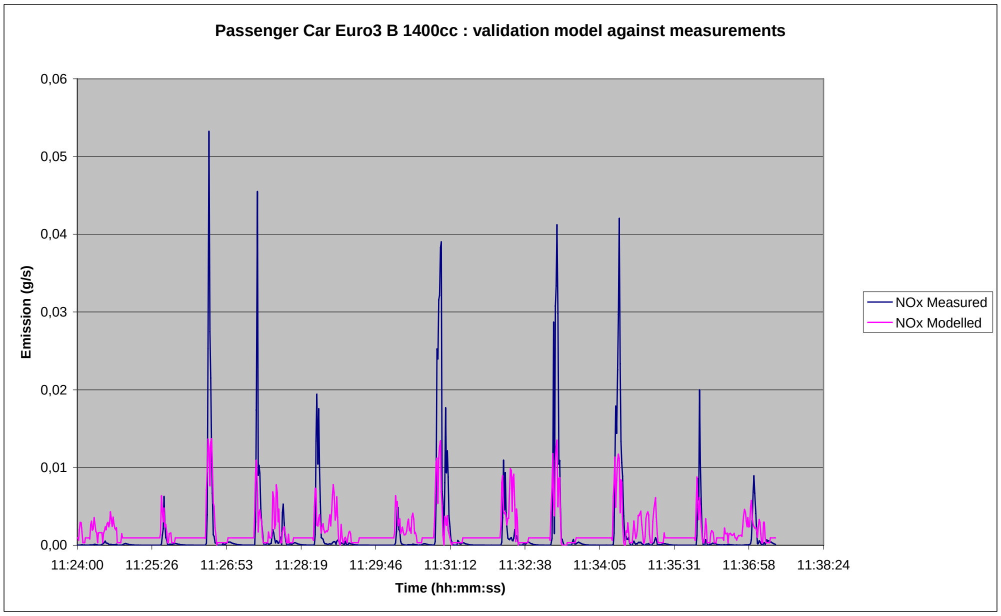


Figure 23 Passenger car Euro3 B 1400cc: validation of model against measurements

The poor correlation is mainly due to the huge differences between vehicles, even between vehicles of the same category.

Figure 24 demonstrates this very well. The correlations, found for 6 different passenger cars, all Euro1 homologated and with a cylinder content less than 1.4 l, were used to calculate the emissions for a particular trip, driven in an urban area and taking about 20 minutes.
Huge differences between the emission estimations were found for CO and VOC. The ratio of standard deviation versus the average of the 6 emission estimations amount to 100% for both pollutions. The differences were less outspoken for NO_x, but still very considerably. The standard deviation is 67% of the mean value. Only for CO_2 did the different emission functions agree with each other; the standard deviation is about 8% of the mean value.

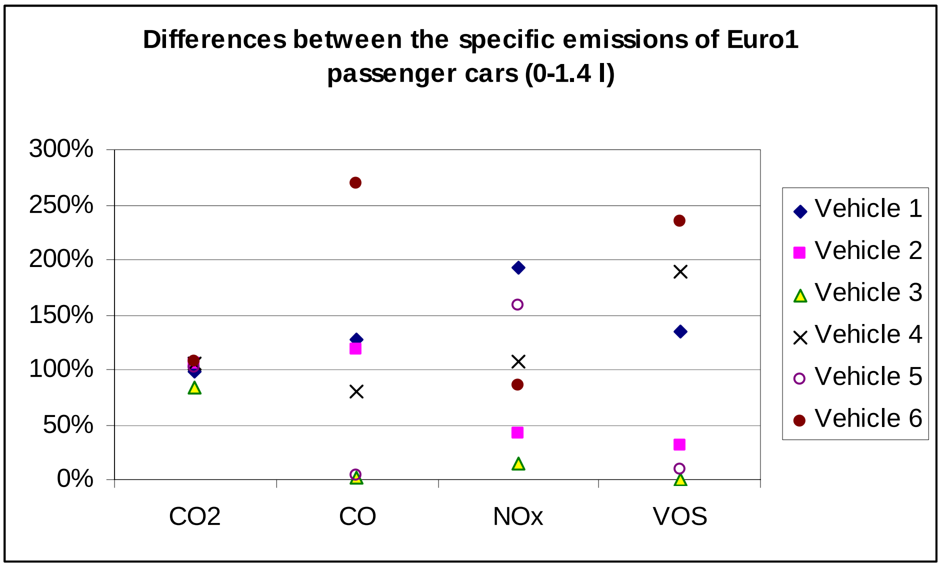


Figure 24 Differences between the specific emissions of Euro1 passenger cars

The emission functions, VITO has developed in the course of the Mobilee project, were used for the emission estimation of a typical day in Gentbrugge based on the microscopic traffic simulation by PARAMICS.

In order to validate these results parallel calculations were carried out using COPERT III emission functions and HBEFA2.1 emission factors in a correct, i.e. in a macroscopic way. Hereto were the vehicle kilometres simulated for urban roads split into three parts, see Figure 25 below:

- a part where the simulated speed exceeds 60 km/h, taken as representative for the roads where the speed limit is 70 km/h;
- a part with simulated speeds between 40 and 60 km/h, representing normal traffic situations on urban roads with a speed limit of 50 km/h;
- a part with simulated speeds not exceeding 40 km/h, representing congested traffic situations on urban roads.
- The vehicle kilometres simulated on the motorway was split into two parts;

- a part with free flow traffic, identified as those vehicle kilometres corresponding with the simulated speed higher than 70 km/h, the minimum speed allowed on a motorway;
- the remainder corresponding to congested traffic.

For each traffic situation and for each vehicle category is the average of the simulated speed taken as input in the COPERT III emission functions or used for the selection of the appropriate HBEFA emission factor.

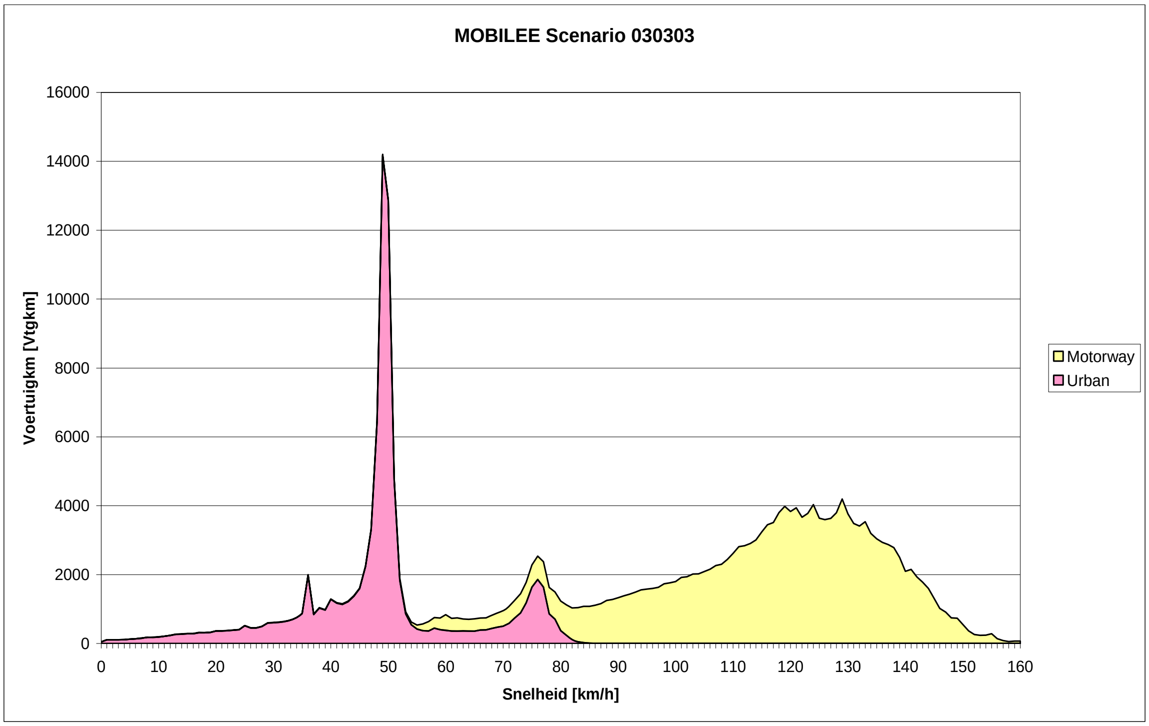


Figure 25: Speed distribution of simulated vehicle kilometres driven

The figure below shows the results (Figure 26).

- The VITO estimate for NO_x is in close agreement with the two macroscopic estimates. The deviation is less than 7%.
- The VITO estimate for VOC is about 20% less than the COPERT III estimate, but is in the same order of magnitude. The HBEFA 2.1 estimate differs however considerably; it is about one fifth of the COPERT estimate and one fourth of the VITO estimate.
- The VITO estimate for PM is about 20% higher than the COPERT estimate and about 67% higher than the HBEFA estimate.

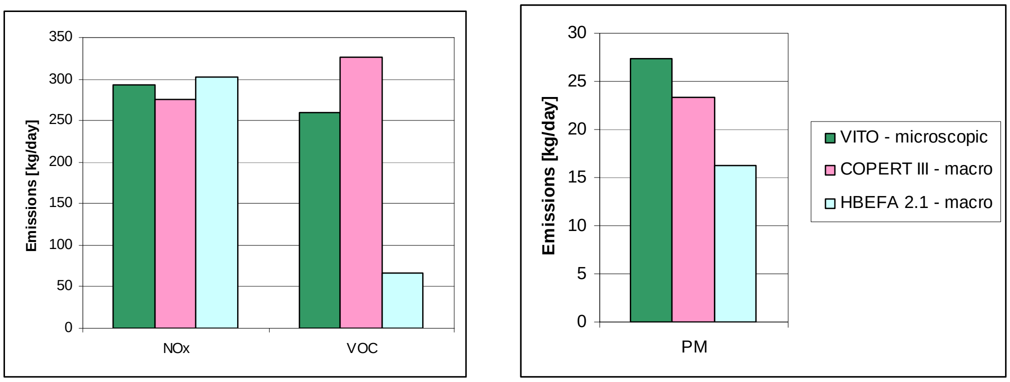


Figure 26 Comparison of exhaust emission obtained with different models

From these results one can conclude that it is hard to validate the emission estimates, as proven methodologies do seem to differ considerably for some pollutants. The order of magnitude corresponds however, so that one can assume that the VITO estimates for the emissions to the air are plausible.

3.6.2 Atmospheric modelling

3.6.2.1 Pollutants

Computations are done for all pollutants in the Paramics output file, that is: CO, CO_2, NO_x, PM and VOS.

3.6.2.2 Output files

The results of the IFDM-OSPM model are written in eight output files. Each type of output file can be produced for either hourly averages or for daily averages. The contents of each type of output file are shortly described in the following sections.

A. Time series

Time series of hourly or daily concentrations can be produced. Because such files are very large, they are produced only on request. Modelling for practical applications is usually done for some statistics of the computed concentrations. The statistics produced by IFDM-OSPM are described in the next sections.

B. Percentiles, Largest value and average per receptor

Extension: **.17 (binary) and .18 (ASCII)**. These are standard IFDM-output files[9].(A first part of the file contains data for the normal IFDM receptors, the second part for the IFDM-OSPM receptors in the street canyons. Most of the contents of these files (Table 14) can be visualized with the standard IFDM Windows Graphical Post-processor. (Figure 27). Export to GIS is possible.

[9] The extensions ".17" and ".18" refer to the unit numbers used for these files in the IFDM Fortran code.

Table 14 Type 1 output file

per receptor: 17 percentiles, maximum value and average value	all over simulation period
Graphical	See Figure 26.
Export X Y value for e.g. GIS	
4 records per street canyon receptor	1) North-East side 2) South-West side 3) all sources minus the line source in the canyon 4) all sources

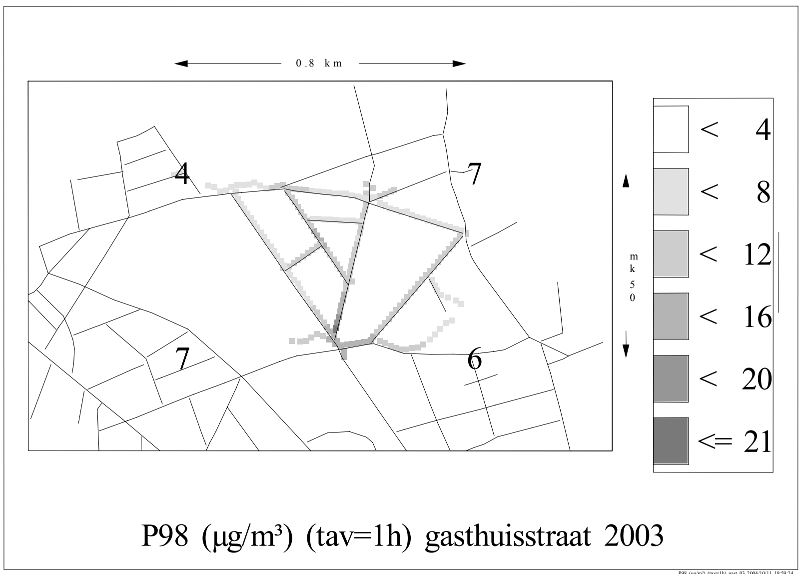


Figure 27: Standard IFDM post processor (Street: NE-side concentrations)

C. Files with average values for each hour

Once IFDM-OSPM has computed a time series of hourly concentrations, the model calculates the average value of all concentrations for the hour between 0 and 1 o'clock, 1 and 2 o'clock, and so on. With these values, one can compute the exposure of a person who moves within the region according to a daily pattern. Table 1 in annex 5.11 gives more information on these files.

Very small Frtran programs can split any of these files, which basically contain records with X,Y co-ordinates and 24 values. It can be split into 25 files, one file per hour of the day, and one file with the average value. Figures 1 a till e in annex 5.11 give a graphical impression of the contents of the different files.

D. Results for PM2.5

Results are presented as coloured maps in Annex 5.3 for PM2.5 and Annex 5.5 for NOx.

The highest concentrations are found along the Brusselsesteenweg and Land van Rode laan, where (given the uncertainty on the emission functions) they seem to represent a noticeable fraction of the urban background. For practical reasons, the PM2.5 emissions coming from traffic on the E17 were not taken into account.
Concentrations are also elevated on most intersections but this should be interpreted with caution on signalised intersections because of a possible overestimation of idle emissions. Nevertheless, the effect can also be seen on other intersections especially at peak times. Concentrations are expected to decrease significantly by 2010 because of lower emissions by modern cars. Expected average concentrations are as low as those currently predicted for the night time. The distribution of the PM concentration is not expected to change. The largest reductions (in absolute numbers) are expected at those sites which currently have the highest concentrations.
When implementing the local traffic plan, a small increase is predicted over the Business-as-usual scenario in most locations (See Figure 11 in Annex 5.3). For some areas a small decrease is possible, although this effect should be interpreted with caution because this depends on the amount of traffic that is rerouted outside the area studied here. The same conclusion can be drawn for scenario 2 where the additional traffic to the ARBED sites results in an tiny extra concentration increase that is spread rather evenly over the entire area.
The PM2.5 concentrations inside the street canyons are significantly higher than the predicted (over-the-rooftops) concentrations discussed above (compare Figures 18 & 19 in Annex 5.3). Annual average concentrations at opposing facades are similar, but can be very different due to meteorological conditions at any given time.

E. Results for NOx

For NOx emissions on the highway E17 were taken into account. This is clearly reflected in the results (e.g. coloured map in Annex 5.5). Concentrations are elevated near the highway but drop of to lower values within the first kilometer. The effect from the E17 dominates the entire picture and little detail can be seen with the Ghentbrugge study areas with the exception of elevated concentrations in small band along the Brusselsesteenweg. Concentrations of NOx are expected to decrease significantly by 2010, especially in those place that currently have the highest concentrations (streets near the E17 and the Brusselsesteenweg). The local mobility plan (Scenario 1) results in an extra reduction of NOx concentrations in many places. Isolated spots (intersections) exist where a local increase may occur. This seems linked to shifting traffic flows and traffic behaviour at intersections. This is also clear from the results of scenario 2 (Figure 13 in Annex 5.5) where the extra traffic to the industrial zones results in slightly higher concentrations centered on the streets that lead to these zones, but not offsetting the positive results of the LMP.

3.6.3 Exposure analysis

$PM_{2.5}$

Results are presented as coloured maps in Annex 5.4 for PM2.5 and Annex 5.6 for NOx. Exposure is high in those areas that have either high concentrations a large population or both. The Steenvoordelaan, Arthur Latourstraat and parts of the Kliniekstraat and

Burvenichstraat stand out. By 2010 exposure will also be reduced most in the street that have the highest exposure in 2003.

The effect of the local mobility plan on local exposure is much smaller than the general trend towards lower emissions that is driven by European legislation. From this point of view, the exposure will be much lower in the near future than it is now, even if no additional action is taken by the local administration.
Exposure to $PM_{2.5}$ is expected to be marginally smaller in some areas by 2010 when the local mobility plan is implemented (e.g. Figure 28 and Annex 5.4). Nevertheless there are also locations (notable the vicinity of two former industrial sites that will be redeveloped) where exposure shows an increase compared to the BAU-scenario (e.g. Figure 29). In any case the absolute value of these changes is small compared to the total concentration (attributable to local traffic). Both figures only show those street segments where the effect is the largest. The effect in all other street segments studied (~ 450) is negligible.

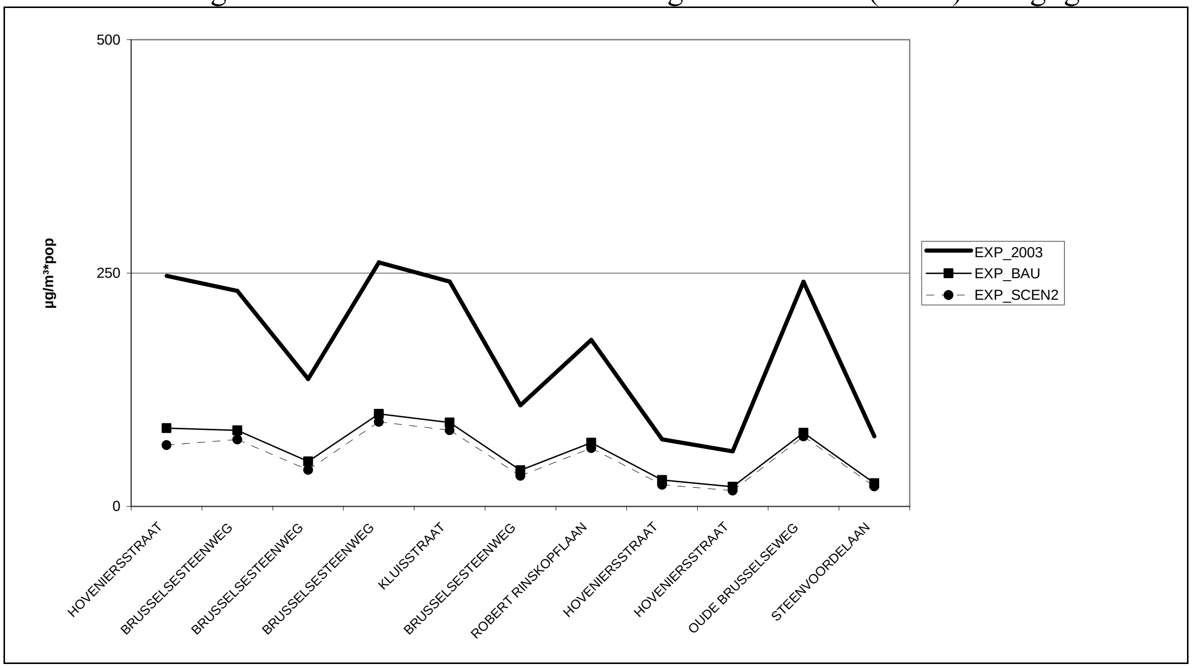


Figure 28: 10 street segments for which the local traffic plan results in the largest reduction of exposure to PM2.5 (Vertical axis = exposure = population times concentration change)

The population weighted exposure in the area of Gentbrugge for the current situation (2003), BAU (2010) and the two scenarios (2010) is calculated with the concentrations based on Gaussian dispersion first, without taking street canyons into account. In Figure 30 it is shown that exposure shifts to lower concentrations in 2010 compared to 2003. The difference in the global population-weighted exposure between the BAU and the two scenarios is not significant.

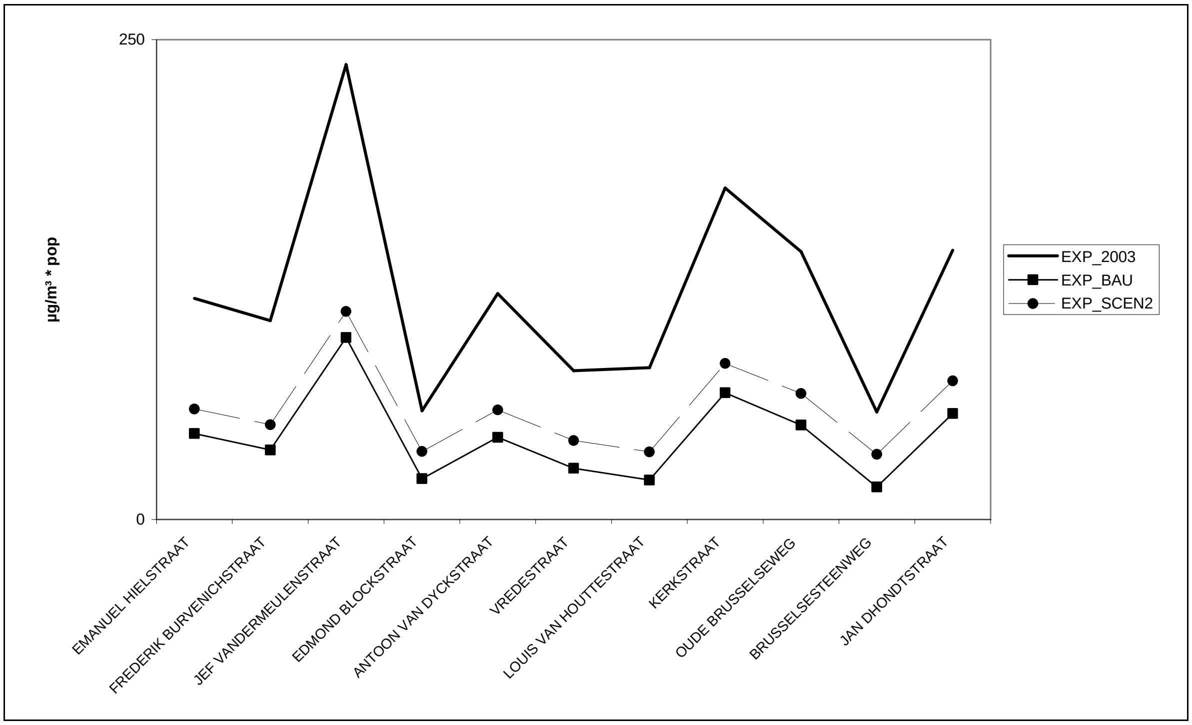


Figure 29: 10 street segments for which the local traffic plan (and development of the industrial sites) results in a (small) increase of exposure to PM2.5.

(Vertical axis = exposure = population times concentration change)

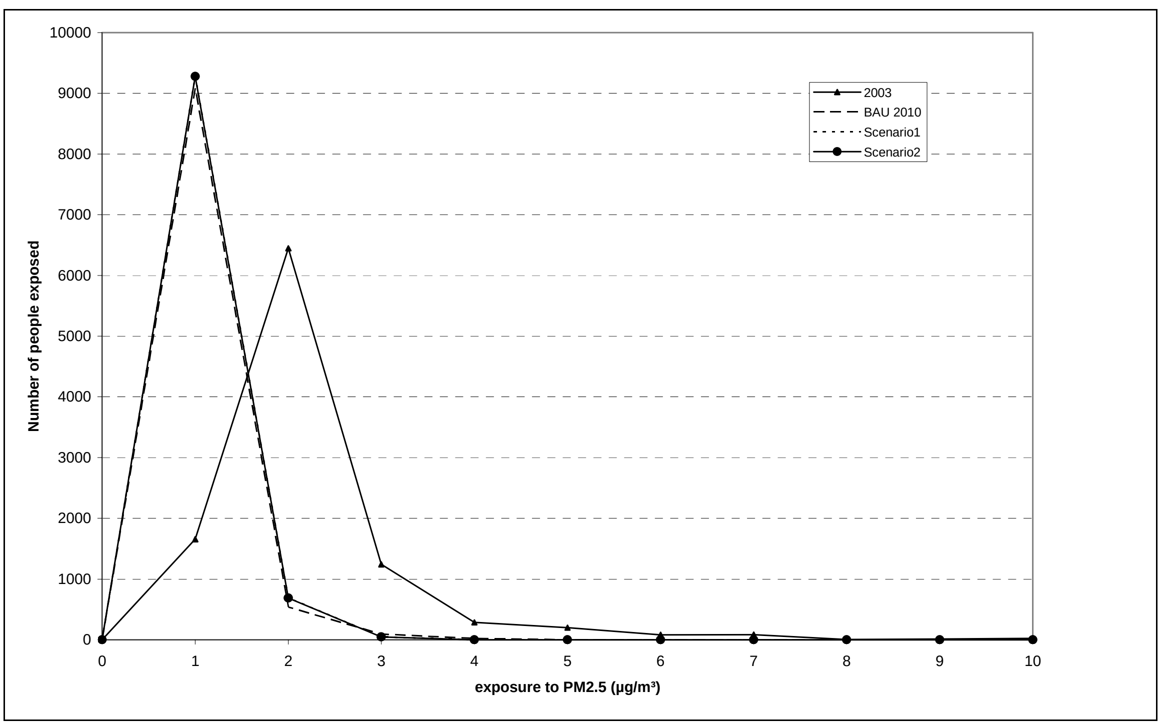


Figure 30 – Histogram of the number of people exposed to 24h average $PM_{2.5}$ concentrations (Gaussian IFDM results). The exposure is aggregated in 1 µg/m³ categories.

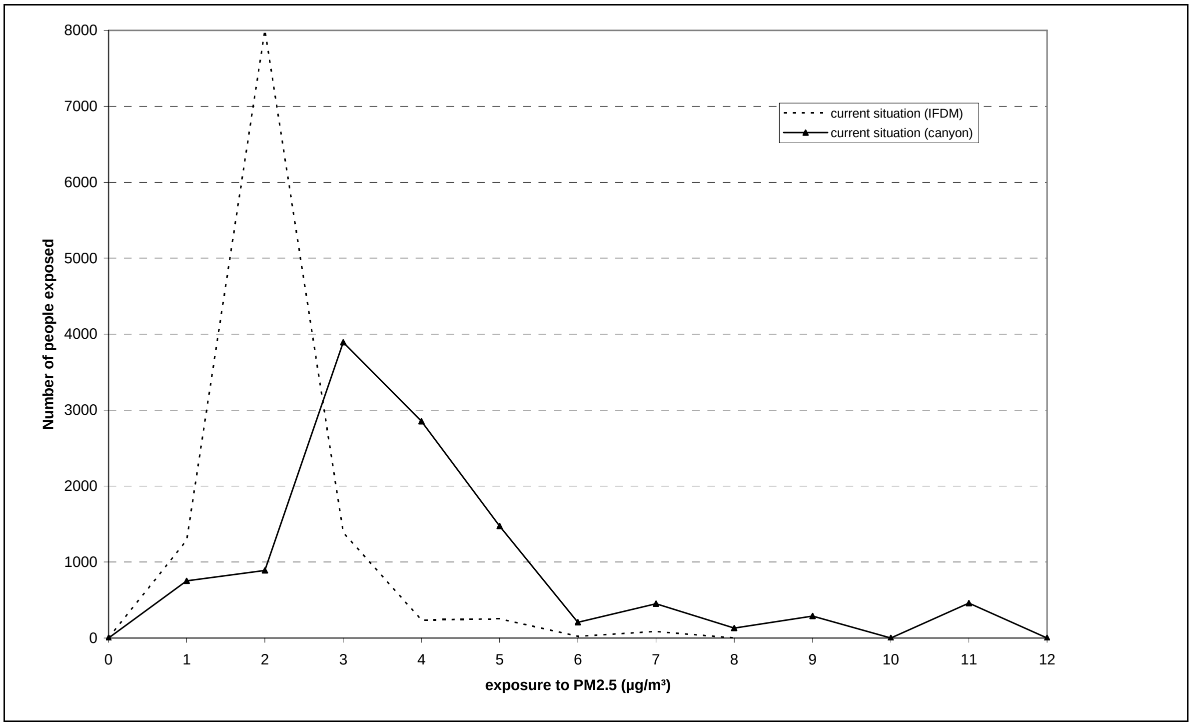


Figure 31: Histogram of the number of people exposed to 24h average $PM_{2.5}$ concentrations (IFDM-OSPM results). The exposure is aggregated in 1 µg/m³ categories.

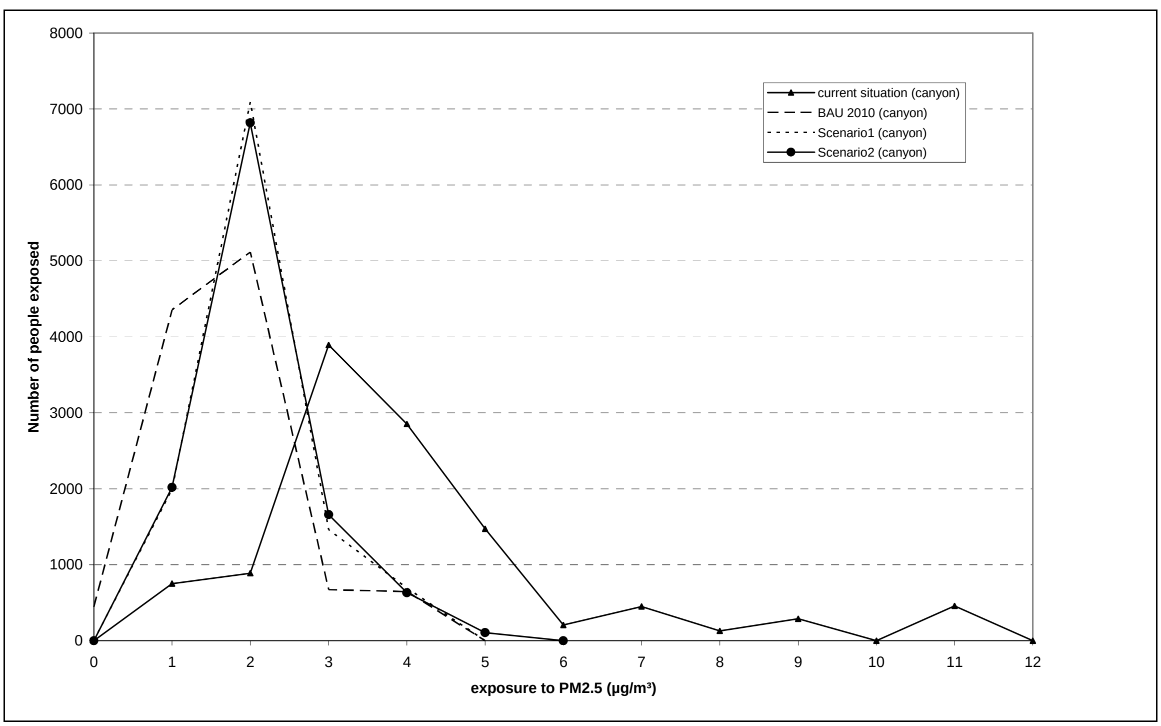


Figure 32: Histogram of the number of people exposed to 24h average PM2.5 concentrations (IFDM OSPM results). The exposure is aggregated in 1 µg/m³ categories.

The influence of taking street canyons into account when modelling exposure is shown in Figure 31, only for those streets where canyon concentrations can be calculated. Exposure shifts to higher concentrations, what was to be expected, and what 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.
Nevertheless the effect of cleaner cars in 2010 is significant (BAU 2010 compared to 2003). Both the scenario1 and 2 generate a higher exposure on the local population in the street canyons. Population weighted exposure is then about 20% higher than in the BAU scenario. Note however that exposure in the BAU scenario in 2010 will be about 60% lower than the exposure in 2003 in the street canyons. Redevelopment of the industrial site (scenario 2) does practically not change the exposure compared to scenario 1 (Figure 32).

In addition calculations were made for a number of typical scenarios. The exposure of people living in the residential streets of central Gentbrugge is compared with people living and working in the Brusselsesteenweg, and with outdoor activities on the Brusselsesteenweg (shopping, walking, traffic control). The hourly concentrations in the street canyons were used. The variability of concentrations on both sides along the roads were taken into account, and a distribution of indoor/outdoor ratios according to Kruize et al. (2000) was included. Because of the marked difference in concentrations between the Brusselsesteenweg and quiet streets, the exposure increases significantly when performing activities (living, leisure or working) on busy roads. Although the south-west (SW) side of the Brusselsesteenweg has higher peak exposures during the day, the difference between left and right side of the road is not significant for people spending 24 hours on the Brusselsesteenweg. However peak exposure can influence the exposure profile of people spending most of their time in the quiet streets (Figure 33).

Figure 33: Relative change of exposure for residents of Gentbrugge for five typical daily activity patterns, relative to residents spending 24 hours in a quiet street.

The concentrations at different moments in time were also compared. Three moments were defined: peak hour (8 am-10 am and 5 pm-8pm), non peak day (6 am-7 am and 11 am -4 pm) and non peak night (9pm-5 am):

- The total exposure over the area during peak hours is almost double of the total exposure during non peak-hours.
- At night exposure drops even further to just a quarter of the peak hour exposure, which seems logical because of the minimum traffic passing by.
- Just as in the daily average exposure, the effect on exposure of the plan scenario is very small in comparison with the change in exposure from 2003 to 2010 under the BAU scenario.

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. It is noticed in literature that this can increase the instantaneous in-car exposure significantly, with a factor 4 to 14 (Scott et al., 2004).

NOx
In comparison with $PM_{2.5}$, the effect of the European legislation on concentrations of NO_x is smaller. The models calculated only a decrease of 10-35% for daily average NO_x against 50-90% for $PM_{2.5}$. Overall exposure of the population within the study area decreases with up to 45% due to European legislation. Exposure decreases most in the Kliniekstraat and relatively more in the northern section of the area than in areas closer to the E17 (on which the LMP has no effect). The mobility plan has a mixed positive and negative effect on NO_x-concentrations depending on the street. This is also the case for the exposure of the people staying in the area. The absolute value of these changes is relatively small compared to the total exposure. Scenario 2 results in more streets with (slightly) increased exposure than Scenario 1 as well as in the exposure of more employees (when compared with the BAU scenario in 2010). Exposure estimates based on in-canyon concentration are significantly higher than the results discussed above (see Annex 5.6).

3.6.4 Impact analysis

Impacts on health have been calculated with the concentrations from the Gaussian IFDM model. We think these concentrations are the closest to the exposure indicators in the original epidemiological studies. We have used common population data in Mobilee, and have used local morbidity statistics if possible. Applied on the population, the results are more likely to underestimate the impact, but at this stage there is limited information on the magnitude of the underestimation. 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 in Gentbrugge that has been taken into account. This is significantly higher that 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 extra effect is to be expected from the local mobility plan.

Table 15: Health impact analysis of the different situations (95% confidence indicated).

		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.

It is very tempting to detail this analysis up to street level as we have done for exposure. We feel however that this would give a false appearance of accuracy to the analysis. It is very unlikely that the exact composition of the population (in terms of age, genetic predisposition, smoking habits, socio-economic status, etc, etc…) of each street segment would match the profile of the population studied in the original epidemiological study. The effect of a certain amount of exposure can vary significantly with a number of factors that average out when applied to large populations, but which make application to small groups impossible. (see also chapter 2.6.4.2)

In addition it is very interesting to see that some streets forming relatively narrow canyons at an angle with prevailing wind directions have significantly higher concentrations than when the pattern of buildings would have been more open.

3.7 Crossability

The results for crossability are shown on maps in Annex 5.7.The crossability is measured by the average time that someone has to wait before he can cross the street. This waiting time is in the first place determined by the intensity of the traffic: the more traffic, the longer the waiting times. This relation is an exponential relation: a slight increase in intensity of traffic causes a bigger increase of the average waiting time. A second component is the crossing-length: the longer the length of the street, the longer people are on the street and then, people need a larger gap between 2 vehicles. So, it will take more waiting time before someone can cross the street. This is also a exponential relationship.

An important feature in this context is the availability of a refuge in the middle of the street between the 2 directions of traffic. This causes a decrease in the average waiting time, caused by 2 reasons. The intensity of traffic is lower (1 direction instead of 2 directions) and the crossing length is lower. Because of the exponential relationships is the sum of the average waiting time for the 2 separate directions smaller than the average waiting time for the whole street.

A third component that determines the average waiting time, is the crossing speed of the pedestrians. This depends on the age (children: 1,6 m/s; adults: 1,4 m/s and elderly people: 0,9 m/s) and the physical health (handicapped people: 0,5 m/s). In general, the crossing speed is set on an average speed of 1,2 m/s.

In general, the accepted waiting time is set on 15 seconds, because after 15 seconds, people start becoming impatient, and begin to take risks, which can result in dangerous situations, and in the worst case in an accident.

In the current situation, the crossability is very low (it means no of almost no waiting time) in most of the streets. The crossability is less good in the Edmond Blockstraat (10 to 15 sec), because this is the road to the bridge, where all the traffic from and to the neighbourhood is concentrated, so the intensity of traffic is higher.

In the Brusselsesteenweg, the situation is bad. In the north-western part, the average waiting time is very high (more than 30 seconds). This is caused by the high intensity of traffic and the big distance to cross (11 meters). In the south-eastern part of this street, the situation is better (less than 15 sec), because in this part the road is split in 2 parts by a refuge.

Based on the calculations of the traffic model, there has been a new calculation of the crossability. Of the 3 components that influence the average waiting time (traffic flow, crossing length and crossing speed), 2 components are held constant: the crossing length and the crossing speed. Because of this, the average waiting time in the future scenario shows a big correlation with the expected traffic flow.

In this future scenario, the average waiting time increases in all segments, but for most sections, the average waiting time stays in the same class. The increase is most in the Rinskopflaan and the Brusselsesteenweg.

4 Conclusions and recommendations

4.1 Perception of Traffic viability

For the examination of the perception of traffic viability we used two methods: a questionnaire and an expert observation survey.
The table gives an overview of the advantages (+) and disadvantages (-) of both methods.

Questionnaire inhabitants	**Observation by experts**
+ inhabitants have a wide spread observation experience (24/24, 7/7)	+ cheap
+ wide spectrum of viability criteria can be examined, also those that cannot be measured (e.g. stench, …)	+ the expert can compare the differences between different streets
+ gives an idea of the relative importance of the different viability aspects interesting input for policy-makers: some problems (e.g. noise) are only significant if they are experienced as being annoying	+ small chance for distortion (although the expert is also a person who is influenced by his own experience)
+ the questionnaire causes public involvement	+ the expert takes the function of the road into account for the evaluation of the viability situation (it's logical that a busy road as Brusselsesteenweg scores worse than a residential street now and in the future)
+ possible to apply other indicators, ask about other matters	- difficult to make a good validation of the results
- risk for distortion (higher response by the more critical inhabitants)	- danger for technocratic planning without democratic / public support
- inhabitants are likely to be more sensitive for short term than for long term effects (health risks)	- how unambiguous is the (temporal) observation of an 'expert'?
- inhabitants can think the effects are caused by traffic, when they are not	
- expensive (preparation, execution, processing , ..)	
+ /- inhabitants will adapt to certain circumstances (e.g. living at the rear, install double glazed windows, put on louder music,…).	

By a combination of both methods, we can bring the best aspects of both methods together. We suggest the following approach

step 1: execution of an observation survey by an expert (reliable for the basic traffic indicators and deducted effects that can easily be measured or observed)
step 2: consultation of a limited amount of inhabitants to give feedback on the results: control and evaluation of effects
step 3: overall evaluation for policy making: this has to be done by the politicians who can rely on the results of the questionnaire (gives an idea of the important, sensitive topics) and the calculated effects of future scenarios

4.2 Avoiding noise annoyance in local traffic plans

To assess the impact of local mobility plans on the noise climate in urban area, a noise mapping model was integrated in the Mobilee toolbox; the general concept of this model was outlined in section 2.5. A GIS based micro simulation, common for all viability aspect models considered in Mobilee, was used as a base to asses the driving forces. This way, aspects of the urban soundscape, other than average noise levels, could be assessed, as stated in section 2.5.1. The HARMONOISE noise emission model was implemented into an emission micro simulation plug-in, to model the pressure on the urban noise climate caused by road traffic. A noise mapping model, based on the beam tracing technique, was integrated in the toolbox, able to process large urban areas as well as smaller neighbourhoods.

The noise mapping model was validated in the Mobilee case study area, and a reasonable good agreement with conventional noise measurements was found. Validation using rides in the case study area revealed that for local roads, traffic is more interrupted in reality than in micro simulation, which could lead to an overestimation of noise levels.

A detailed assessment of the uncertainties connected with noise mapping the impact of local traffic plans was conducted. For larger areas or for when resources are limited, the need for a model not much more complex than existing emission models was expressed, which should be able to bypass the micro simulation of traffic flows. For this, a generalized emission model outline was developed, based on the simulation of traffic flows for characteristic situations and comparison with given environmental settings using Fuzzy Rule Based systems and Fuzzy Neural Networks. The uncertainties in the noise mapping process itself were examined in detail; a model based on extended numbers was presented which is able to assess the sensitivity of the noise mapping model to differences in the input data, and was applied to the case study area. Finally, the case of modelling the noise level at the quiet side of a house facing a street canyon under various meteo conditions was considered in great detail; it was concluded that refraction by wind and diffuse reflection need to be taken into account when accurately predicting sound levels in highly shielded urban areas.

Different aspects of noise impact were considered in the course of the Mobilee project, such as the population averaged noise annoyance, annoyance by smaller subgroups, annoyance corrected for noise level fluctuation and sleep disturbance. The concept of fuzzy noise limits was introduced to be able to present these health effects in a map.

4.3 Local determinants for exposure to air pollution

4.3.1 Summarized conclusions for air pollution

- Air quality is expected to improve considerably everywhere in the area studied. The reductions are highest in the street that currently have the highest concentrations and in the vicinity of crossroads.
- Emissions in the immediate vicinity of the crossroads are higher than midway the street segments.
- Following a drastic reduction in speed limits in the residential areas, emissions are expected increase slightly. This is a consequence of the draft emission functions used and should be studied in much more detail before it can be confirmed. In any case an exponential rise as predicted by the (wrong) use of Copert seems unlikely
- An integrated methodology was developed allowing fast calculation of emissions and of "back yard" and "canyon" concentrations under alternative scenarios.
- Traffic measurements or local mobility plans need to invoke drastic measures to have a discernable influence on local air quality, but the combined effect of measures throughout the entire city may well be more important?
- The methodology developed is accurate enough to discern who benefits and who loses when local mobility plans are implemented.
- Insufficient data on indoor exposure is currently available to estimate health risks at the scale of street segments.
- There are still too few epidemiological studies taking into account a detailed dynamic exposure of individuals.

4.3.2 Main innovative results for air pollution

1. Given the instantaneous emission functions that were derived here (with all the uncertainty that surrounds them, it is clear that emissions at intersections are higher than at midlink locations. The ability to generate emissions with this spatial resolution is becoming increasingly important. Whereas dispersion models have attained a resolution that is probably much higher than necessary for the study of policy options, emissions models have not known a similar evolution.

2. We stress that our functions need further validation, but they are based on real in-traffic measurements (although on a small sample of cars).

3. With these instantaneous emission functions it is also shown that major reductions of the speed limit from 50 to 30 km/h yield only slightly higher emissions. Using the classic Copert-type approach would have resulted in much higher emissions. It seems from our preliminary functions that the reduced acceleration effectively reduces emissions more than that cruising at 30km/h raises emissions. Again we stress that this need further validation (e.g. gear shifting behaviour could be important).

Nevertheless we have demonstrated that it is plausible that implementing 30 km/h zones does not necessarily increase emission levels. A similar result was found in three other European cities (studying the effect of ISA) in the 5th FP project PROSPER that has adopted VITO's new functions.

4. Although most results presented in the report refer to average concentrations, hourly values were also calculated. It is evident that large spatial and temporal differences exist. Even at very small scales (within one street) it is possible to predict that concentrations will be significantly lower at certain times or at certain nearby locations behind the houses (in certain street canyons). Using this knowledge effectively when ventilating the house (often not automatically, but by simply opening the windows for a certain time) may change the indoor/outdoor ratio significantly. In addition this is an action that residents can make themselves without relying on low-effective actions of the local council or long-term trends brought about at higher policy levels.

4.4 Integrated evaluation and comparison of mobility plans

4.4.1 Objectives of the Integrated evaluation step

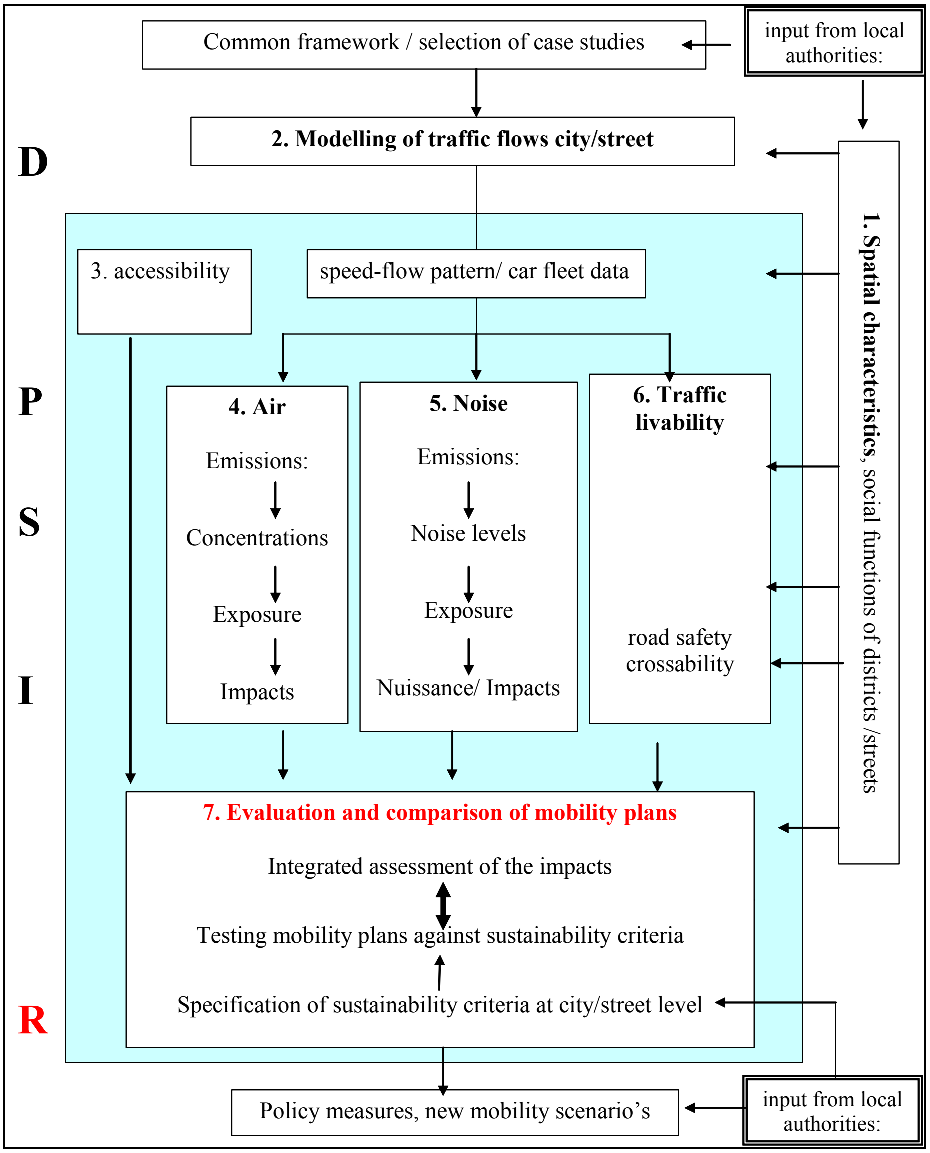
The objective of Mobilee is to test to which extent local mobility plans contribute to sustainable development on the local level. To this purpose, the integrated evaluation step of the methodology is to compare different mobility plans with criteria related to sustainable development. As this study does not tackle the full dimension of sustainable development, it is limited to the aspects and area's covered in mobile, i.e. air quality, noise, viability. On the other hand, the sustainability of the study area will also have to take into account sustainability requirements for a larger area.

For Mobilee, we follow the well known DPSIR scheme, and we calculate based on the best available and practical scientific methods the impacts of different mobility plans, using specialised models and techniques for the different selected impacts. However, the results in terms of impacts as such are not sufficient to evaluate a mobility plan. A further step is required to interpret how important these impacts are, to compare different impacts and the total impacts for the area as a whole and for street(segments) in particular.

This step cannot solely rely on the scientist, but input on priorities from local people and decision makers is required. Scientific methods are required to gather and interpret these priorities, and to compare results of the analysis with the priorities.

- Different impact categories need to be weighted against each other, or aggregated to a common indicator.
- It needs to inform decision makers which mobility plans is best for the study area as a whole, and for different parts of the study area
- It needs to inform decision maker if the plans are good enough for the study area a whole and for different parts of the study.

- The weighting needs to be based on the importance the local people attach to these different impacts.
- The interpretation step needs to take into account uncertainties and omissions related to the assessment of these impacts.

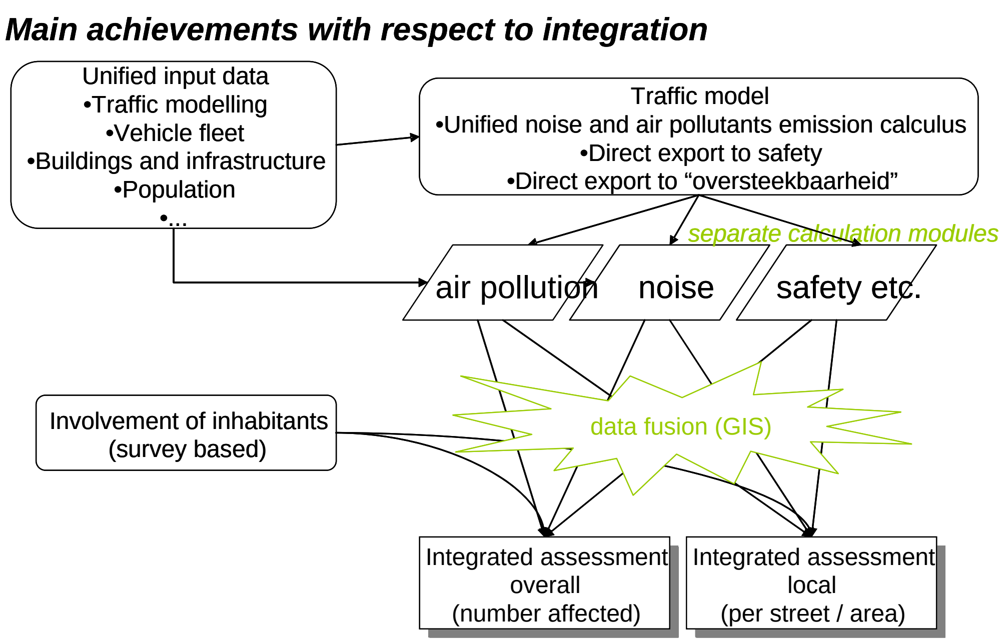


There is no generic weighting system that meets all these criteria. And allows end users of Mobilee to weigh the different impacts an objective and scientific valid method applicable to all the impact categories and to the level of detail needed for this study. A weighting system would need to meet the following criteria:

Economic valuation of impacts can in principle give us a lot of information about the value people attach to the different impact categories. However, data are not available for all categories and at the level required for this study. Simply relying on benefit transfer would not be a sufficient basis to evaluate local plans. Second, economic valuation may be used to collect and present the information about the impacts on welfare for the selected area as a whole. All impacts are expressed in a single term.

The chart below (Figure 34) gives the main achievements regarding integration. The calculation models as such will not be integrated in a single software package. The integration concerns mainly the unified input data, the common use of a single traffic model, and the integration of the output for assessment both at locally and as an overall exposure (expressed in terms of number of people (seriously) affected). The calculation modules themselves, which are rather know-how intensive and subject to changes that reflect the evolving state-of-the-art, are handled by experts in the field at their own institutes.

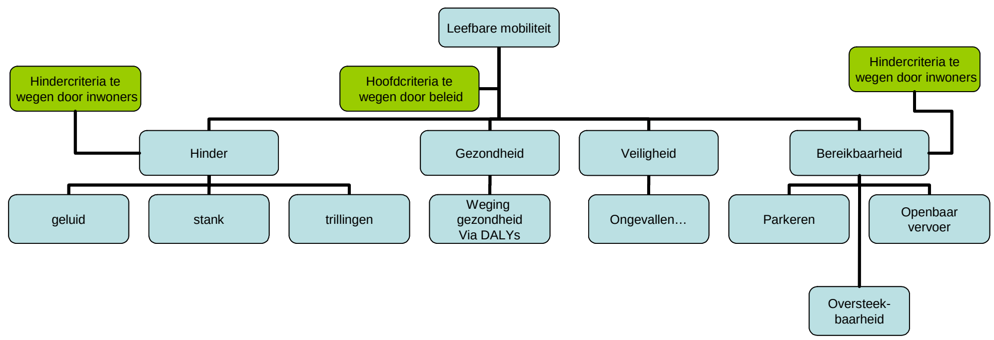
Figure 34



The figure below (Figure 35) gives more detail on the aggregation to a single indicator. It develops the outline of an aggregation module which is very flexible in order to answer a wide range of policy related questions, and which develops indicators to summarise our results.

Different users of the mobile models will have different questions, depending on the most important environmental problems, the problems as perceived as important by the stakeholders, etc.

Figure 35



The module and data management should aggregate data at a level that

- allows to answer the most relevant questions
- is manageable, and focuses on the added value of the approach, i.e. focussing on dynamic analysis of exposure.
- allows to summarise it in a consistent way for the different types of impacts, related to air, noise, safety and viability.

Therefore, this module should be flexible

- To allow to focus on the specific questions and issues relevant for the users
- To ensure consistency between the different problem area's;

4.4.2 The aggregation module

In terms of data management, we have two type of questions:

a) questions related to one <u>single environmental stressor</u>: air, noise, safety, … these questions can be related to standards, impacts, thresholds, improvements, etc. Furthermore these questions can be related to the
   - study area as a whole (averages,…)
   - to specific zones within the areas
   - distribution of exposure, impacts, etc; within specific zones

   The smallest area that can be considered is a <u>street segment</u>

b) questions related to the <u>cumulative impact of different stressors</u>, either at
   - study area as a whole (averages,…)
   - to specific zones within the areas
   - distribution of exposure, impacts, etc; within specific zones

In order to be able to interpret the information it is required that the data should be gathered and kept at a detailed level, i.e. at **the level of individual exposure and exposure in a street segment**.

These data can be used to build a wide set of indicators, to answer specific questions. We call these the MQI's = mobilee quality of living environment indicators.

The "Mobilee quality of living environment' indicator

We define a MQI mobile quality of living environment indicator that can have different dimensions.

A. The MQI for a single issue-problem

The MQI for air, noise, etc. can be expressed in terms of
- exposure
- impact
- external costs

The MQI is calculated for
- Current situation, as a reference
- BAU: business a usual situation for a point in the future,
- PLAN A: situation in future with execution of the plan.

to which extent the living environment under current situation or a plan indicates the distance to target

The MQI s can be calculated for the different environmental issues, and from different perspectives.
- MQI-air-standard: is a measure to indicate the distance to target, compared to the standard.
- MQI-air-impacts = calculates the N° of impacts, related to concentrations above a threshold,
  The endpoint of the impacts can be different, depending on the issue, different public health impacts can be summarised into Daly's (disability adjusted life years)
- MQI-air-external costs = weights the N° of impacts in euros.

B. The cumulative impacts

a) A number of policy questions do not require a single indicator, but may require a similar and consistent analysis.
   E.g. which street segments do improve, get worse,
   And to which extent (in % of e.g. current situation)

   These types of questions do not need aggregation.

b) In some cases, aggregation over different problem areas may be required to calculate single indicators.

   To be elaborated, making distinction between:

   - Problems with similar impacts, e.g. on public health, and which can be added.
   - Aggregating indicators that have no specific dimension (e.g. distance to target in % of the legal standard).
   - Aggregating indicators with different dimensions.

4.4.3 Illustration of MQI ai

MQI ai = **m**obile **q**uality of living environment **i**ndicator for **a**ir, **i**mpact based.

Analysis of the air quality and air quality related health impacts in the current, reference (business as usual) scenario and scenario with plan 1, 2,..etc.

Questions to be answered:

1. From the perspective of a (local) policy maker or public interest group, the most relevant questions will relate to **group risks** (i.e. the changes in risks, depending on changes in concentrations along street segments, weighted by the N° people living in that street segment);

   - *What is the risk for air pollution health effects from the perspective of a group inhabitants (depending on the street they live in) of the study area?*
   - *How does it relate compared to standards? (this requires standards at the level of group exposure or group risk, for air pollution, this does not* [10]
   - *Does the situation improve for everybody and at any place?*
     - *Does the situation improve for every group (street segment) in the BAU and plan scenarios?*
     - *If it improves, does it improve for all the street segments, and to a similar extent?*
     - *If the situation worsens in the plan scenario, is there still an improvement compared to the current situation?*
     - *Are these problem-street segments grouped in a certain neighbourhood? This may indicate that a local plan may need to do something in that area.*
     - *Or are these problem-street street segments related to other characteristics and occur throughout the whole study area? (e.g. street crossings,…)*
     - *Street segments that get worse off in the plan scenario, are those that were already highly exposed or not?*

[10] exist (for other risks it does, and a risk for 1 in a million is considered to be acceptable)

Indicators to be developed

- YOLL/street segments
- Distribution of yoll's within the study area: distribution of percentiles (this approach is comparable to presentation and analysis of e.g. income distribution)

Noot: dit is een moeilijk issue, omdat de street segments "willekeurig" zijn.

- Quality of living environment gap = how does the 10 % worst off relate to the average, and to the 10 % best of (comparable to wage gaps in economics)

A second group of questions relates to **individual risks**, and checks whether there are no individuals that get worse off, notwithstanding the general improvement in the area?

- *What is the risk for air pollution health effects from the perspective of an individual person, inhabitant of the study area?*
- *How does it relate compared to standards? (air quality standards are based on concentrations, and implicitly on individual risks)*
    - *Does the situation improve for everybody in the BAU and plan scenarios?*
    - *Are those for whom the situations worsens, those that were already highly exposed or not?*
    - *What is the impact of the plan on the*
        - *Average impact*
        - *Modus impact*
        - *Does the impact gap between 10 % worst of and best off widens or tightens*
- *What is the risk for air pollution health effects from the perspective of a group inhabitants (depending on the street they live in) of the study area?*
    - *Does the situation improve for every group in the BAU and plan scenarios?*
    - *Are those for whom the situation worsens, those that were already highly exposed or not?*
    - *What is the impact of the plan on the*
        - *Average impact*
        - *Modus impact*

- What is the level of impacts in current situation , in YOLL/person
- Can this be related to standards, other risks, average situation for Flanders or cities in Flanders
- How is this distributed within the study area: distribution of percentiles (this approach is comparable to presentation and analysis of e.g. income distribution)
- Quality of living environment gap = how does the 10% worst off relate to the average, and to the 10 % best of (comparable to wage gaps in economics)

4.4.4 Results for the case study

The integrated results for the Gentbrugge case study are shown under the form of maps in Annex 5.9 Simultaneous evaluation of all indicators.
It is important to stress that the results discussed here, and shown on the map, only reflect the impact of the actions of the city of Ghent compared to a situation where the local authority would take no action at all.

It is evident at first glance that for most of the area the sign of the results for noise and PM are different. It is plausible that at low speeds an additional decrease of the speed results in a decrease of noise but an increase of PM emissions. At moderate speeds a decrease of PM is more likely (e.g. Land van Rode laan). On the other hand there can be a synergy with traffic flows tending to avoid low speed areas, whereas positive effects may be masked by increased streams elsewhere. This is most evident at major intersections where differences in queuing times may produce the most obvious differences.

Green areas (both indicators improve) are mostly found on those streets and street section that have high noise and emissions levels in the current situation. The local action enhances the general trend towards better living quality. Streets that are slightly less well of are mostly found in the areas relatively close or leading to the redeveloped industrial sites.

5 Annexes

5.1 References

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http://www.belspo.be/fedra, research action CP, project CP/37

5.3 Maps PM2.5 concentrations

5.4 Maps PM2.5 exposure

5.5 Maps NOx concentrations

5.6 Maps NOx exposure

5.7 Maps Crossability

5.8 Maps of noise levels and exposure

5.9 Simultaneous evaluation of all indicators

5.10 Instruments for subjective liveability

5.10.1 Observational survey (in Dutch)

5.10.2 Nuisance survey (in Dutch)

5.11 Output files atmospheric modelling

The following annex 5.12 can only be obtained from VITO:

5.12 Van Paramics naar IFDM – OSPM (in Dutch)