National Environmental Research Institute
University of Aarhus · Denmark

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Phase1: Specifications for a Danish Highway Air Pollution Model

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Data sheet

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Abstract: The report outlines the specifications for a new user-friendly Danish highway air pollution model as a tool for environmental impact assessment and mapping of air quality along highways. A prototype of the model was developed earlier based on the regulatory air pollution model OML. The model was tested previously on Danish measurements and as part of this project also for a Norwegian data set, both showing good performance of the model. The new user-friendly model version will have a close coupling with Geographic Information Systems (GIS) both for creating model input data and visualising model results.

Keywords: OML, highway traffic, air pollution, model validation, GIS, environmental impact assessment

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Contents

1 Summary in English

The objective of this report is to outline specifications for a new user-friendly Danish highway air pollution model. The Danish Road Directorate is interested in a tool for environmental impact assessment of air pollution from highways and has initiated this study to outline specifications for such a model. Based on these specifications the Danish Road Directorate will decide whether or not to proceed with the model development.

During 2003-2005, the National Environmental Research Institute (NERI) developed a prototype highway air pollution model. This model is based on the Danish regulatory air pollution model OML which originally was developed for use with stationary air pollution sources. The model has now been adapted for modelling air pollution from motorway traffic. The model parameterisation was successfully validated against data from a three month measurement campaign of NO_x and NO_2 at different distances from a busy section of a Danish motorway in 2003. Subsequently, the model was applied for mapping of air quality and human exposure along the motorways in the County of Roskilde in Denmark. At a later stage, the model has also been successfully validated against a Norwegian measurement data set. At present, the model is a prototype model that is not suitable for application outside the research community due to lack of user friendliness.

As part of the present study, a number of application areas were identified where a new Danish highway air pollution model would be useful and provide new information:

Environmental Impact Assessment – to improve information about air pollution as part of legal requirements to assess environmental impacts for new major highway constructions or alteration of existing highways.

EU Ambient Air Quality Limit Values – to be able to assess current or future air quality levels along highways in relation to European Union air quality limit values that have been implemented in Danish legislation.

Systematic Mapping of Air Quality and Human Exposure – to provide overview of the current and future state of air quality and human exposure along a large road network to identify hot spots and areas that merit further analysis and assessment of mitigating measures.

"What-if" Scenario Analysis – to predict future air quality levels under different scenario assumptions e.g. construction of noise barriers, changed traffic volumes and emission factors.

Ranking of Road Investments based on Cost-benefit Analysis – a potential spin-off in a long-term perspective although it is not within the scope of the proposed new highway model at present.

A new Danish highway air pollution model should meet the following overall model criteria:

The model should be operational, user-friendly and GIS based, and organized in a single software package that allows application of existing GIS based data.

Standard input data should be available for quick estimates, but user-defined data should also be an option for more detailed analyses. A standard emission module reflecting Danish conditions should be available, along with e.g. standard data for meteorological data and typical diurnal variation of traffic.

Users are expected to have experience within air pollution modelling and GIS applications. Potential users may be the Danish Road Directorate, municipalities, consultants and expert institutions.

The model should have an English user-interface and a user manual in English.

The proposed overall model strategy is to integrate the prototype OML highway model and supporting GIS tools and background models into a single GIS based software. This software might be SELMA^{GIS} that is an existing system for air pollution modelling and visualization developed by the German company Lohmeyer and applied in many places in Europe. As part of the present project we conducted a workshop with Lohmeyer in October 2006 to discuss the integration of the prototype highway model into SELMA^{GIS}.

It requires a considerable effort of man-power to transfer the current, fragmented system - a prototype air pollution model, combined with ad hoc GIS scripts and manual preparation of data at many levels - into the proposed semi-automatic system that can be applied in a flexible way for a wide range of applications.

The specifications of the model's input and output are also discussed in further details in this report.

2 Dansk resume

Formålet med denne rapport er at beskrive specifikationer for en ny dansk brugervenlig luftkvalitetsmodel for motorveje. Vejdirektoratet er interesseret i et værktøj til vurdering af luftkvaliteten langs motorveje og hovedlandeveje. Direktoratet har derfor igangsat nærværende projekt med at udarbejde overordnede specifikationer for en ny motorvejsmodel. På baggrund af specifikationerne vil Vejdirektoratet beslutte, hvorvidt man vil gå videre med at støtte udviklingen af en sådan model.

Danmarks Miljøundersøgelser (DMU) har i perioden 2003-2005 udviklet en prototype af en luftkvalitetsmodel for motorveje. Modellen er baseret på den danske OML model, der oprindeligt blev udviklet til regulering af industrielle punktkilder. Denne model er blevet modificeret, således at den kan beskrive luftforurening fra motorveje. Modellen er med godt resultat blevet evalueret på baggrund af en tre måneders målekampagne i 2003, hvor NO_x og NO_2 blev målt i forskellige afstande fra en stærkt befærdet dansk motorvejsstrækning og sammenlignet med de beregnede værdier. Efterfølgende er modellen blevet anvendt til at kortlægge luftkvaliteten og befolkningseksponeringen langs motorvejene i det tidligere Roskilde Amt. Modellen har også gennemgået en succesfuld validering ved sammenligning med norske målinger. Da modellen på nuværende tidspunkt er en prototype model egner den sig ikke til anvendelse uden for et forskningsmiljø.

I nærværende undersøgelse er der identificeret en række anvendelsesområder for en ny, brugervenlig motorvejsmodel:

Vurdering af Virkning på Miljøet – VVM vurderinger er lovpligtige i forbindelse med etablering af nye eller væsentlige ændringer af eksisterende motorvejsstrækninger. En ny motorvejsmodel vil kunne tilvejebringe ny information om luftkvalitet.

EU's grænseværdier for luftkvalitet – en ny model vil gøre det muligt at sammenligne beregnet luftkvalitet med gældende EU grænseværdier for luftkvalitet, som er implementeret i dansk lovgivning.

Systematisk kortlægning af luftkvalitet og eksponering – en ny model kan skabe overblik over den nuværende og fremtidige luftkvalitet og befolkningseksponering langs et større motorvejsnet, og dermed identificere problemområder, som kræver yderligere detailanalyser og mulige foranstaltninger til begrænsning af luftforureningen.

"What-if" analyser – en ny model kan forudsige den fremtidige luftkvalitet under forskellige forudsætninger. Det kan fx være scenarieanalyser af forskellige forudsætninger for trafikmængder og emissionsfaktorer eller opføring af støjskærme.

Prioritering af vejinvesteringer ud fra cost-benefit analyser – på længere sigt kan en potentiel afledt effekt af en ny motorvejsmodel være at resultater herfra kan indarbejdes i de cost-benefit analyser, der ligger til grund for prioritering mellem forskellige vejinvesteringer. I de skitserede specifikationer er denne funktionalitet dog p.t. ikke indbygget.

En ny dansk luftkvalitetsmodel for motorveje skal opfylde følgende overordnede modelkriterier:

Modellen skal være operationel, brugervenlig og GIS baseret, og være implementeret i en samlet programpakke, som tillader anvendelse af eksisterende GIS data, som Vejdirektoratet benytter.

En række standard input data skal være til rådighed for let at kunne foretage beregninger, men det skal også være muligt at anvende brugerdefinerede data fx til detaljerede analyser. Der skal være et standard emissionsmodul som afspejler danske emissionsforhold. Der skal ligeledes være standard data for meteorologiske data samt typiske profiler for trafikkens døgnvariation på motorveje.

Brugere af modellen forventes at have ekspertise inden for luftkvalitetsmodellering og GIS. Potentielle brugere af modellen kan være Vejdirektoratet, kommuner, konsulenter og forskningsinstitutioner.

Modellen skal have en engelsk brugerflade og brugervejledning på engelsk.

Den overordnede modelstrategi er at integrere prototypen af OML motorvejsmodellen, tilhørende GIS metoder og programmer samt en baggrundsmodel ind i en eksisterende GIS-baseret programpakke. Denne programpakke kunne være SELMA^{GIS}, som er et eksisterende system til luftkvalitetsmodellering og visualisering udviklet af det tyske firma Lohmeyer. SELMA^{GIS} anvendes en række steder i Europa. I forbindelse med nærværende projekt blev der afholdt en workshop med Lohmeyer i oktober 2006 for at diskutere integration af motorvejsmodellen i SELMA^{GIS}.

Det nuværende system er ganske fragmenteret, idet det består af en prototype luftkvalitetsmodel, en række GIS programmer, hjælpeprogrammer og en baggrundsmodel, hvor der kræves manuel tilrettelæggelse af data på mange niveauer i processen. Det vil kræve en betydelig indsats at implementere disse elementer i det tilsigtede, semiautomatiske system, så det fremtræder fleksibelt og brugervenligt.

Nærværende rapport indeholder en diskussion af de detaljerede specifikationer for ind- og uddata for den nye luftkvalitetsmodel for motorveje.

3 Foreword

The objective of this report is to outline specifications for a new user-friendly Danish highway air pollution model. The Danish Road Directorate is interested in a tool for environmental impact assessment of air pollution from highways and has initiated this study to outline specifications for a new user-friendly Danish highway air pollution model. Based on these specifications the Danish Road Directorate will decide whether or not to proceed with development of a user-friendly highway air pollution model.

The Danish Road Directorate manages about 3,800 km of state roads. About 1,000 km of motorways, 300 km of express roads and 1,500 km of other main roads. The term 'highway' is used for these roads indicating that the majority of these roads are in rural areas or in areas where closely located buildings do not restrict the dispersion of air pollution.

During 2003-2005, the National Environmental Research Institute (NERI) developed a prototype highway air pollution model. The model is based on the Danish regulatory air pollution model OML, which originally was developed for use with stationary pollution sources. This model has now been adapted for modelling pollution from motorway traffic. The main model extension is in implementation of the traffic-produced turbulence into the description of the Gaussian plume dispersion parameters. The traffic-produced turbulence has a considerable influence on the dispersion conditions close to the traffic sources. Models that do not take this effect properly into account will over predict concentrations close to the road. The model parameterisation was successfully validated against data from a three month measurement campaign of NO_x and NO_2 at different distances from a busy section of a Danish motorway in 2003. Subsequently, the model was applied for mapping of air quality and human exposure along the entire motorway network of the County of Roskilde in Denmark. At this stage, the model is a prototype model that is not suitable for application outside the research community due to lack of user friendliness.

Chapter 4 gives a brief introduction to international highway models. The new prototype highway model is described in Chapter 5 as well as a summary of model performance by comparing predicted and observed air pollution concentrations from Danish and Norwegian data sets. Part of the present project has been to carry out the validation of the model for the Norwegian data set. Chapter 6 outlines the overall objectives of a new user-friendly Danish highway model. Chapter 7 describes input and output criteria and Chapter 8 the coupling with Geographic Information Systems (GIS). The appendices give some more details about the highway model, and outline a new measuring campaign with focus on particle measurements in order to improve emission factor estimates for highway driving.

A NERI project group has prepared the report. The group included Ruwim Berkowicz, Matthias Ketzel, Martin Hvidberg and Steen Solvang Jensen. An advisory steering group from the Danish Road Directorate included Ole Kirk and Lene Nøhr Michelsen

4 Introduction

Road traffic continues to be one of the most significant pollution sources in urban as well as in rural areas. However, there is a significant difference in the way traffic air pollution affects the ambient pollution levels depending on the characteristics of the surroundings.

It is well known that the highest traffic pollution levels can be found in urban areas. It is here that traffic is most dense, but the elevated pollution levels are also due to the special dispersion conditions in urban street canyons (Figure 4). However, the high pollution levels in urban areas are very local. Away from street canyons, or just in a backyard, pollution levels are substantially lower than in a busy street canyon.

The situation is different for roads in rural areas with no buildings along the road. A considerable part of trafic work takes place on this kind of roads. As an example, 26% of all km travelled in the Greater Copenhagen Area in Denmark is are spent on highways, which are in most cases located outside built-up areas.

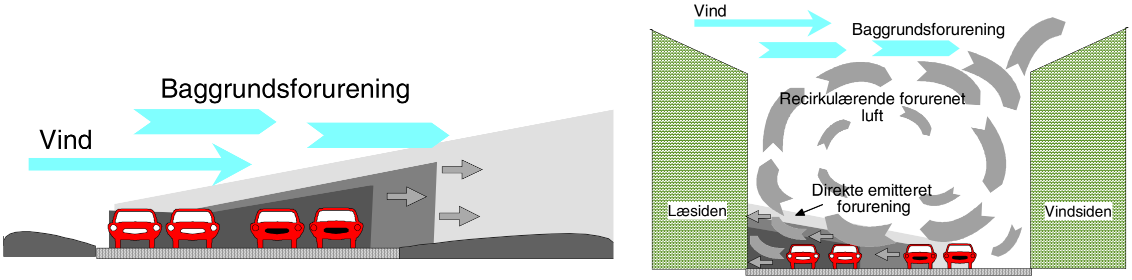


Figure 4. Dispersion conditions at open road sides compared to urban street canyons.

The highway traffic is generally more intense than urban street traffic. The traffic speed is also higher. Because of open surroundings, the influence of pollution from highway traffic can extend to much larger distances than pollution from urban streets.

4.1 Currently applied highway models

Several models have been formulated to predict pollutant concentration near highways or roads by approximating them as line sources. Highway dispersion models are generally used for analysing the output of existing or proposed highways/roads at a distance of tens to hundreds of meters downwind. In this region, the effect of vehicular pollution and vehicular activity is considered to be the primary consideration for air quality prediction analysis. Several of the models were developed during the early 70's and with some modifications they are still in use now. Some of the most widely used models are (the short descriptions are from the available literature):

CALINE4

CALINE4 (Benson, 1989) is the last in a series of line source air quality models developed by the California Department of Transportation (Caltrans). It is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over the roadway. The purpose of the model is to assess air quality impacts near transportation facilities. Given source strength, meteorology and site geometry, CALINE4 can predict pollutant concentrations for receptors located within 500 meters of the roadway. In addition to predicting concentrations of relatively inert pollutants such as carbon monoxide (CO), the model can predict nitrogen dioxide (NO_2) and suspended particle concentrations. It also has special options for modelling air quality near intersections, street canyons and parking facilities.

HIWAY-2

The HIWAY model (Petersen, 1980) was developed by U.S. EPA for the evaluation of air pollution due to a motorway in flat terrain and for a given traffic condition (assumed to be equivalent to a linear pollution source). It is based on the Gaussian plume approximation which is adapted to represent the pollution due to each lane, and corrected to account for low wind conditions.

ROADWAY-2

ROADWAY-2 model (Rao, 2002), developed with support of the U.S. National Oceanic and Atmospheric Administration (NOAA), incorporates an atmospheric boundary layer (ABL) model with turbulent kinetic energy (TKE) closure and up-to-date surface parameterisations to derive the mean and turbulence profiles from input meteorological data. The atmospheric mean velocities and TKE are adjusted to account for the velocity deficit and turbulence production in vehicle wakes. The wake parameterisations in ROADWAY-2 are derived from the vegetation canopy flow theory (e.g., Kaimal and Finnigan, 1994) and wind tunnel measurements in vehicle wakes by Eskridge and Thompson (1982).

CAR-FMI

The Finish Meteorological Institute (FMI) has developed a highway model named CAR-FMI. The model (Härkönen et al., 1996) includes an emission model, a treatment of the meteorological and background concentration time series, a dispersion model, statistical analysis of the computed time series of concentrations and a Windows-based user interface. The dispersion model is based on a partly analytical solution of the Gaussian diffusion equation for a finite line source. It allows for any wind direction with respect to the road. The dispersion parameters are modelled in a form which facilitates the use of the meteorological preprocessor. The chemical transformation is modelled by using a modified form of the discrete parcel method. The chemistry model contains the basic reactions of nitrogen oxides, oxygen and ozone.

This list of models is by no means complete but should only be considered as being representative for currently used type of roadway models. Except ROADWAY-2 model, all the models listed here make use of a Gaussian plume approximation. They differ however in the way that the Gaussian dispersion parameters are described, how the emissions from roads are integrated and especially how the effect of traffic produced turbulence (TPT) is incorporated in the model. TPT is important for concentration levels close to the road, as discussed in subsequent chapters of the report. To our best knowledge there have never been done a systematic evaluation and intercomparison of this type of models. An attempt to conduct such a study was recently initiated within the Nordic Council of Ministers project on "Validated models describing Nordic urban and regional concentration of particles and organic/elemental carbon" – NORPAC (Ketzel et al., 2004). The work is in progress.

The previously developed prototype of a Danish highway air pollution model (described in chapter 5) is similar to the above described models. The treatment of TPT has received much attention. The Danish model has been successfully validated for several data sets and uses the same principles as the other Danish local scale air pollution models and allows and easy coupling between the models. It is the obvious candidate for a further integration in a user-friendly GIS interface.

4.2 Danish local scale air pollution models

In Denmark three operational models were developed with focus on local scale pollution. OML model (Olesen et al., 2007) is designed for stationary point and area sources and is used for regulatory purposes. The Operational Street Pollution Model (OSPM) (Berkowicz, 2000a) deals with urban streets with special emphasis on street canyons and is recommended by the Danish Environmental Protection Agency for assessment of air pollution in urban streets. The Urban Background Model (UBM) (Berkowicz, 2000b) is for calculation of urban background pollution with a resolution of typically 1x1 km^2. All these models are based on similar methods for description of atmospheric dispersion of pollutants and are used on an operational basis. The OML and OSPM models are commercially available whereas the UBM model is a research model. These models have been applied in mainly urban air quality assessment and management studies as well as in epidemiological studies that examine the relation between air pollution exposure and health effects.

The models have not been especially adopted to describe the dispersion of air pollution under highway conditions. The following chapter describes a recently conducted project on adaptation of OML for highway conditions.

5 A prototype Danish highway air pollution model

In 2003-2004 a pilot project was conducted for the County of Roskilde. In that project the standard operational version of OML was adapted for calculation of traffic pollution from highways (Jensen et al., 2004). The result was a prototype highway model, which is discussed in the present chapter.

5.1 Standard OML model

OML is a modern Gaussian plume model intended to be used for distances up to about 20 km from the source (Olesen et al. 1992; 2007). The source is typically one or more stacks, and possibly also area sources. Typically, the OML model is applied for regulatory purposes. In particular, it is the recommended model to be used for environmental impact assessments when new industrial sources are planned in Denmark. The model can be used for both high and low sources. It is a characteristic of the OML model that it does not use traditional discrete stability categories, but instead describes dispersion processes in terms of basic boundary-layer scaling parameters, such as friction velocity, Monin-Obukhov length, and the convective velocity scale. Thus, before being used by the model, meteorological measurements must be processed by a preprocessor. In the OML model, the Gaussian dispersion parameters σ_y and σ_z are not - as in conventional operational models - functions only of stability category and distance from the source. Instead, they are continuous functions of several boundary layer parameters. The dispersion parameters are regarded as the result of contributions from several mechanisms: convective turbulence, mechanical turbulence, plume buoyancy and building downwash. Their dependence on source height is taken explicitly into account.

The NO_2 concentrations are calculated in the OML model using a simple chemistry model which describes formation of NO_2 due to oxidation of the directly emitted NO by ozone.

5.2 Implementation of Traffic-produced Turbulence (TPT)

The prototype highway model is based on the standard OML model. In order to adapt the model for description of pollution from motorway traffic an additional turbulence production mechanism had to be introduced – the traffic-produced turbulence. The traffic-produced turbulence has a significant influence on the dispersion conditions close to the traffic sources and neglecting this term leads to a significant overestimation of the resulting pollution levels. The largest overestimation occurs under low wind speed conditions when the traffic-produced turbulence is the dominant turbulence production mechanism. The concept used to model the traffic-produced turbulence is similar to the method applied in the Operational Street Pollution model (OSPM) (Berkowicz 2000a). However, in order to take into account the diminishing effect of the traffic-produced turbulence with the distance from the motorway, an exponential decay term was introduced. The parameterisation of this decay term was deduced from analyses of the campaign measurements and comparison with model results.

An important feature of the model is that the motorway emissions are treated as area sources and not as a single line source. The along-wind extension of the traffic source has a significant influence on the concentrations calculated at distances close to the traffic. Due to the method by which the calculations for area sources are made in OML, each of the traffic lanes is divided in a number of small rectangular area sources.

5.3 Traffic and Emissions

The OML model requires hourly emission strengths. Such data are generated combining the temporal variation of traffic and emission factors for different vehicle categories (e.g. light duty vehicles, heavy duty vehicles). The temporal variation of traffic may be based on automatic counting equipment that describes the temporal variation as a time-series. However, the temporal variation is usually described by average hourly diurnal profiles for each vehicle category for working days, Saturdays and Sundays. These temporal profiles are constructed in a way so they can decompose Annual Average Daily Traffic (ADT) into hourly traffic volumes. Similar temporal emission profiles are generated based on emission factors from the emission module of the OSPM model. Validation of emission factors under urban conditions are given in Berkowicz et. al. (2006) and Ketzel et al. (2003).

NO_x is emitted as NO and NO_2. NO is rapidly transformed to NO_2 in the atmosphere in reaction with ozone. The amount of available ozone sets an upper limit for the formation of NO_2 by this reaction. The fraction of NO_2 which is directly emitted by traffic is not negligible. For the pilot study in 2004 this fraction was assumed to be 15% but a large uncertainty connected to this value must be expected. Very little is known about direct NO_2 emissions under highway driving conditions and with a large proportion of heavy-duty diesel vehicles. However, recent studies for urban conditions indicate that primary NO_2 exhaust emission fraction has increased in recent years due to increased penetration of diesel vehicles and particle filters, see Carslaw & Beevers (2005).

5.4 Background Concentrations and Meteorological Data

The basic input to the OML model enables it to calculate the contribution to pollution from the local sources in question. However, in order to compute the total pollution level, OML also requires inputs about the background concentrations. Background levels are modelled with the Urban Background Model (UBM, Berkowicz 2000b) for a receptor grid net of 1x1 km^2 covering the motorway network. GIS tools have been developed to generate km travelled on a 1x1 km^2 grid net as input to an emission tool (UrbEmi) that calculates emission data for the UBM model. Traffic data on a GIS road network has to be available for this approach. The UBM model requires inputs about the regional air pollution contribution. This is usually based on measurements from a representative regional background station (Keldsnor) and as well as meteorological data from another representative regional background station.

5.5 Mapping of Air Quality and Human Exposures along a Motorway Network

The prototype highway model has been applied for mapping of air quality and human exposure along the motorway network in the county of Roskilde (about 70 km motorway) within a distance up to 1,000 m from the motorway. Calculations were carried out for 2003 (Jensen et al. 2005; 2006).

A new GIS application in Avenue (ArcView GIS 3.3) was developed to semi-automatically generate input data for the air quality model for the entire motorway network (emission sources, receptor points and exposure areas).

Calculations were carried out for annual levels of NO_2 and compared to European Union ambient air quality limit values (Figure 3.1). Human exposures at all residential addresses within 1,000 m of the motorways were also calculated based on information of the number of people living at each address (data from the Central Person Register (CPR)).

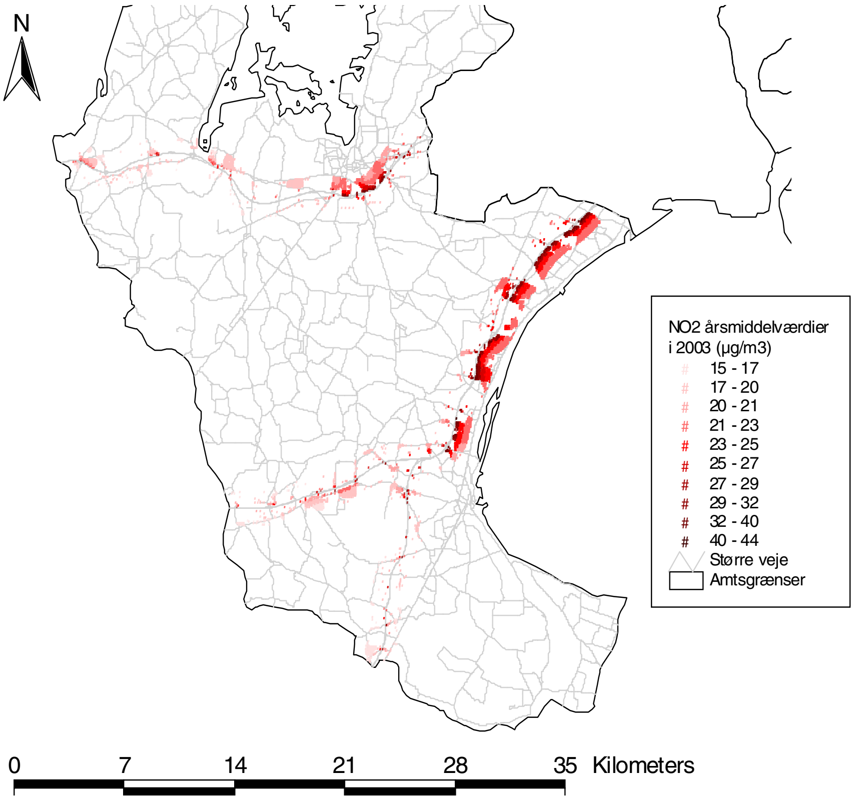


Figure 5.1 An example of mapping of air quality along a motorway network. Annual mean of NO_2 in 2003 for all residential addresses within 1,000 m of the motorway network in the County of Roskilde in Denmark. The annual air quality limit value for NO_2 in the European Union is 40 µg/m^3 to be complied with by latest 2010.

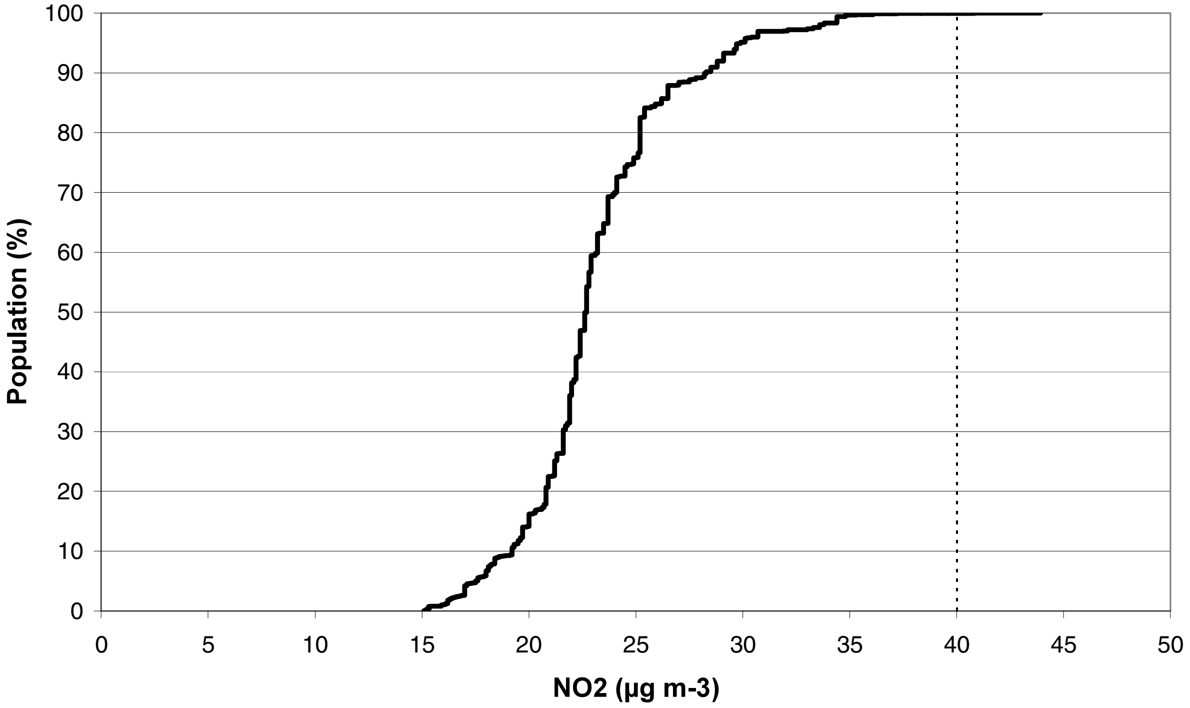


Figure 5.2 An accumulated distribution function of population exposure to NO_2 in 2003 for people living within 1,000 m of the motorway. For example, 10% of the people live at addresses exposed to annual NO_2 levels above 28 µg m-3.

5.6 Model Validation

The prototype highway model has been tested on two independent experimental datasets: the measuring campaign at the Køge Bugt Highway, Greve 2003 in Denmark and the measuring campaign at a Norwegian highway, Nordbysletta, north of Oslo, 2002 in Norway.

Figure 5.3 Location of monitors (background='bg' and 1-3) during the monitoring campaign at the Køge Bugt highway in Denmark.

Figure 5.4 Location of the monitors during the monitoring campaign at the Nordbysletta highway in Norway.

At both locations, the traffic related pollution was measured at 4 monitoring sites with 3 monitors on one side of the road and one on the other side. The purpose of the single monitor was to provide background data for the three other monitors. Maps of the locations are shown in Figure 3.3 and Figure 3.4. Both campaigns were conducted for approx. 3 months. The Danish campaign (Køge Bugt) was performed in the period September-December 2003, while the Norwegian campaign (Nordbysletta) took place in January-April 2002. Hourly values of NO_X and NO_2 were measured at the Køge Bugt site, while additionally also hourly values of O_3 and PM_{10} were measured at the Nordbysletta site. Daily averages of $PM_{2.5}$ and PM_{10} were also measured at the Norwegian site. At both sites a meteorological mast provided the necessary meteorological data.

Køge Bugt highway is a heavily trafficked six lane motorway (three lanes in each direction). The average daily traffic on working days is ca.

107,000 veh/day, of which ca. 6% are heavy-duty vehicles. The average traffic speed is ca. 110 km/h.

The Nordbysletta motorway is a four lane road (two lanes in each direction). The average daily traffic on working days is ca. 45,000 veh/day, of which ca. 7% are heavy-duty vehicles. The average traffic speed is ca. 90 km/h.

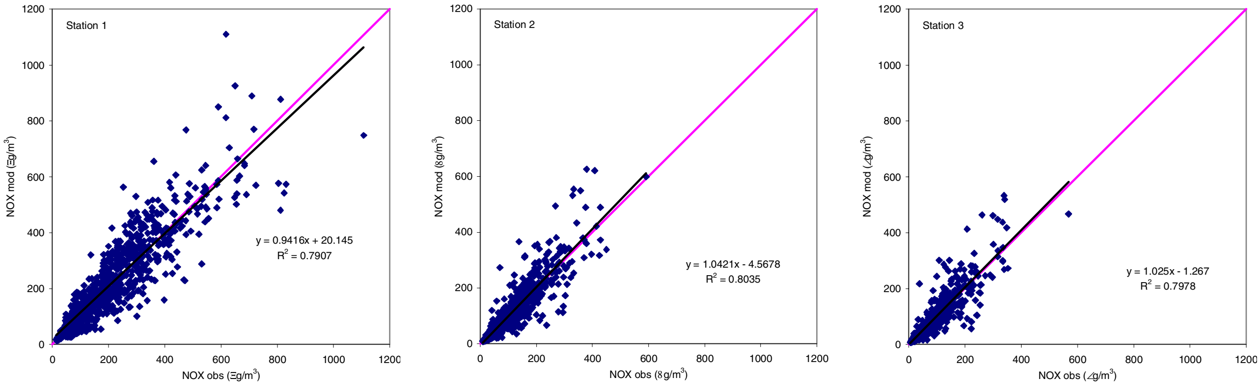


Figure 5.5 Køge Bugt motorway in Denmark. Comparison of measured and modelled concentrations. Only wind directions for which the monitoring stations were downwind of the road (DD>=240 or DD<=60). The stations 1, 2 and 3 are located 3m, 50m and 100m, respectively, from the outer traffic lane.

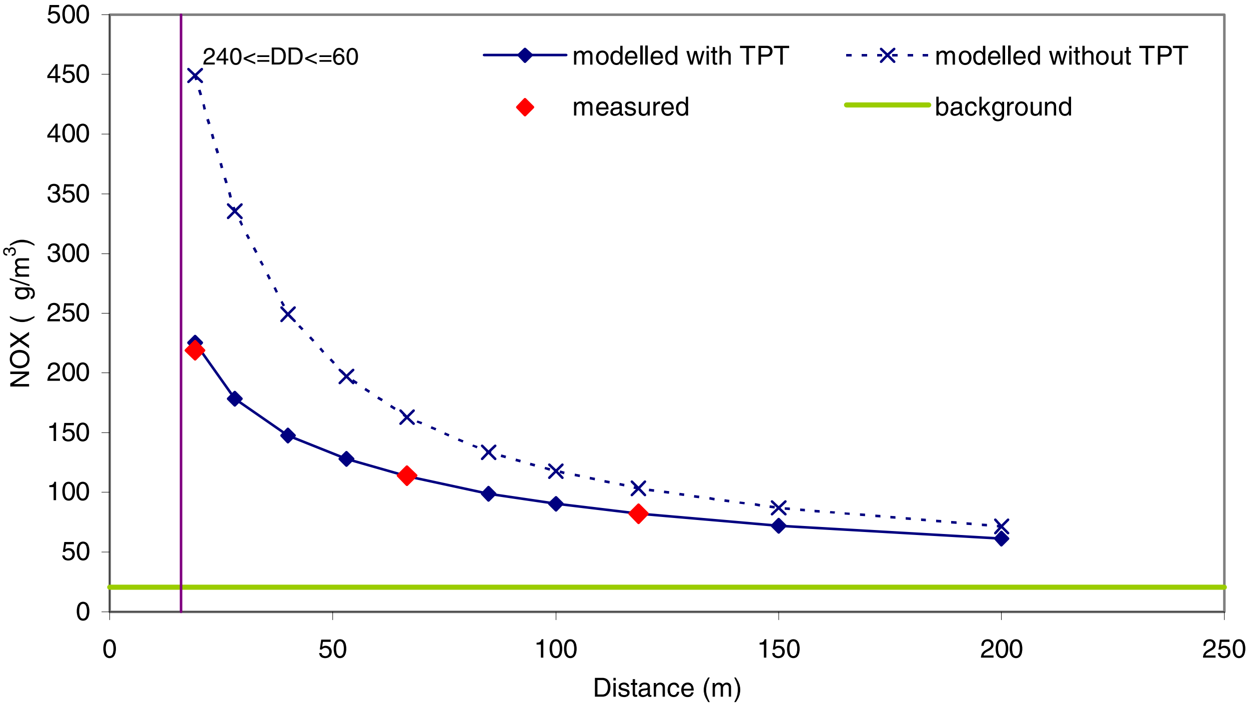


Figure 5.6 Køge Bugt motorway in Denmark. Variation of concentrations with the distance from the center of the road. Modelling results are shown for calculations with traffic produced turbulence (TPT) included and without TPT. Concentrations are averaged over the entire measuring campaign period. The distance is measured from the centre of the road. The vertical line indicates location of the edge of the nearest traffic lane.

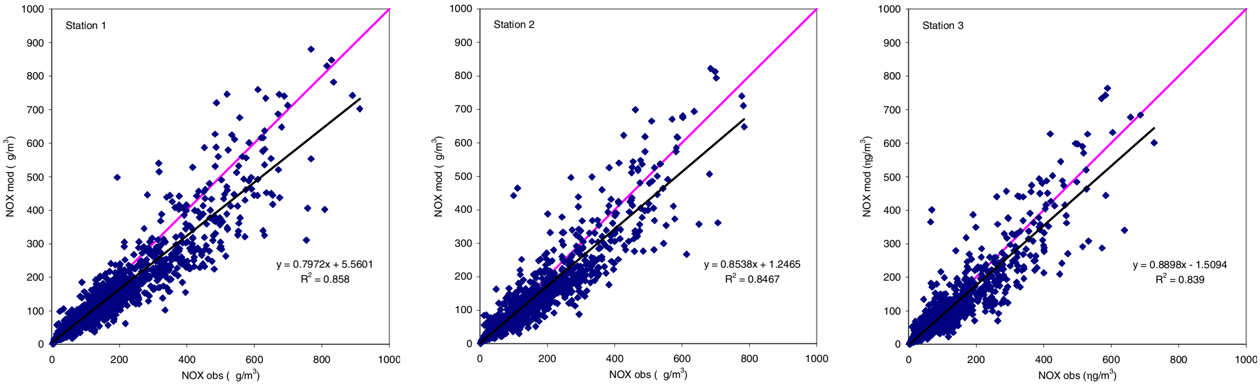


Figure5.7 Nordbysletta motorway in Norway. Comparison of measured and modelled concentrations. Only wind directions for which the monitoring stations were downwind of the road (60<=DD<=240). The stations 1, 2 and 3 are located 7m, 17m and 47m, respectively, from the border of the outer traffic lane.

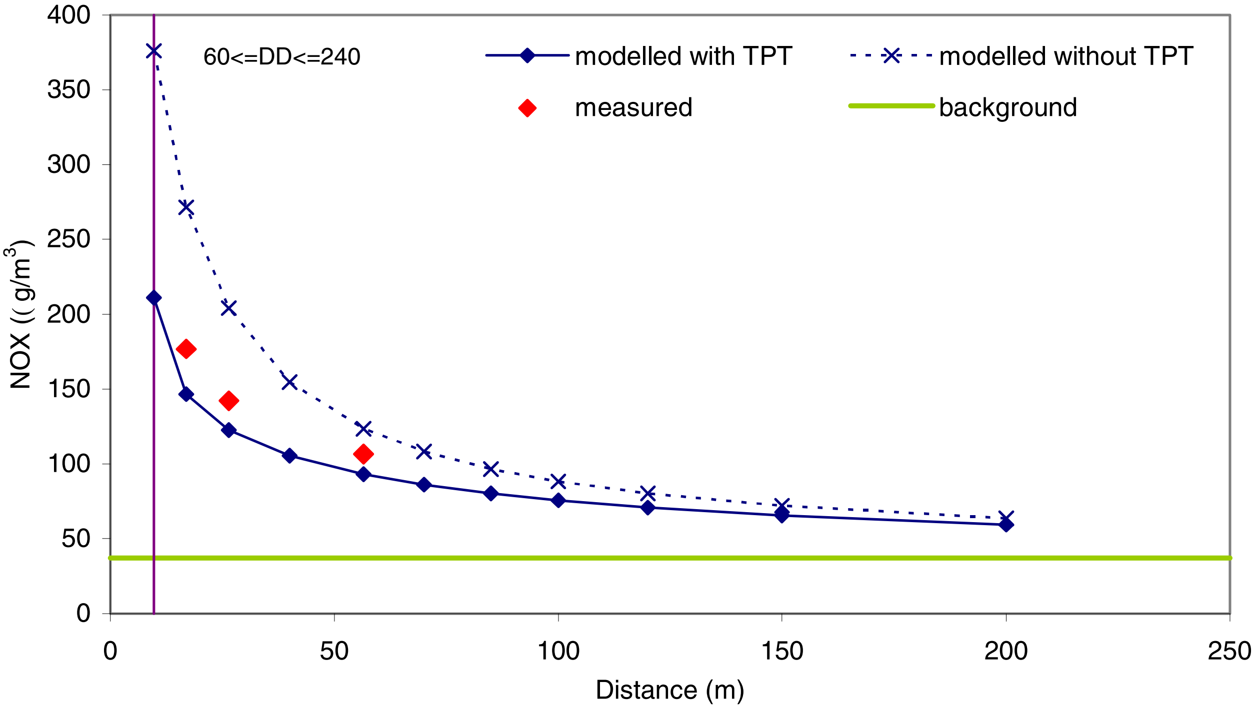


Figure 5.8 Nordbysletta motorway in Norway. Variation of concentrations with the distance from the center of the road. Modelling results are shown for calculations with traffic produced turbulence (TPT) included and without TPT. Concentrations are averaged over the entire measuring campaign period. The distance is measured from the centre of the road. The vertical line indicates location of the edge of the nearest traffic lane.

Details about the Køge Bugt monitoring campaign in Denmark can be found in Jensen et al., (2004). The Nordbysletta campaign in Norway is described in Hagen et al., (2003).

Data from the Danish Køge Bugt site have been used for development of the prototype version of the OML Highway model. OML was applied in its standard version (Olesen et al,. 2007) but with special extensions which are relevant for traffic pollution modelling. In particular, traffic produced turbulence (TPT) is crucial to pollution levels close to a road.. Especially in the case of low wind speed conditions, TPT is the dominating factor determining the degree of mixing, and thus dilution of traffic emissions. The procedure for estimation of the traffic produced turbulence used in OML is based on the method implemented in the street pollution model OSPM (Berkowicz, 2000a) but with a modification necessary for taking into account the attenuation of TPT with distance from a road (Jensen et al., 2004).

Comparison between the measured and modelled hourly concentrations of NO_X is shown in Figure 3.5. The results presented here refer to all hours with wind direction for which the 3 monitoring stations where downwind of the road. Variation of the measured and modelled concentration levels of NO_X with the distance from the road is shown in Figure 3.6. Model results are shown both with TPT included and without TPT. In the first case there is almost a perfect agreement with the measured data, while for the case without TPT an overprediction of more than twice is evident for distances close to the edge of the road. This illustrates the importance of properly taking into account the effect of TPT in modelling traffic pollution.

More details on model results for Køge Bugt Highway are given in Jensen et al., (2004), where also model performance in the case of NO_2 is presented.

A new study on model performance was performed recently using data from the Norwegian site, the Nordbysletta Highway. This study was conducted as a part of a Nordic Council of Ministers project on "Validated models describing Nordic urban and regional concentration of particles and organic/elemental carbon" – NORPAC (Ketzel et al., 2004). More details on this model evaluation study are given in Appendix 1: 'Modelling results with OML for Nordbysletta'.

Comparison between the measured and modelled hourly concentrations of NO_X is shown in Figure 3.7. The results presented here refer to all hours with wind direction for which the 3 monitoring stations were downwind of the road. Variation of the measured and modelled concentration levels of NO_X with the distance from the road is shown in Figure 3.8. Model results are shown both with TPT included and without TPT. Similarly to the Køge Bugt case, the very large influence of TPT on concentration levels close to the road is evident.

Performance of OML for the Nordbysletta case is comparable with the Køge Bugt case but some tendency for consistent underestimation is evident (see Figure 3.8). It should be noted that no adjustments to model formulation have been made compared to the version used for the Køge Bugt case. The Nordbysletta data contain much more observations with very low wind speed (< 1 m/s) than the Køge Bugt data. Model optimisation with respect to the low wind speed conditions will probably improve performance of the model. This question will be explored in connection with the general OML model update mentioned in the beginning of appendix 1.

The Danish and the Norwegian data have also been used for intercomparison of the OML model and a newly developed Norwegian highway model, WORM (Berger et al., 2007).

5.7 Limitations and Potential

At the present stage the prototype highway model is a research model. It is not very user-friendly as it requires application of a number of data handling steps involving several small programs and routines in different programming languages that are not integrated in one user interface. The integration with GIS should also be stronger.

In the model calculations it is assumed that the dispersion takes place in flat terrain. The dispersion will be affected in locations where the motorway is below the terrain or where noise barriers/earth banks are located along the motorway. In these cases, the initial dispersion will probably be larger leading to lower concentrations further away from the motorway. The model is likely to overestimate concentrations under these conditions.

The prototype model has been successfully validated for the pollutant NO_x against two independent datasets - a dataset from Denmark and a dataset from Norway. That justifies development of a user-friendly interface for wider application of this model.

A PM measuring campaign as described in Appendix 2 is recommended for improvement of the uncertainty connected with PM emission factors for highway driving conditions.

In the following we will provide more detailed specifications of a new more operational and user-friendly version of a Danish Highway Air Pollution Model.

6 Development of a user-friendly Danish Highway Air Pollution Model

The Danish Road Directorate manages about 3,800 km of state roads. In 2007 the Danish Road Directorate took over a large part of the highways previously managed by the Danish counties. That happened as part of a municipal reform that closed down the counties and left the state and the municipalities to manage the road network. The majority of these roads are in rural areas or in areas where closely by located buildings do not restrict the dispersion of air pollution. However, a smaller part of the network is in urban areas although none of the network can be characterised as fitting street canyon conditions. Many of the smaller highways pass through villages or small towns, and parts of the motorways pass through urban areas. The motorway network also attracts especially commercial development close to the roads.

The next section outlines the potential usefulness of a Danish highway air pollution model for highway management within a number of application areas.

6.1 Application areas

Environmental Impact Assessment

The Danish Road Directorate is engaged in a number of activities that requires environmental impact assessment. A European Union (EU) directive implemented in Danish legislation requires the Danish Road Directorate to carry out an environmental impact assessment for new major highway constructions or alteration of existing highways e.g. if substantial increases in traffic volumes are predicted. The legislation lists the different environmental impacts to be considered, among others air pollution, but it does not provide details on how to take into account air pollution.

Until now, the Danish Road Directorate has treated air pollution by considering vehicle emissions. This has provided information about the relative change in emissions from e.g. a proposed new highway but it has not provided any information about air concentrations, human exposure or relation to air quality limit values.

Part of an environmental impact assessment is also to provide information to the public about the potential impacts of proposed new highways and describe possible mitigating measures to reduce impacts. This has to be done for different alternatives of line routing.

Until now, the Danish Road Directorate has built up a capacity to model the impacts of traffic noise, effects of mitigating measures like noise barriers as well as a description of expected traffic noise levels in relation to traffic noise guidelines from the Danish Environmental Protection Agency.

A similar model capability should be built up for air pollution. It should be possible to model air quality and human exposure along the highway network, effects of mitigating measures and to compare predicted air quality levels with EU limit values.

EU Ambient Air Quality Limit Values

In the context of European environmental regulation the European Union (EU) has established health based air quality limit values or target values for a number of pollutants starting in 1996 with directives on assessment and management of ambient air quality (EU Council, 1996). Despite improvements in air quality, the adverse health and environmental impacts remain significant. According to these EU directives on assessment and management of ambient air quality, it is a requirement that the nationally designated institutions prepare an action plan to ensure that the limit values set out in the directives are met in the case that measured air quality levels are in excess of the limit levels plus a margin of tolerance. This means that there is a legal obligation for member states to act in response to observed violation of limit values. In Denmark the Danish Environmental Protection Agency, in co-operation with local authorities and other agencies, has the overall responsibility to ensure compliance with air quality limit values.

Mapping of NO_2 in 2003 along the motorway network in the County of Roskilde in Denmark showed that the entire network complied with NO_2 limit values plus the margin of tolerance in 2003 (see section 3.5). This could be considered a worst case scenario as some of busiest motorways in Denmark are located in the County of Roskilde. The margin of tolerance will gradually decrease until 2010 where the limit value has to be met. The combined effect of expected increase in traffic volumes and decrease in NO_x emissions per vehicle is uncertain and NO_2 emissions might even increase due to a higher share of direct NO_2 emission for newer vehicles (Carslaw & Beevers, 2005, Lambrecht et al. 2006). There is a risk that at some locations along the road network with high traffic volumes and closely located buildings, the air quality limit values may be exceeded in 2010.

Especially, exposure to particulate matter (PM) raises health concerns and no reliable information is available about PM along the motorway network as no measurements are available and model calculations are uncertain due to non-validated emission factors for highway conditions with high travel speeds. At present there is a PM_{10} limit value (2005) and a set of new $PM_{2.5}$ limit values have been proposed but have not yet been decided upon. PM_{10} are particles less than 10 micron and $PM_{2.5}$ are particles less than 2.5 micron in aerodynamic diameter.

Systematic Mapping of Air Quality and Human Exposure

A model tool for systematic mapping of air quality and human exposure along the entire state road network would provide an important overview of the current state of air quality and human exposure along the road network. Giving such information hot spots could be identified that merit further analysis and assessment of mitigating measures.

What if Scenario Analysis

The tool should be able to predict scenarios of future air quality levels so they can be compared with air quality limit values in future. It should be able to describe, e.g. the combined effects of increase in traffic volumes and decrease in emission factors. The Danish Road Directorate already has detailed information about the road network as well as traffic data (the GIS based VIS data base). The model would need to include an emission module.

The model should be able to answer the following "what if" questions related to changes in: alternative line routings, road layout (e.g. width of carriageway), traffic volume, vehicle composition, speed, and emissions). Examples of emission changes could be the effect of the general increase in the share of diesel vehicles or increases in directly emitted NO_2 from diesel vehicles.

If it is feasible to implement a quantitative description of the effect of e.g. noise barriers/earth banks on air quality concentrations as well as terrain effects, such features should also be implemented.

Given the above mentioned 'what if' features the model would be a powerful tool for environmental impact assessment and mitigation analysis.

Ranking of Road Investments based on Cost-benefit Analysis

The Danish Road Directorate ranks future road construction investments based on cost-benefit principles. Emissions are one of the parameters that are included. A new highway air pollution model that includes air quality and human exposure may further qualify these estimations. It is not within the scope of the proposed new highway model to provide input to the ranking investment procedure nor is it to improve the present emission methodology to an air quality and exposure methodology but it might be a potential spin-off in a long-term perspective.

6.2 Overall Model Development Criteria and Strategy

A new Danish highway air pollution model should meet the following criteria:

The model should be a useful tool in the following contexts:

- being part of the environmental impact assessment procedure with a detailed description of air quality and exposure in a limited area, using the best available inputs and models
- mapping and information of the public in a larger area but with more general less detailed input data
- for 'what if' scenario analysis and impact assessment of mitigation measures.

The model should be operational, user-friendly and GIS based, and organized in a single software package that allows application of existing GIS based data.

Standard input data should be available for the quick estimates, but user-defined data should also be an option for a more detailed analysis. A standard emission module reflecting Danish conditions should be available, along with e.g. standard data for meteorological data and typical temporal variation of traffic.

Users are expected to be experienced within air pollution modelling and GIS applications. Potential users may be the Danish Road Directorate, consultants and expert institutions.

The model should have an English user-interface and a user manual in English.

The proposed overall model strategy is to integrate the prototype OML highway model and supporting GIS tools and background models into a single GIS based software. This software might be SELMA^{GIS} that is an existing system for air pollution modelling and visualization developed by the German company Lohmeyer and applied in many places in Europe. As part of the present project we conducted a workshop with Lohmeyer in October 2006 to discuss the integration of the prototype highway model into SELMA^{GIS}.

It requires a considerable effort of man-power to transfer the current, fragmented system - a prototype air pollution model, combined with ad hoc GIS scripts and manual preparation of data at many levels - into the proposed semi-automatic system that can be flexibly applied for a wide range of applications.

The specifications of the model are discussed in further details in the following chapters.

7 Input/Output criteria

7.1 Concentration and exposure output

The structure of the model must be open, so calculations for different pollution components are possible without any changes to the model code. The only criterion for calculation of a pollution component should be the availability of the necessary emission data. This is the same method as applied in the Operational Street Pollution Model WinOSPM. Emission data are external to the model and can be provided by the user as pre-calculated emissions or as emission factors (g/veh*km).

As a minimum, the model should provide results for:

- NO_X
- NO_2
- $PM_{2.5}$
- PM_{10}
- Particle number
- CO_2 (only emissions)

Modelling of NO_2 involves a simple chemical reaction between NO and ozone. Additionally, direct emissions of NO_2 must be known for highway driving conditions.

Modelling of $PM_{2.5}/PM_{10}$ pollution requires also taking into account non-exhaust emissions. Road-wear, tyre-wear and re-suspension of the road material contribute significantly to particle pollution levels.

Outputs should be available in the form of tables, files and maps. It should be possible to visualise geographically e.g. air quality levels as contour maps. It should also be possible to compare predicted air quality levels with EU limit values.

Output should be locations with coordinates that serve as calculation points (or receptor points).

Exposure calculations should be possible relating air quality levels at e.g. addresses with the number of people living at the address. Such calculations require data on the number of people at address level.

7.2 Input data

The model should be able to accommodate input data of different complexity. It should be possible to make calculations based on detailed hour-by-hour data but it should also be possible to use synthesised data e.g. in the form of average diurnal profiles to describe the diurnal variation of traffic.

The basic input data to the model consists of:

- geometrical specifications of the road segments
- terrain/surroundings data
- meteorological data
- traffic/emission data
- calculation points (receptor points)

Geometrical Specifications of the Road Segments

In the prototype version of the model, which is based on OML, the road geometry is specified as a number of rectangular area sources covering all the traffic lanes. An example is shown in Figure 5.1. The presently used algorithm in OML restricts the shape of an area source with respect to the ratio between the sides of the rectangle. The longest cannot be more than 10 times the shorter. The procedure used for construction of the area sources is external to the model. It should be considered to incorporate this procedure into the model code so that any ratio between the longest and the shortest length is allowed. However, this will require substantial modifications to the OML code, while gaining more flexibility in specification of the area sources. More detailed analysis is required to assess if the benefits exceed the cost of this implementation.

A GIS road network is usually represented as a collection of unique polygon segments. Attribute data e.g. Average Daily Traffic, travel speed etc. are associated to each segment. For the prototype highway model a new GIS application in Avenue (ArcView GIS 3.3) was developed to semi-automatically generate input data for the air quality model for the entire motorway network (area/emission sources, receptor points and exposure areas), see Figure 5.2. In this procedure the road network was represented as individual segments for each direction. Another small GIS tool was developed to represent each lane in each direction for detailed analysis at a specific location. These procedures have to be implemented into the SELMA^{GIS} software. This has to be done for road networks digitized as individual directions (as for the prototype) as well as for a road network represented as a single line (as for a smaller highway).

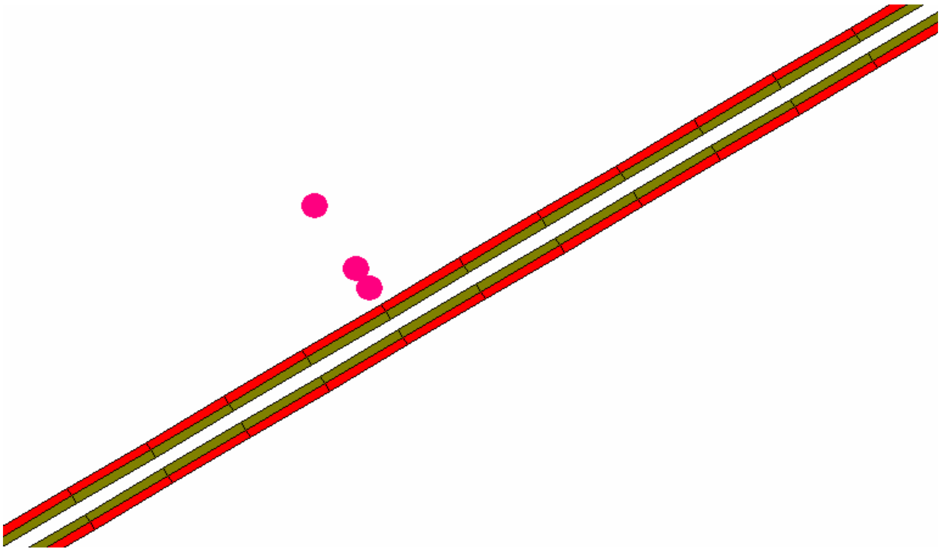


Figure 7.1 Example of representation of the road lanes as a series of rectangular area sources.

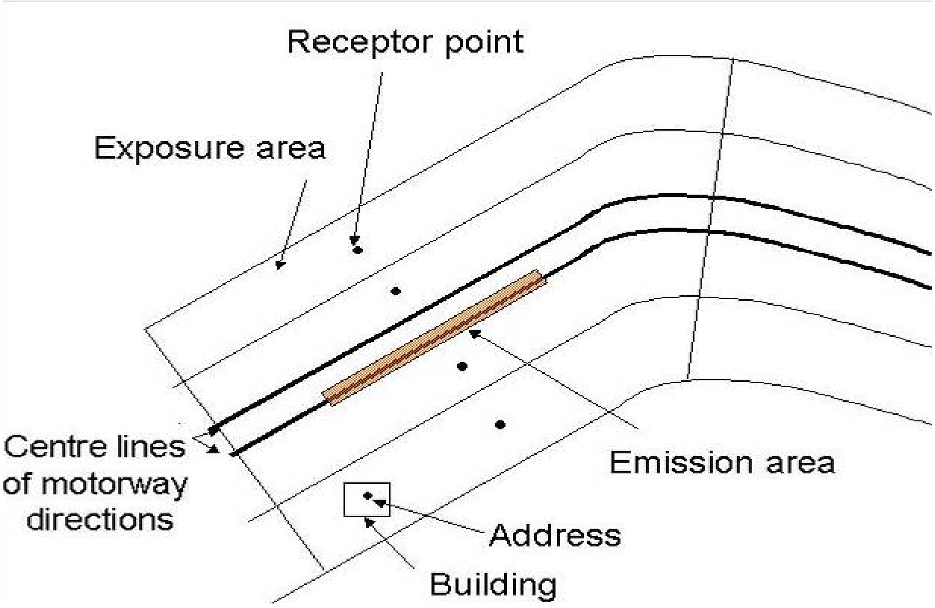
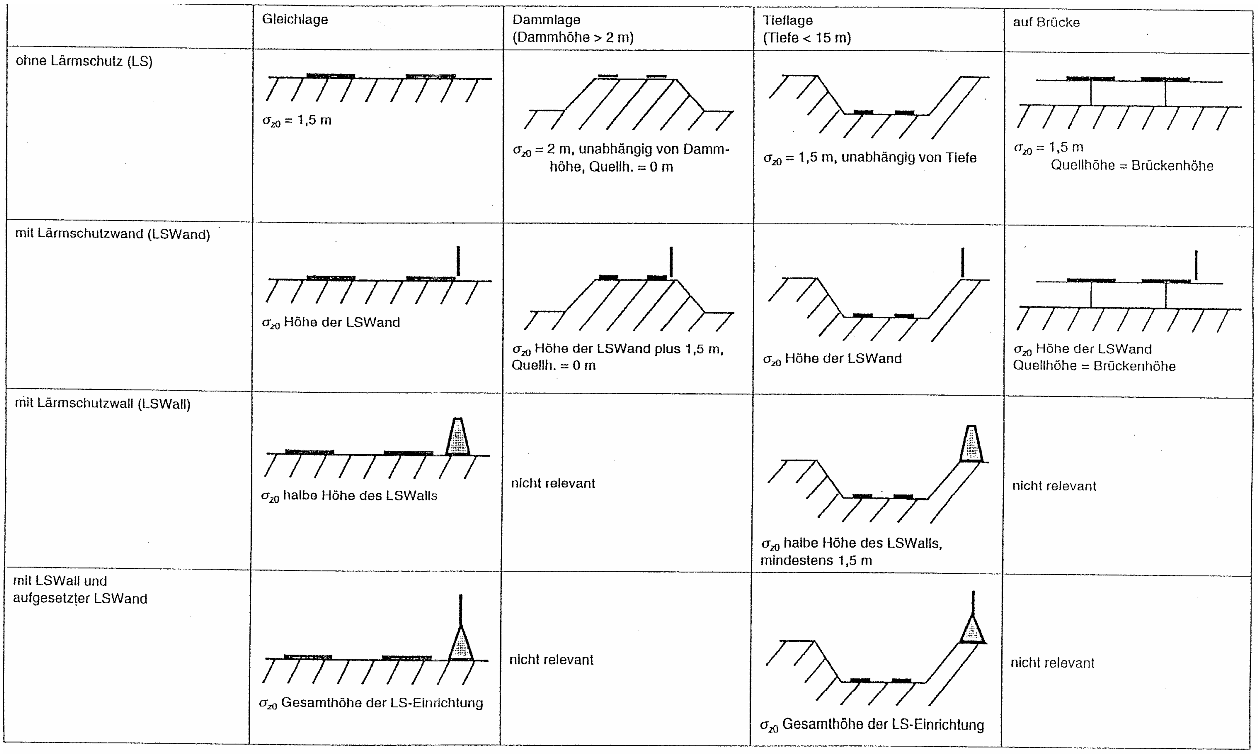


Figure 7.2 A new GIS application was developed to semi-automatically generate input data for the air quality model for the entire motorway network (emission sources, receptor points and exposure areas)

Terrain/surroundings data

Terrain data are usually not crucial for this kind of modelling in Denmark. It is expected that the model will primarily be used for roads with open surroundings with no significant terrain features. However, some criteria must be established for using (or not using) the model in build-up areas.

Some special features, such as noise barriers/earth banks, should also be considered. If feasible the impact on dispersion should be described and implemented into the model. It will only be possible to implement this feature if it can be based on existing guidelines and parameterisation. Germany has some experience in this field as illustrated in Figure 5.3 from the draft of guideline VDI 3782, Blatt 8: 1998, Entwurf, Ausbreitungsrechnung fuer Kfz-Emissionen, Beuth Verlag, Berlin. These recommendations have to be evaluated for their applicability in connection with OML-Highway and under Danish conditions.



	Gleichlage	Dammlage (Dammhöhe > 2 m)	Tieflage (Tiefe < 15 m)	auf Brücke
ohne Lärmschutz (LS)	σ_{z0} = 1,5 m	σ_{z0} = 2 m, unabhängig von Dammhöhe, Quellh. = 0 m	σ_{z0} = 1,5 m, unabhängig von Tiefe	σ_{z0} = 1,5 m Quellhöhe = Brückenhöhe
mit Lärmschutzwand (LSWand)	σ_{z0} Höhe der LSWand	σ_{z0} Höhe der LSWand plus 1,5 m, Quellh. = 0 m	σ_{z0} Höhe der LSWand	σ_{z0} Höhe der LSWand Quellhöhe = Brückenhöhe
mit Lärmschutzwall (LSWall)	σ_{z0} halbe Höhe des LSWalls	nicht relevant	σ_{z0} halbe Höhe des LSWalls, mindestens 1,5 m	nicht relevant
mit LSWall und aufgesetzter LSWand	σ_{z0} Gesamthöhe der LS-Einrichtung	nicht relevant	σ_{z0} Gesamthöhe der LS-Einrichtung	nicht relevant

Bild A8. Additive Terme σ_{z0} für den vertikalen Ausbreitungsparameter σ_z für verschiedene Straßenlagen und Lärmschutzeinrichtungen

Die Werte sind unabhängig von der Fahrgeschwindigkeit anzusetzen und unabhängig davon, ob die LS-Einrichtungen nur auf einer Seite der Straßen existieren oder beidseitig, und auch unabhängig vom Abstand der Lärmschutzeinrichtungen zur Fahrbahn.

Figure 7.3 Suggestion from VDI guideline on how to handle the position of the road and presence of the noise barrier in road dispersion models by changing the initial dispersion parameters.

Meteorological Data

In the present version of the model all the meteorological data are provided in the same form as for the standard OML model. These data are created using either standard meteorological observations or special mast or radio sounding measurements but they require a pre-processing with external software, OML Meteorological Pre-processor, such as:

- wind speed
- wind direction
- solar radiation
- temperature
- heat flux
- mixing layer height
- stability (Monin-Obukhov length)

Some alternative procedures may be considered taking into account that not all the meteorological parameters are equally important for roadside applications. Modifications of the currently used format of the meteorological data for OML may also be considered. More detailed analysis is required to assess if the benefits exceed the cost of this implementation.

It is recommended that a Danish highway model includes a typical meteorological data set as the user should not be expected to provide such data. It should also be possible to use user-specified meteorological data as long as it complies with the OML format.

Traffic/emission data

Traffic and emission data are the most essential (critical) elements concerning all traffic air pollution modelling. However, depending on the application, data at different levels of detail might be applied for the modelling. In the present prototype version of the model both the traffic and the emission data are treated as input data to the model. There are no facilities available for generation of the emissions based on the available traffic data. The emissions are presently generated externally using the emission module implemented in WinOSPM (2007). In WinOSPM, both the traffic and emission data can be specified in several different forms. Which type of traffic and emission data is used depends on the purpose of the application and the availability of data (Figure 5.4).

It is recommended that the emission module of WinOSPM and the way that traffic data is represented in WinOSPM is re-used and integrated into the SELMA^{GIS} software.

Traffic

The following figures illustrate how traffic data are represented in the WinOSPM traffic modul.

Pre-defined diurnal traffic types are expected to be used when only minimum information on traffic is available. This will often be the case when dealing with planned road segments or work under construction. The only available information at this stage will probably be the expected Average Diurnal Traffic (ADT) and travel speed. Diurnal variation of the traffic flow and vehicle composition could in this case be specified using typical data based on experience from other roads with a similar function. Examples of such a "typical" pre-defined traffic type file is shown in Figure 5.4 and 5.5.

In the case of the WinOSPM model eight different typical urban street types have been identified, and pre-defined data on vehicle composition and temporal variation of traffic exists. The user simple chooses the type of street that best represent the street under consideration. A similar approach is recommended for highways. Hence, a limited number of typical highways has to be identified and characterized according to vehicle composition and temporal variation of traffic, including speeds and cold start. Cold starts may be assumed to be insignificant. This characterization should be based on analysis of traffic count data.

The traffic data can also be specified in terms of **explicit traffic flow values** (veh/h) for all the vehicle types. The structure of such data is very similar to the generic type. An example is shown in Figure 5.6. This type of data will normally be used when real hourly traffic counts are available but only for a short time period (days, weeks). Some average values can thus be constructed using these data. Taking into account that the diurnal variation of the traffic flow and composition is normally very persistent, using such average values for long term calculations is acceptable.

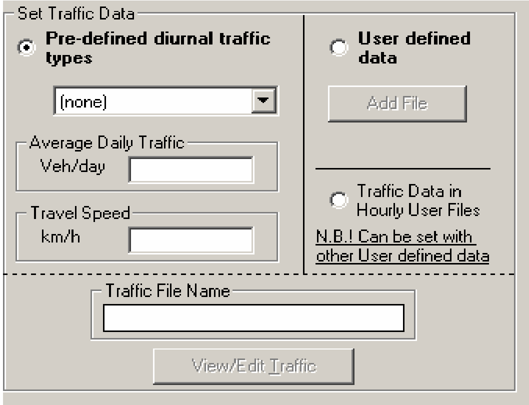
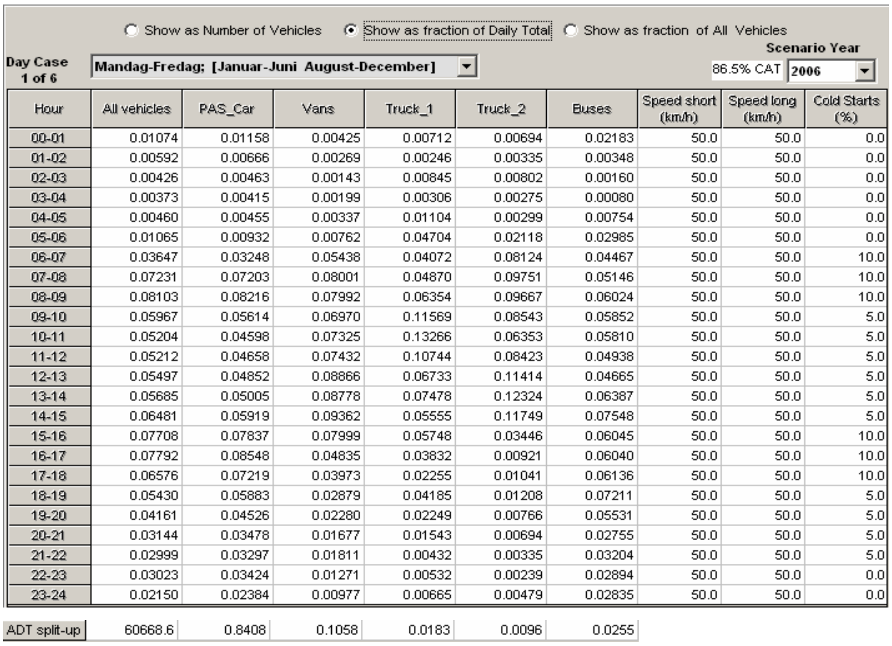


Figure 7.4 The traffic data can be provided as files with a pre-defined vehicle type composition and diurnal/weekly temporal variation (upper left option) or as user defined files (upper right) with explicit specification of vehicle numbers for each hour of a weekday. The most detailed form implies traffic data provided in input files on hour-by-hour basis (right middle).



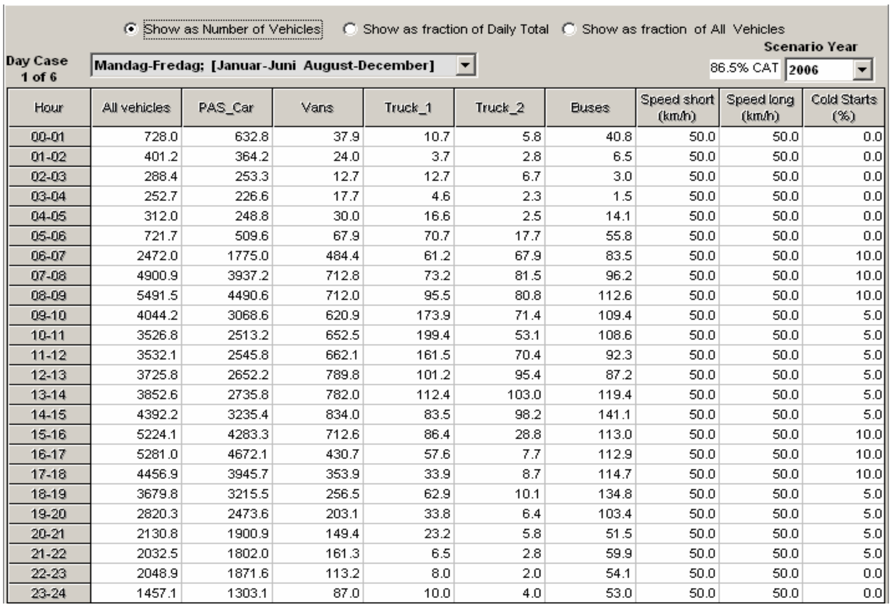
○ Show as Number of Vehicles ● Show as fraction of Daily Total ○ Show as fraction of All Vehicles

Day Case 1 of 6: Mandag-Fredag; [Januar-Juni August-December]

86.5% CAT Scenario Year: 2006

Hour	All vehicles	PAS_Car	Vans	Truck_1	Truck_2	Buses	Speed short (km/h)	Speed long (km/h)	Cold Starts (%)
00-01	0.01074	0.01158	0.00425	0.00712	0.00694	0.02183	50.0	50.0	0.0
01-02	0.00592	0.00666	0.00269	0.00246	0.00335	0.00348	50.0	50.0	0.0
02-03	0.00426	0.00463	0.00143	0.00845	0.00802	0.00160	50.0	50.0	0.0
03-04	0.00373	0.00415	0.00199	0.00306	0.00275	0.00080	50.0	50.0	0.0
04-05	0.00460	0.00455	0.00337	0.01104	0.00299	0.00754	50.0	50.0	0.0
05-06	0.01065	0.00932	0.00762	0.04704	0.02118	0.02985	50.0	50.0	0.0
06-07	0.03647	0.03248	0.05438	0.04072	0.08124	0.04467	50.0	50.0	10.0
07-08	0.07231	0.07203	0.08001	0.04870	0.09751	0.05146	50.0	50.0	10.0
08-09	0.08103	0.08216	0.07992	0.06354	0.09667	0.06024	50.0	50.0	10.0
09-10	0.05967	0.05614	0.06970	0.11569	0.08543	0.05852	50.0	50.0	5.0
10-11	0.05204	0.04598	0.07325	0.13266	0.06353	0.05810	50.0	50.0	5.0
11-12	0.05212	0.04658	0.07432	0.10744	0.08423	0.04938	50.0	50.0	5.0
12-13	0.05497	0.04852	0.08866	0.06733	0.11414	0.04665	50.0	50.0	5.0
13-14	0.05685	0.05005	0.08778	0.07478	0.12324	0.06387	50.0	50.0	5.0
14-15	0.06481	0.05919	0.09362	0.05555	0.11749	0.07548	50.0	50.0	5.0
15-16	0.07708	0.07837	0.07999	0.05748	0.03446	0.06045	50.0	50.0	10.0
16-17	0.07792	0.08548	0.04835	0.03832	0.00921	0.06040	50.0	50.0	10.0
17-18	0.06576	0.07219	0.03973	0.02255	0.01041	0.06136	50.0	50.0	10.0
18-19	0.05430	0.05883	0.02879	0.04185	0.01208	0.07211	50.0	50.0	5.0
19-20	0.04161	0.04526	0.02280	0.02249	0.00766	0.05531	50.0	50.0	5.0
20-21	0.03144	0.03478	0.01677	0.01543	0.00694	0.02755	50.0	50.0	5.0
21-22	0.02999	0.03297	0.01811	0.00432	0.00335	0.03204	50.0	50.0	5.0
22-23	0.03023	0.03424	0.01271	0.00532	0.00239	0.02894	50.0	50.0	0.0
23-24	0.02150	0.02384	0.00977	0.00665	0.00479	0.02835	50.0	50.0	0.0
ADT split-up	60668.6	0.8408	0.1058	0.0183	0.0096	0.0255			

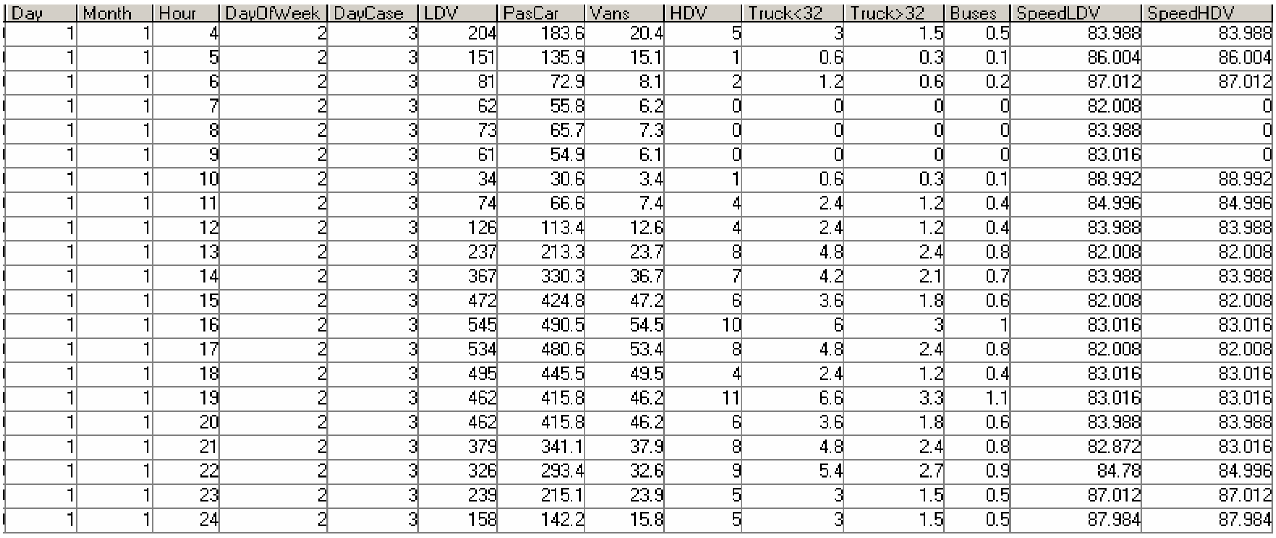
Figure 7.5 An example of traffic data with specification of the relative diurnal variation and vehicle composition.



Hour	All vehicles	PAS_Car	Vans	Truck_1	Truck_2	Buses	Speed short (km/h)	Speed long (km/h)	Cold Starts (%)
00-01	728.0	632.8	37.9	10.7	5.8	40.8	50.0	50.0	0.0
01-02	401.2	364.2	24.0	3.7	2.8	6.5	50.0	50.0	0.0
02-03	288.4	253.3	12.7	12.7	6.7	3.0	50.0	50.0	0.0
03-04	252.7	226.6	17.7	4.6	2.3	1.5	50.0	50.0	0.0
04-05	312.0	248.8	30.0	16.6	2.5	14.1	50.0	50.0	0.0
05-06	721.7	509.6	67.9	70.7	17.7	55.8	50.0	50.0	0.0
06-07	2472.0	1775.0	484.4	61.2	67.9	83.5	50.0	50.0	10.0
07-08	4900.9	3937.2	712.8	73.2	81.5	96.2	50.0	50.0	10.0
08-09	5491.5	4490.6	712.0	95.5	80.8	112.6	50.0	50.0	10.0
09-10	4044.2	3068.6	620.9	173.9	71.4	109.4	50.0	50.0	5.0
10-11	3526.8	2513.2	652.5	199.4	53.1	108.6	50.0	50.0	5.0
11-12	3532.1	2545.8	662.1	161.5	70.4	92.3	50.0	50.0	5.0
12-13	3725.8	2652.2	789.8	101.2	95.4	87.2	50.0	50.0	5.0
13-14	3852.6	2735.8	782.0	112.4	103.0	119.4	50.0	50.0	5.0
14-15	4392.2	3235.4	834.0	83.5	98.2	141.1	50.0	50.0	5.0
15-16	5224.1	4283.3	712.6	86.4	28.8	113.0	50.0	50.0	10.0
16-17	5281.0	4672.1	430.7	57.6	7.7	112.9	50.0	50.0	10.0
17-18	4456.9	3945.7	353.9	33.9	8.7	114.7	50.0	50.0	10.0
18-19	3679.8	3215.5	256.5	62.9	10.1	134.8	50.0	50.0	5.0
19-20	2820.3	2473.6	203.1	33.8	6.4	103.4	50.0	50.0	5.0
20-21	2130.8	1900.9	149.4	23.2	5.8	51.5	50.0	50.0	5.0
21-22	2032.5	1802.0	161.3	6.5	2.8	59.9	50.0	50.0	5.0
22-23	2048.9	1871.6	113.2	8.0	2.0	54.1	50.0	50.0	0.0
23-24	1457.1	1303.1	87.0	10.0	4.0	53.0	50.0	50.0	0.0

Figure 7.6 An example of traffic data (Unit: vehicle per hour) with explicit specification of the traffic data for each hour of a weekday.

The most detailed procedure is providing the **traffic data on hour-by-hour basis** (Figure 5.7). This type of data is normally available only for limited time periods and will typically be used in connection with special monitoring campaigns. The practical experience is that real hour-by-hour traffic data do not necessarily improve model results compared with averaged traffic data. One of the reasons for this is that this kind of data is often gathered using automatic traffic counts. Automatic traffic counts might provide reliable results with respect to the total traffic flow but the vehicle composition is either missing or is much less reliable. The composition is crucial for emission estimations, and application of an averaged traffic composition might in any case be the only practical solution.



Day	Month	Hour	DayOfWeek	DayCase	LDV	PasCar	Vans	HDV	Truck<32	Truck>32	Buses	SpeedLDV	SpeedHDV
1	1	4	2	3	204	183.6	20.4	5	3	1.5	0.5	83.988	83.988
1	1	5	2	3	151	135.9	15.1	1	0.6	0.3	0.1	86.004	86.004
1	1	6	2	3	81	72.9	8.1	2	1.2	0.6	0.2	87.012	87.012
1	1	7	2	3	62	55.8	6.2	0	0	0	0	82.008	0
1	1	8	2	3	73	65.7	7.3	0	0	0	0	83.988	0
1	1	9	2	3	61	54.9	6.1	0	0	0	0	83.016	0
1	1	10	2	3	34	30.6	3.4	1	0.6	0.3	0.1	88.992	88.992
1	1	11	2	3	74	66.6	7.4	4	2.4	1.2	0.4	84.996	84.996
1	1	12	2	3	126	113.4	12.6	4	2.4	1.2	0.4	83.988	83.988
1	1	13	2	3	237	213.3	23.7	8	4.8	2.4	0.8	82.008	82.008
1	1	14	2	3	367	330.3	36.7	7	4.2	2.1	0.7	83.988	83.988
1	1	15	2	3	472	424.8	47.2	6	3.6	1.8	0.6	82.008	82.008
1	1	16	2	3	545	490.5	54.5	10	6	3	1	83.016	83.016
1	1	17	2	3	534	480.6	53.4	8	4.8	2.4	0.8	82.008	82.008
1	1	18	2	3	495	445.5	49.5	4	2.4	1.2	0.4	83.016	83.016
1	1	19	2	3	462	415.8	46.2	11	6.6	3.3	1.1	83.016	83.016
1	1	20	2	3	462	415.8	46.2	6	3.6	1.8	0.6	83.988	83.988
1	1	21	2	3	379	341.1	37.9	8	4.8	2.4	0.8	82.872	83.016
1	1	22	2	3	326	293.4	32.6	9	5.4	2.7	0.9	84.78	84.996
1	1	23	2	3	239	215.1	23.9	5	3	1.5	0.5	87.012	87.012
1	1	24	2	3	158	142.2	15.8	5	3	1.5	0.5	87.984	87.984

Figure 7.7 An example of an input file with hour-by-hour specification of the traffic data (in veh/hour and for speed km/h).

Emission data

Similarly to traffic data, emission data might also be provided in several different ways. Basically, the road traffic emissions are calculated from traffic data as

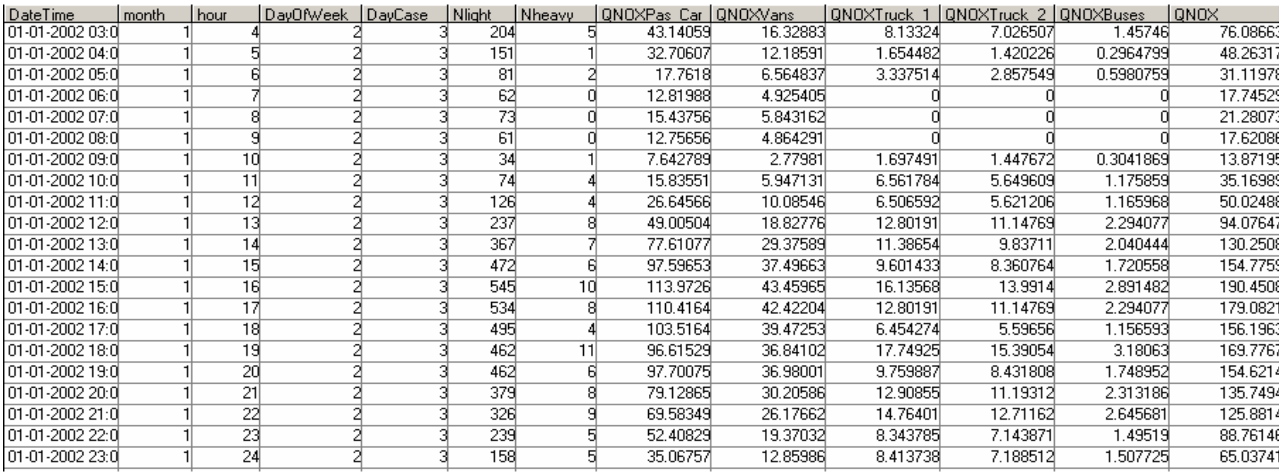
Road Emissions (*g/km/h*) = Traffic (*veh/h*) * Emission Factors (*g/veh/km*)

Emission factors are vehicle specific and depend on engine load. This means that that they depend on vehicle type, fuel, road slope, vehicle load and driving conditions. The method used for classification of vehicle types depends on the particular emission model in use. Also driving conditions can be defined using different parameters or criteria. The street pollution model, WinOSPM, contains a built-in emission module, which can make use of user specified vehicle type classification, while the traffic speed is used as the driving condition parameter. Classification of vehicles is based on the method used in the emission model COPERT (in its latest version 4 from 2006), developed by the European Environmental Agency, but the emission module is not restricted to the particular classes defined in COPERT. COPERT emission factors are believed to underestimate emissions (version III more than 4) and therefore also a Danish set of emission factors have been defined in WinOSPM. Emission factors are calculated by the emission module based on user specified input files, which are text files containing expressions for the dependence of emission factors on the travel speed. A special MathParser translates these expressions into an appropriate computer code. The basic procedure for calculations of the emissions is the same regardless the type of the traffic data. In the case of average type traffic data (Figure 5.5 and Figure 5.6) the emissions will also be calculated as average values with daily and/or weekly variation. In the case of traffic data given on hour-by-hour basis, also the emissions will be calculated on hour-by-hour basis.

For some applications it might be feasible to use pre-calculated emissions, especially in the case when the method implemented in the built-in emission module is not suitable for the application. The procedure currently used in WinOSPM is similar to the procedure used for traffic data; pre-calculated emissions can either be provided on hour-by-hour basis (Figure 5.8) or as average emissions with daily and/or weekly variation (Figure 5.9). In the last case, also the traffic data are expected to be provided as averaged values.

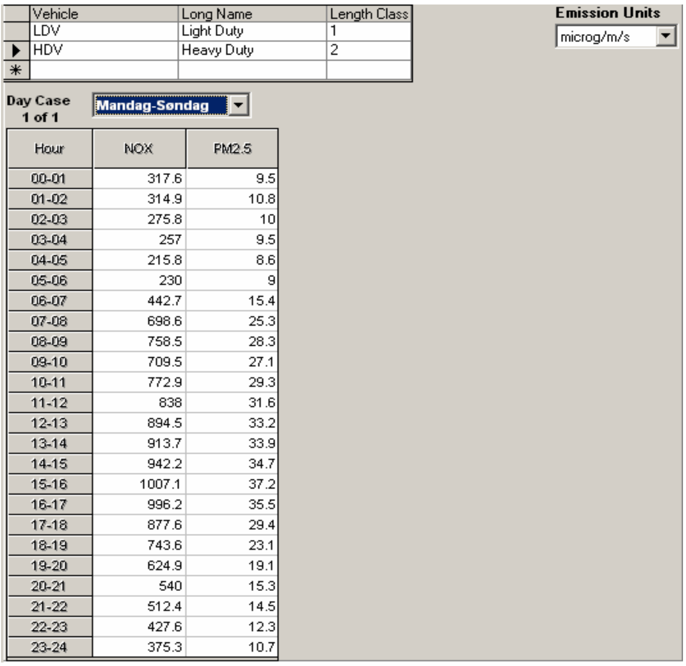
The different possible procedures are illustrated in Figure 5.10. Traffic data must be provided to the dispersion model even in the case when the emissions are pre-calculated. Traffic is not only the source of emissions. The turbulence produced by moving vehicles (traffic produced turbulence – TPT) is also an important factor influencing dispersion and dilution of the emitted pollutants. The method used currently for calculation of TPT requires information on vehicle flow divided into light-duty and heavy-duty vehicles and the corresponding travel speed.

Emission factors for particles are particularly uncertain and they have not been validated for Danish highway condition with high travel speed. Therefore, it is recommended that a measurement campaign be conducted of particles of different size distribution (PM_{10}, $PM_{2.5}$ and number of particles) together with gaseous pollutants to be able to estimate particle emission factors. Further details are provided in Appendix 2: Outline of an experimental campaign for particle pollution from Highway traffic in Denmark.



DateTime	month	hour	DayOfWeek	DayCase	Nlight	Nheavy	QNOXPas Car	QNOXVans	QNOXTruck 1	QNOXTruck 2	QNOXBuses	QNOX
01-01-2002 03:0	1	4	2	3	204	5	43.14059	16.32883	8.13324	7.026507	1.45746	76.0866
01-01-2002 04:0	1	5	2	3	151	1	32.70607	12.18591	1.654482	1.420226	0.2964799	48.2631
01-01-2002 05:0	1	6	2	3	81	2	17.7618	6.564837	3.337514	2.857549	0.5980759	31.1197
01-01-2002 06:0	1	7	2	3	62	0	12.81988	4.925405	0	0	0	17.7452
01-01-2002 07:0	1	8	2	3	73	0	15.43756	5.843162	0	0	0	21.2807
01-01-2002 08:0	1	9	2	3	61	0	12.75656	4.864291	0	0	0	17.6208
01-01-2002 09:0	1	10	2	3	34	1	7.642789	2.77981	1.697491	1.447672	0.3041869	13.8719
01-01-2002 10:0	1	11	2	3	74	4	15.83551	5.947131	6.561784	5.649609	1.175859	35.1698
01-01-2002 11:0	1	12	2	3	126	4	26.64566	10.08546	6.506592	5.621206	1.165968	50.0248
01-01-2002 12:0	1	13	2	3	237	8	49.00504	18.82776	12.80191	11.14769	2.294077	94.0764
01-01-2002 13:0	1	14	2	3	367	7	77.61077	29.37589	11.38654	9.83711	2.040444	130.250
01-01-2002 14:0	1	15	2	3	472	6	97.59653	37.49663	9.601433	8.360764	1.720558	154.775
01-01-2002 15:0	1	16	2	3	545	10	113.9726	43.45965	16.13568	13.9914	2.891482	190.450
01-01-2002 16:0	1	17	2	3	534	8	110.4164	42.42204	12.80191	11.14769	2.294077	179.0821
01-01-2002 17:0	1	18	2	3	495	4	103.5164	39.47253	6.454274	5.59656	1.156593	156.196
01-01-2002 18:0	1	19	2	3	462	11	96.61529	36.84102	17.74925	15.39054	3.18063	169.776
01-01-2002 19:0	1	20	2	3	462	6	97.70075	36.98001	9.759887	8.431808	1.748952	154.621
01-01-2002 20:0	1	21	2	3	379	8	79.12865	30.20586	12.90855	11.19312	2.313186	135.749
01-01-2002 21:0	1	22	2	3	326	9	69.58349	26.17662	14.76401	12.71162	2.645681	125.881
01-01-2002 22:0	1	23	2	3	239	5	52.40829	19.37032	8.343785	7.143871	1.49519	88.7614
01-01-2002 23:0	1	24	2	3	158	5	35.06757	12.85986	8.413738	7.188512	1.507725	65.03741

Figure 7.8 An example of an input file with hour-by-hour specification of the traffic data and pre-calculated emissions.



Vehicle	Long Name	Length Class
LDV	Light Duty	1
HDV	Heavy Duty	2

Emission Units: microg/m/s

Day Case 1 of 1: Mandag-Søndag

Hour	NOX	PM2.5
00-01	317.6	9.5
01-02	314.9	10.8
02-03	275.8	10
03-04	257	9.5
04-05	215.8	8.6
05-06	230	9
06-07	442.7	15.4
07-08	698.6	25.3
08-09	758.5	28.3
09-10	709.5	27.1
10-11	772.9	29.3
11-12	838	31.6
12-13	894.5	33.2
13-14	913.7	33.9
14-15	942.2	34.7
15-16	1007.1	37.2
16-17	996.2	35.5
17-18	877.6	29.4
18-19	743.6	23.1
19-20	624.9	19.1
20-21	540	15.3
21-22	512.4	14.5
22-23	427.6	12.3
23-24	375.3	10.7

Figure 7.9 Pre-calculated emissions density (unit: µg/m/s) for the road elements can also be provided in form of a specified daily variation.

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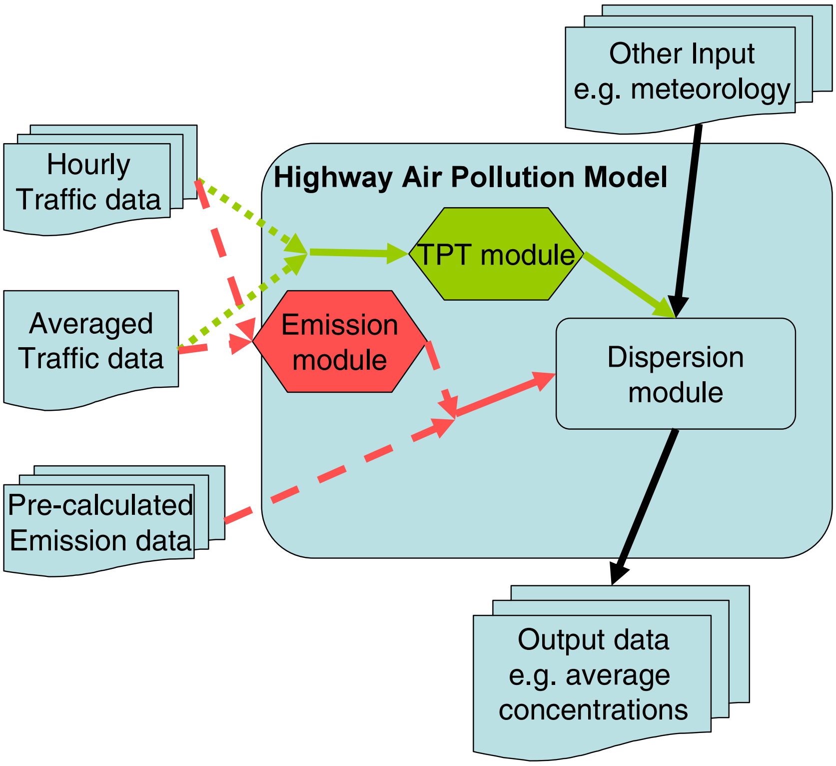

Figure 7.10 Traffic and emission data can be provided to a highway dispersion model in several different ways (options are indicated by dashed lines). Emissions can be internally calculated from traffic data using a built-in emission module or they can be provided in separate input files. Traffic data are required in all cases for the TPT calculation,

8 Coupling between the Highway Model and GIS

Coupling between the air quality model and a Geographical Information System (GIS) can significantly optimise the process of preparation of input data and visualisation of the results.

The benefit of using GIS as a data generation engine is that a GIS program contains efficient tools to handle spatial data with a user-friendly graphical interface. The spatial data are usually co-related with a number of properties (attributes), which makes it possible to select data according to the specified geographical area and other properties. In the case of a highway air pollution model the procedure may be as follows.

The GIS data contain geographical information on the entire road network within a region (can be a whole country, administrative unit, etc.).

These data are connected with attributes on the type of the road and the relevant traffic data. Depending on the GIS, the data can be stored in one or several different databases. Joining the data is usually performed by the GIS.

The user selects the data by specification of the geographical region and road type. The selection can be done using the graphical interface or by a special query.

The GIS generates the relevant data, which are provided as input to the air pollution dispersion model. Not all required data might be stored within the GIS. This can e.g. be the meteorological data, which typically will reside in external databases but again, the GIS can either directly perform the selection of data or create an appropriate link to the database.

Typically, the data stored within the GIS must be pre-processed before they can be used by the dispersion model. Area source and emission have to be generated. Meteorological and urban background data reside in this case in external databases and are directly accessed by OML Highway.

The GIS can also be used for generation of the calculation points (receptor net). Depending on the application, it can e.g. be a regular grid or a net of points following the selected road segments.

Results of calculations with the model can be transferred back to GIS for presentation on the GIS created map and subsequent spatial analyses. These may include:

- marking of the areas where limit values or certain threshold values are exceeded,
- estimation of population exposure by joining the concentration data with population data in the GIS database,

- visualisation of modifications to air quality along the road network due to different traffic scenarios or new road constructions.

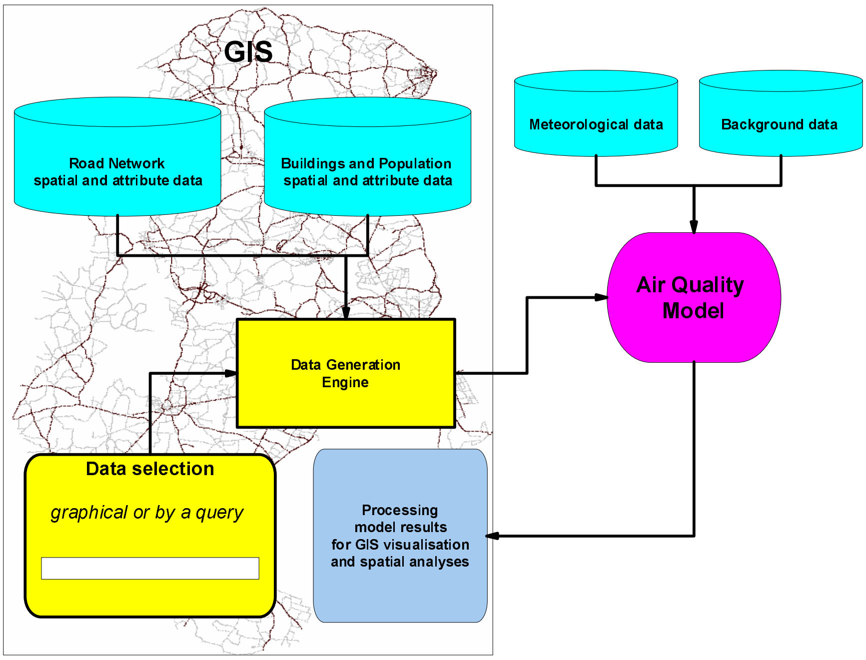

Figure 8.1. Schematic illustration of coupling between the Air Quality Model and a GIS. Road emissions are calculated by the built-in emission module using traffic data supplied by GIS. Meteorological data will typically be stored in external databases, while background concentration data might be generated by a separate model with input data also provided by GIS.

An example of a possible structure of a GIS – Air Quality Model coupled system is shown in Figure 8.1. In this example, the Air Quality Model is an external (with respect to GIS) program. The communication between GIS and the model takes place by exchanging input/output files. Generation of the necessary files is performed by a Data Generation Engine built-in in GIS. Typically, this will be geometrical data describing the selected road network and the associated attributes, as e.g. traffic on the selected roads. GIS has the ability to store stationary data. Time dependent data, such as meteorological data or time variation of traffic flow, will normally be stored in external databases. The task of the Data Generation Engine will in this case be to select and create the required data files based on the available GIS information and to create a project file with specification of the file locations, incl. files residing in the external databases. Subsequently, the air quality model can be invoked with the project file as a command line parameter. The benefit of using this type of coupling between GIS and an air quality model is that the same model program can be used both with and without a GIS. Model execution can be done independently of the GIS but using the files generated by GIS.

The main drawback of the described method is that any communication between the GIS and the model can only be done by exchanging some files. The program execution can be invoked from GIS but there is no easy way to monitor the external program's execution from GIS. Any messages from the external program, such as e.g. error messages, cannot be directly forwarded to the GIS program. Some special procedures must be developed in order to be able to detect when the model execution has finished and the model results can be transferred to GIS for the subsequent presentation and analysis.

An alternative procedure would be to implement the air quality model within the GIS program in form of a Dynamic Link Library (DLL), which is standard for Windows programming. This would make the communication between GIS and the model easier. However, the work required for implementation of a complete DLL-solution might be substantial.

A feasible solution might be implementation of some of elements of the Air Quality Model in form of DLL modules within the GIS. This might e.g. be the Emission module of WinOSPM, which will make it possible to calculate traffic emissions directly within the GIS, without using any external model. Such a module can also be used for calculation of CO_2 emissions or fuel consumption, which is relevant for climate change issues but not for local air quality.

8.1 SELMA^{GIS}

The proposed overall model strategy is to integrate the prototype OML highway model and supporting GIS tools and background models into SELMA^{GIS} that is an existing system for air pollution modelling and visualization developed by the German company Lohmeyer.

SELMA^{GIS} offers a unique graphical user interface to work with different dispersion models. It is based on the Geographical Information System ArcGIS 9.x and is used as an extension in ArcMap (Figure 8.2 and Figure 8.3). SELMA^{GIS} makes it easy to work with different sophisticated dispersion models utilizing all advantages from the large functionality of ArcGIS, e.g. getting and preparing input data from large data bases, result evaluation by spatial joining with different theme layers and 3D-visualisation (requires 3D-Analyst extension from ESRI).

See: http://www.lohmeyer.de/Software/SELMAGIS-AG9-english.htm

More details about how to integrate the prototype OML highway model into Selma^{GIS} is outlined in Appendix 4 Proposal from a German Consulting Company (Ing.-Büro Lohmeyer GmbH & Co.) on coupling of air pollution models with a GIS software.

More details concerning the required input formats of the prototype OML highway model is outlined in Appendix 3: Description of the input formats for OML-Highway.

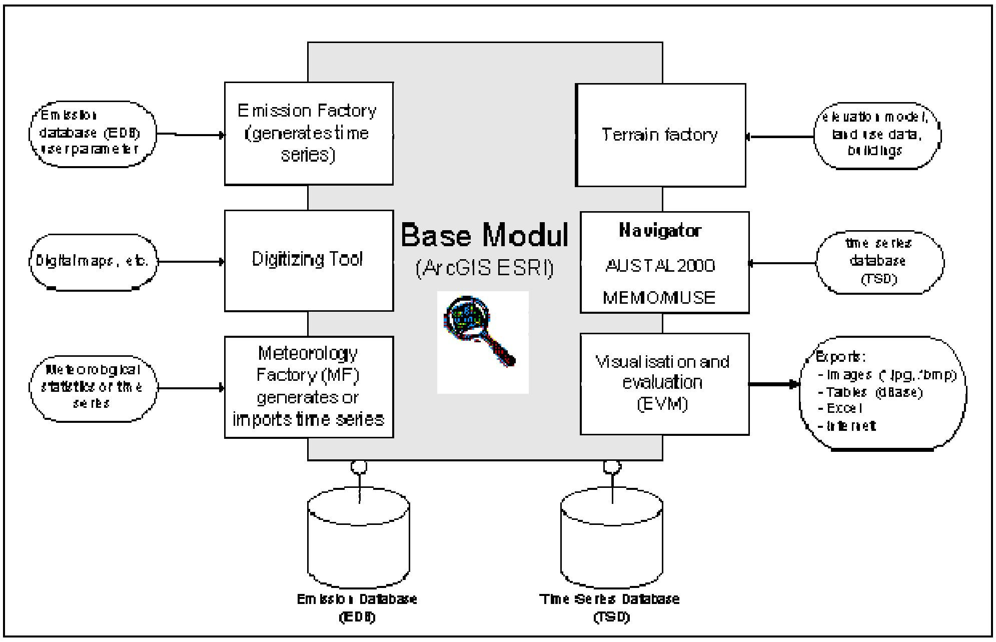

Figure 8.2. Overview of structure in SELMA^{GIS}

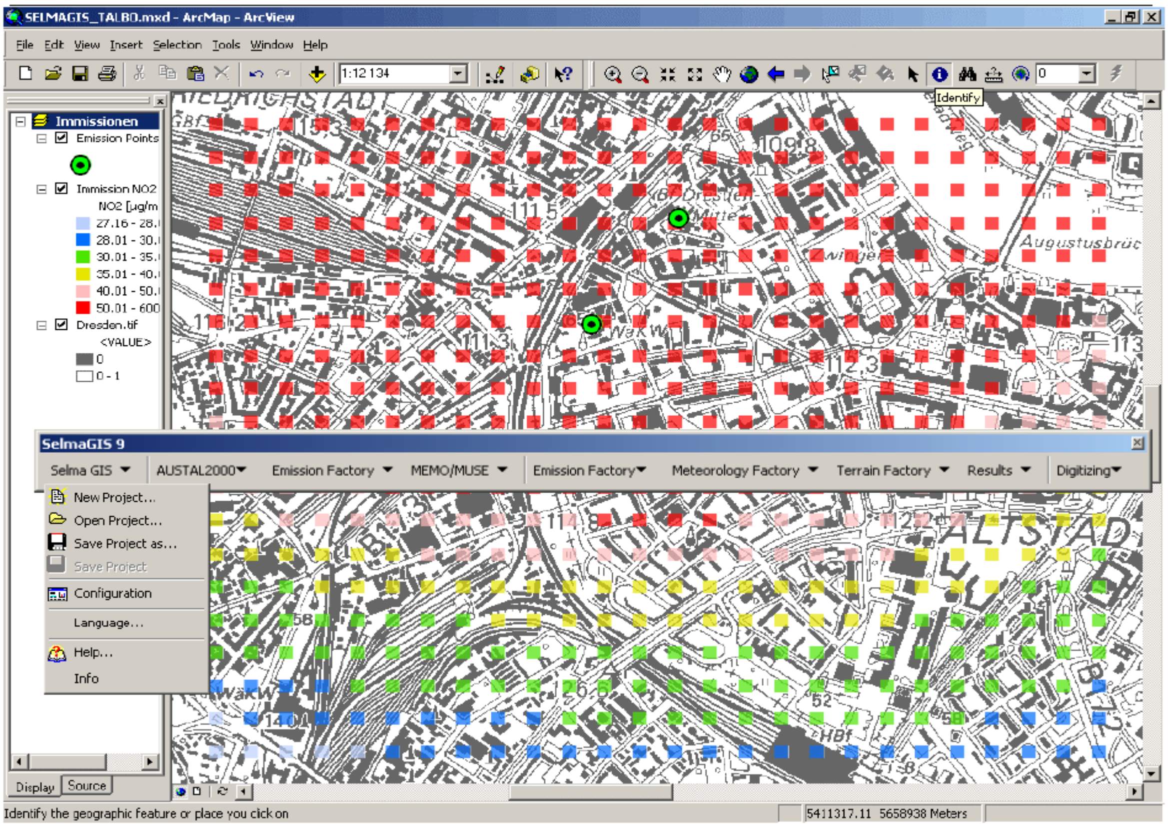

Figure 8.3. Screen print of SELMA^{GIS} as plug-in in ArcMap

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Appendix 1: Modelling results with OML for Nordbysletta in Norway

By Per Løfstrøm & Ruwim Berkowicz

Modelling for Nordbysletta was done with the same model formulation as in the study for the Køge Bugt Highway (see section 3.6). It should be noted that the OML model is currently being revised (Olesen et al., 2007) but none of the planned revisions were included in the model version used here.

The meteorological data required for OML calculations were compiled using measurements from the meteorological mast located at the site. For consistency, the same similarity functions were applied as in the standard version of OML (Businger's similarity functions with κ=0.35). This procedure is also being currently revised.

When using OML for calculations of road traffic pollution the traffic lanes are treated as area sources with the geometrical dimensions of the areas corresponding to the width and length of the traffic lanes. The initial dilution height is set to a typical height of the vehicle mixing zone (≈3m) and this height is not dependent on the traffic speed. This means that the vehicles are rather treated as "bluff bodies" and the effect of the movement of the traffic is instead simulated by the additional turbulence – the traffic produced turbulence (TPT). TPT is calculated using the same procedure as in the street pollution model OSPM (Berkowicz, 2000). The additional turbulence created by traffic is assumed to decay exponentially with the distance from the road (Jensen et al., 2004)).

$$\sigma_{\mathrm{w\,TPT}}(t) = \sigma_{\mathrm{w\,TPT}}(0)e^{-t/\tau} \qquad (1)$$

where t is the travel time (t=x/u) and τ is turbulence decay time. The value of τ was deduced empirically based on the data from the Køge Bugt experiment. The enhancement of the vertical dispersion parameter (σ_z) due to TPT is given by integration of (1) over travel time from the source to the receptor,

$$\Delta\sigma_z(t) = \sigma_{\mathrm{w\,TPT}}(0)\int_0^t e^{-s/\tau}ds = \tau \cdot \sigma_{\mathrm{w\,TPT}}(0) \cdot \left(1 - e^{-t/\tau}\right) \qquad (2)$$

The total σ_z is calculated using the principle of superposition of contributions from different turbulence generation processes,

$$\sigma_z^2 = \Delta\sigma_{\mathrm{turb}}^2 + \Delta\sigma_{\mathrm{TPT}}^2 + \Delta\sigma_{\mathrm{initial}}^2 \qquad (3)$$

Where σ_{turb} refers to dispersion which is due to the ambient turbulence (composed also of the mechanical and convective part), σ_{TPT} is due to the traffic created turbulence and $\sigma_{\mathrm{initial}}$ is the initial enhancement of vertical dilution ("bluff-body effect").

Comparison between modelled and measured NO_X concentrations is shown in Figure 1. The wind is required to be within a certain sector such that the monitoring stations are located downwind of the highway (60<=DD<=240). Modelling results are shown both with TPT included and without TPT. Note that the initial dilution is the same in both cases.

Model results with TPT somewhat underestimate the measured concentrations (ca. 20% for station 1), whereas a dramatic overprediction is evident in the case of model results without TPT. The effect of TPT is most pronounced at low wind speeds. Dependence of measured and modelled concentrations on wind speed is shown in Figure 2. Only traffic contribution is shown (background subtracted). Wind direction sector as in Figure 1 and only working days hours 6 to 21. Modelling results are shown both with TPT included and without TPT. The effect of TPT on model results is still significant even for winds approaching 3-4 m/s.

Dependence of concentrations on wind direction is also to some extent influenced by the distribution of the wind speeds. As shown in Figure 3, on average the wind speed was especially low in the wind sector 80 – 160 degree, which has resulted in extra elevation of the pollution levels. The effect of TPT is also most pronounced for this wind direction sector.

Variation of pollution levels with the distance from the road is shown in Figure 4. The influence of TPT decreases rapidly with distance but is still important up to a distance of about 150m from the road.

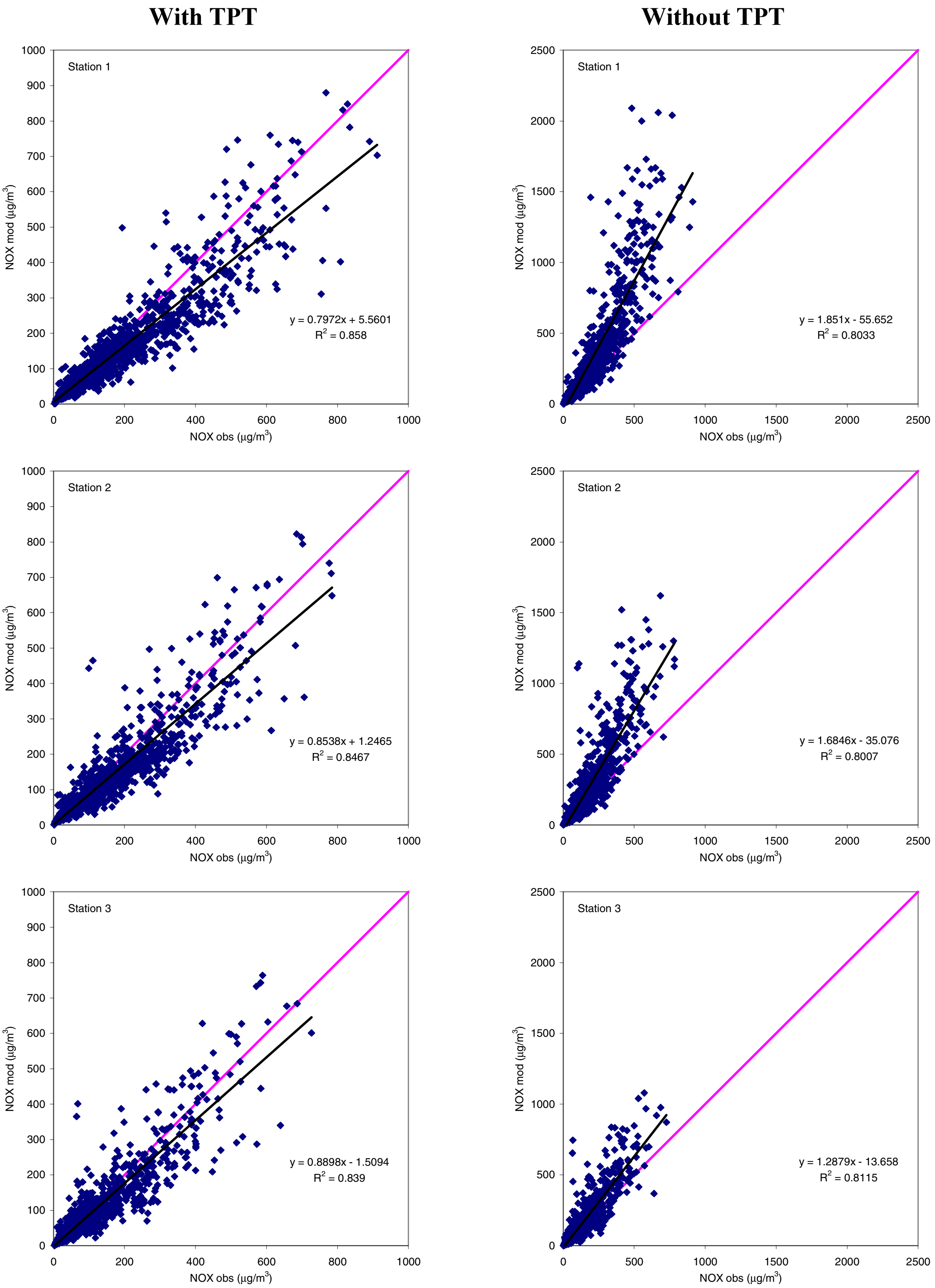

Figure 1. Comparison between modelled and measured NO_X concentrations on an hourly basis. Only the wind direction sector is selected for which the monitoring stations are downwind of the highway (60<=DD<=240). Results are shown for the three monitoring stations 1, 2 and 3 located at 7m, 17m and 47m distance from the outer traffic lane. Left panel: OML calculations with TPT. Right panel: OML calculations without TPT.

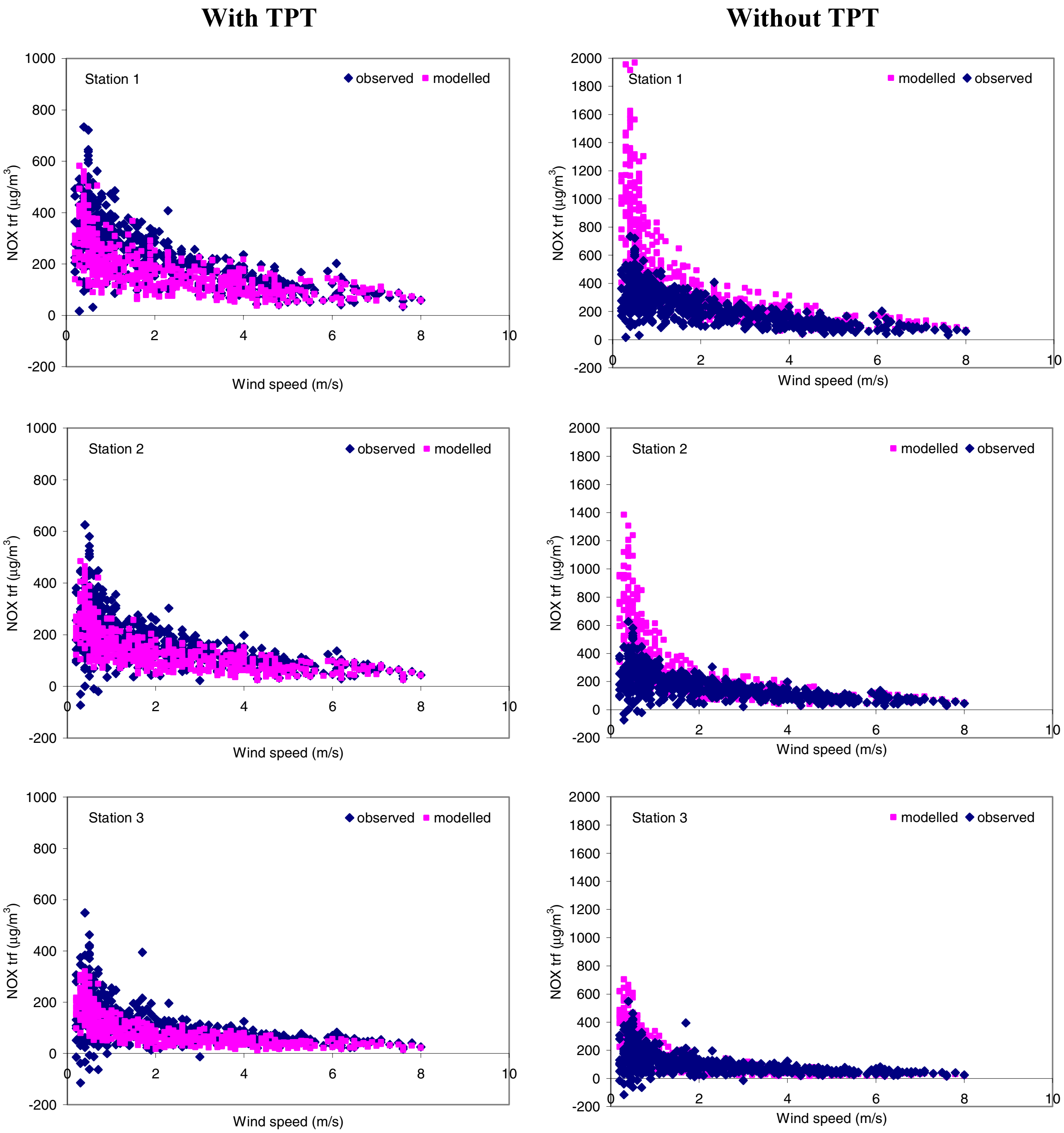

Figure 2. Dependence of measured and modelled concentrations on wind speed. Only traffic contribution is shown (background subtracted). Wind direction sector as in Figure 1 and only working days hours 6 to 21. Left panel: with TPT. Right panel: without TPT.

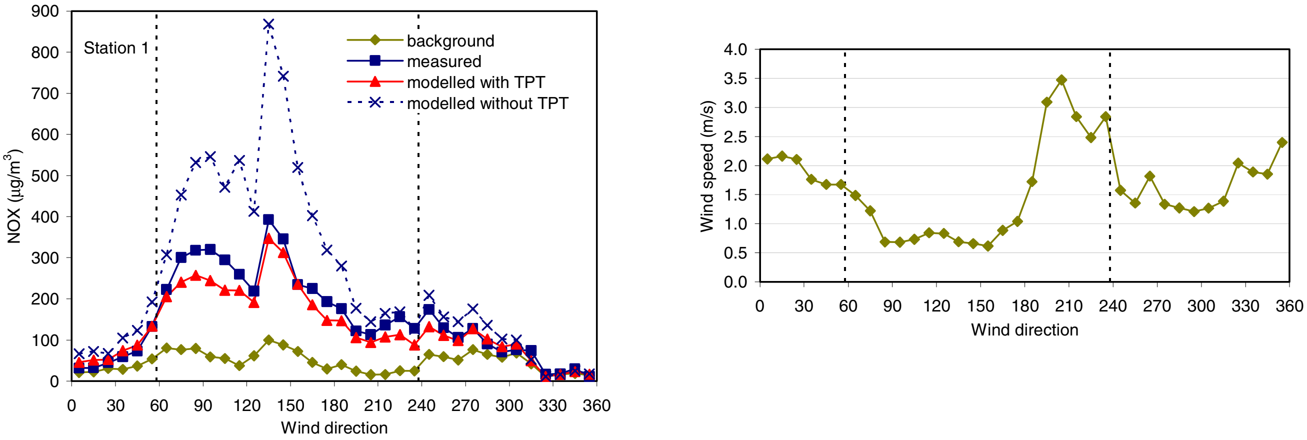

Figure 3. Upper panel: Dependence of measured and modelled concentrations on wind direction. Lower panel: The average variation of wind speed.

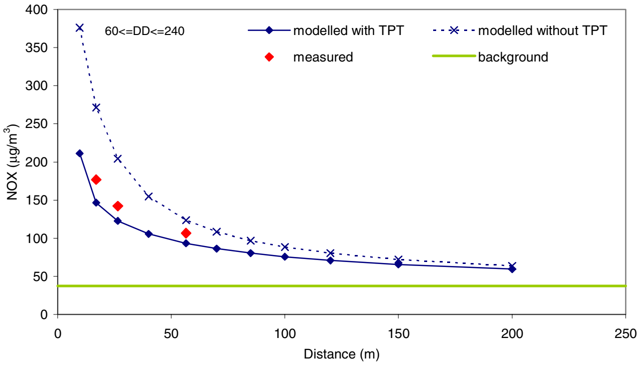

Figure 4. Variation of average pollution levels with the distance from the road.

References

Olesen, H.R., Berkowicz, R.B, Løfstrøm, P., (2007): OML: Review of model formulation. National Environmental Research Institute, Denmark. NERI Technical Report No. 609, pp. 130, http://www2.dmu.dk/Pub/FR609.pdf

Berkowicz R. (2000): OSPM–a parameterised street pollution model. Environmental Monitoring & Assessment 65, 323-331.

Jensen, S.S., Løfstrøm, P., Berkowicz, R., Olesen, H.R., Frydendal,J., Fuglsang, K., Hummelshøj, P. (2004): Air quality along motorways – Measurement campaign and model calculations. National environmental Research Institute, Denmark, 67 p. – NERI report No. 522. http://www2.dmu.dk/1_Viden/2_Publikationer/3_Fagrapporter/rapporter/FR522_2udgave.pdf

Appendix 2: Outline of an experimental campaign for particle pollution from Highway traffic in Denmark

Baggrund

Vejdirektoratet har udtrykt interesse for, at der gennemføres en målekampagne med fokus på partikler fra motorvejstrafik.

En målekampagne er tidligere blevet gennemført i Roskilde Amt langs Køge Bugt motorvejen ved Greve for en 3 måneders periode i efteråret 2003, hvor der blev målt NO_x (NO og NO_2) i forskellige afstande af motorvejen (Jensen et al., 2004). Målingerne viste, at niveauet af NOx var væsentligt forhøjet uden dog at komme helt op på niveau med trafikerede veje i det indre København. Den undersøgte vejstrækning skønnes at være repræsentativ for de mest belastede motorvejsstrækninger i Danmark, idet trafikken på hverdage er større end 100.000 køretøjer pr. døgn. Der blev ikke målt partikler ved denne undersøgelse, men man kan foretage et skøn over trafikkens bidrag til partikler ved at benytte forholdet mellem partikler og NO_x, som er blevet bestemt ved undersøgelser på gader i København. Der kan dog kun blive tale om et groft skøn, da hastigheden på motorvejen er langt større end på de Københavnske gader, og dette vil kunne have betydning for det faktiske partikel/NO_x-forhold. Da der sjældent bremses på en motorvej, fratrækkes bidraget fra bremsestøv. Dette er dag af mindre betydning i sammenligning med problemet, at der ikke tages hensyn til en eventuel forøget mængde af ophvirvlet vej- og dækstøv på grund af den høje hastighed.

Estimering af forventede niveauer

Ved målingerne på motorvejen blev den gennemsnitlige NO_x-koncentration i umiddelbar nærhed af motorvejen (1 meter fra rabatten) bestemt til 75 ppb. Til sammenligning viser målinger i landlig baggrund (Lille Valby nord for Roskilde) en koncentration på i gennemsnit 8 ppb. Trafikkens ekstra bidrag var altså i gennemsnit ca. 67 ppb. I større afstande fra motorvejen var trafikbidraget mindre. Ved vindretninger, der førte forureningen vinkelret fra motorvejen hen mod et målested 50 meter borte, var bidraget således faldet til ca. det halve. Ved at multiplicere de 67 ppb med partikel/NO_x-forholdet målt på Københavnske gader (Jagtvej og Folehaven), hvor bidraget fra bremsestøv er fratrukket, beregnes det gennemsnitlige skønnede partikelbidrag fra motorvejen til henholdvis 8.7 µg/m^3 for PM_{10}, 4.0 µg/m^3 for $PM_{2.5}$ og 20000 partikler/cm^3 for ultrafine partikler. Til sammenligning er koncentrationerne i landlig baggrund henholdsvis ca. 15 µg/m^3, 10 µg/m^3 og 3000 partikler/cm^3. PM_{10} - og $PM_{2.5}$-værdierne er gældende for målinger med TEOM-monitor, som DMU/ATMI benytter ved målinger af PM fra trafik. Det estimerede partikelbidrag fra motorvejen er så stort i sammenligning med baggrundsniveauet, at samtidige partikelmålinger ved motorvejen og i baggrundsluft vil kunne give en ret sikker bestemmelse af den lokale trafiks bidrag. Dette skønnes også at gælde i det tilfælde, at baggrundsmålingerne foretages i en større afstand fra motorvejen, f.eks. med baggrundsmålinger i Lille Valby ved Roskilde og motorvejsmålinger ved Køge.

Den praktiske gennemførsel af projektet

Målingerne gennemføres i en kampagne af ca. to måneders varighed i løbet af 2007. En motorvejsstrækning udvælges i samråd med Vejdirektoratet i et åbent landligt område udenfor København i ikke alt for stor afstand fra baggrundsstationen i Lille Valby. Vejdirektoratet leverer trafikdata. En varighed af kampagnen på ca. to måneder vil sikre, at der måles under mange forskellige vindforhold, således at resultatet kan betragtes som repræsentativt for målinger på årsbasis. Den lange varighed vil også sikre, at udsving, som skyldes den geografisk afstand mellem målestedet og baggrundsstationen, udjævnes ved beregning af middelværdier.

Ved motorvejen anbringes en mobil målestation i umiddelbar nærhed af kørebanen (vigesporet), f.eks. 1 meter fra rabatten. Der gennemføres parallelle målinger med en halv times tidsopløsning på den mobile målestation og i Lille Valby af følgende størrelser: TEOM_PM$_{10}$, TEOM_PM$_{2.5}$, ultrafine partikler (størrelsesfordeling), sod, NO$_x$ og CO. Sod, NO$_x$ og CO er indikatorer for udstødning. NO$_x$ og CO kan betragtes som indikatorer for henholdsvis diesel- og benzintrafik.

Forventede resultater

PM-målingerne med TEOM korrigeres for tab af flygtige forbindelse på grundlag af andre målinger på målestationer i Københavnsområdet, hvorefter målingerne ved motorvejen kan sammenlignes med målinger andre steder i Danmark og med grænseværdier. Ved subtraktion af baggrundsmålingerne fra motorvejsmålingerne bestemmes de lokale trafikbidrag til forurening med partikler og gasser. Forholdet mellem partikler og NO$_x$ bestemmes og sammenlignes med forhold, der er bestemt ved gademålinger. Det vil blive undersøgt, om der kan skelnes mellem bidrag fra henholdsvis diesel- og benzintrafik.

Mulig betydning for andre projekter

Den tidligere undersøgelse af NO$_x$-emissionen fra en motorvej, der også inddrager en spredningsmodel for NO$_x$, vil på grundlag af projektets resultater kunne generaliseres til også at omfatte en emissions- og spredningsmodel for partikler langs motorveje.

Referencer

Jensen SS, Løfstrøm P, Berkowicz R, Olesen HR, Frydendall J, Fuglsang K, Hummelshøj P (2004): Luftkvalitet langs motorveje, Faglig rapport fra DMU, nr. 522.

Appendix 3: Description of the input formats for OML-HighWay

General:

Time format: values 1-24 indicating the end of the hour for which averages are given

The files listed below are needed and samples are given below. (Sample of NOx-NO2-O3-calculations):

NOxNO2O3.are : Definition of the area sources.

Kat01_standard_v2.dat : Emission of category 01. (Continuous numbering up to 16, Kat02…dat, etc.)

Kilder_Modsat.dat : For the opposite lane a simplified way of defining the area source is possible (but not required in principle all area sources could be defined in the *.are file.

StofBeregn.dat : Indicator for type of calculation: 1:NOx-NO2-O3 2: PM10 3: PM2.5

UBM_1_NO2NOxO3.dat : Background concentrations

FILE: NOxNO2O3.are

```
1710 Ver.5.03
NOx     NO2     O3
```

(All the next lines containing numbers are read, but line 6-41 are not used.)

```
Nr ID             X(m)      Y(m)      L1(m)     L2(m)  TETA  HS(m) HB(m)    Q1(ÅDT/1e4)   Q2(NO2/NOx*Q1)     Q3(g/s)    Type
  1 1           675476   6170506       80         8     82    1.0    4.0 1.3222000E+0000 1.9830000E-0001 0.0000000E+0000  6
  2 2           675555   6170517       80         8     80    1.0    4.0 1.3222000E+0000 1.9830000E-0001 0.0000000E+0000  6
  3 3           675634   6170531       80         8     78    1.0    4.0 1.3222000E+0000 1.9830000E-0001 0.0000000E+0000  6
  4 4           675712   6170547       80         8     77    1.0    4.0 1.3222000E+0000 1.9830000E-0001 0.0000000E+0000  6
  5 5           675790   6170566       80         8     78    1.0    4.0 1.3222000E+0000 1.9830000E-0001 0.0000000E+0000  6
  6 6           675868   6170583       80         8     79    1.0    4.0 1.3222000E+0000 1.9830000E-0001 0.0000000E+0000  6
  7 7           675947   6170599       80         8     82    1.0    4.0 1.3222000E+0000 1.9830000E-0001 0.0000000E+0000  6
  8 8           676026   6170610       80         8     85    1.0    4.0 1.3222000E+0000 1.9830000E-0001 0.0000000E+0000  6
  9 9           676106   6170618       80         8     88    1.0    4.0 1.3222000E+0000 1.9830000E-0001 0.0000000E+0000  6
 10 10          676186   6170612        8        80      0    1.0    4.0 1.3222000E+0000 1.9830000E-0001 0.0000000E+0000  6
 11 11          676266   6170612        8        78      3    1.0    4.0 1.3222000E+0000 1.9830000E-0001 0.0000000E+0000  6
 12 12          677116   6170331        8        80     35    1.0    4.0 1.4151000E+0000 2.1230000E-0001 0.0000000E+0000  6
……… .
…
…

1707 1707        697355   6150227        8        80     86    1.0    4.0 1.5489000E+0000 2.3230000E-0001 0.0000000E+0000 16
1708 1708        697351   6150307        8        80     87    1.0    4.0 1.5489000E+0000 2.3230000E-0001 0.0000000E+0000 16
1709 1709        697349   6150387        8        80     89    1.0    4.0 1.5489000E+0000 2.3230000E-0001 0.0000000E+0000 16
1710 1710        697348   6150466        8        79     90    1.0    4.0 1.5489000E+0000 2.3230000E-0001 0.0000000E+0000 16
```

Comment [MKE15]: Number of line sources, version number and name of compouds

Comment [MKE16]: Defines always the western most corner of the line source.

Comment [MKE17]: L1 length of the line source in north eastern direction, max ratio L1/L2 for line sources is 1:10 (or 10:1)

Comment [MKE18]: Angle with respect to north values 0-90 possible

Comment [MKE19]: source height here constant 1 m

Comment [MKE20]: initial dispersion height also constant 4m

Comment [MKE21]: ADT annual daily traffic in 10000 veh/day

Comment [MKE22]: DTV*per centage of NO2 direct emissions , here 15%

Comment [MKE23]: O3 =0 Ozone emission are zero

Comment [MKE24]: indicates the emission type and points to a file for each type

File: Kilder_Modsat.dat

```
Arealkildefil fra motorvejsprojekt.                         (Line 1-6 is not read)
Udarbejdet af PVM og SSJ. Emiss1 og Emiss2 er ÅDT/10000
Dato 3.2.2005
TextID  Emiss1  ModsatKategori Vejbredde-Total_both_directions
Integer    real        modsat      W
             ÅDT/1e4    (1-16)      m
       1      1.3222        5    21.2     (free format)
       2      1.3222        5    21.2
       3      1.3222        5    21.7
…
….
…
    1702      1.5489       15    22.6
    1703      1.5489       15    22.4
    1704      1.5489       15    22.2
    1705      1.5489       15    22.1
    1706      1.5489       15    22.5
    1707      1.5489       15    22.3
    1708      1.5489       15    22.8
    1709      1.5489       15    23.7
    1710      1.5489       15    24.8
```

Comment [MKE25]: Total Width of the highway over both lanes

Comment [MKE26]: ADT on the opposite lane

Comment [MKE27]: Cathegory for the opposite lane

File: StofBeregn.dat

```
1  39  3  24  istof, idum,idum,idum      (Only first number used from this file to indicate the type of calculation performed.)
1=NOx   2=PM10  3=PM2.5
```

File: Kat01_standard_v2.dat

This file gives the daily variation of emissions and traffic volume (light /heavy) traffic speed, this will be somehow scaled with the total emissions given in the *.are file. (Right Per?)

```
Emission data and data for traffic produced turbulence for one category.                           (Line 1-3 is not
read)
Hr            Dummy         NOx         PM10         PM2.5      N_light     N_heavy    V_light     V_heavy
Hverdag      (not used)     g/m/s        g/m/s        g/m/s        veh/h       veh/h    km/h       km/h
       1          3.391     8.213E-05   4.655E-06    3.277E-06      147           7     118.3       84.5  (Free format)
       2          1.544     3.757E-05   2.132E-06    1.512E-06       66           3     120.5       83.2
       3          0.867     2.071E-05   1.204E-06    8.560E-07       39           1     121.4       82.3
…
      21          8.086     1.964E-04   1.108E-05    7.821E-06      347          16     118.9       85.4
      22          6.496     1.581E-04   8.926E-06    6.303E-06      278          13     119.1       84.8
      23          5.958     1.446E-04   8.184E-06    5.769E-06      258          12     118.5       85.0
      24          5.353     1.299E-04   7.342E-06    5.161E-06      232          11     117.5       85.3
Lørdag                                                                                                ("dummy")
       1          4.061     8.707E-05   5.346E-06    3.582E-06      219           3     110.3       88.5
       2          3.127     6.701E-05   4.128E-06    2.794E-06      167           2     113.1       85.2
…
      21          4.603     9.876E-05   6.056E-06    4.087E-06      244           4     112.5       86.0
      22          4.073     8.720E-05   5.350E-06    3.601E-06      217           3     111.9       86.5
      23          4.299     9.201E-05   5.640E-06    3.778E-06      231           3     110.7       88.2
      24          4.692     1.005E-04   6.156E-06    4.112E-06      253           4     109.7       89.9
Søndag                                                                                                ("dummy")
       1          2.757     5.839E-05   3.630E-06    2.439E-06      151           1     111.7       87.2
       2          3.183     6.715E-05   4.182E-06    2.804E-06      175           2     111.4       87.6
       3          1.919     4.078E-05   2.527E-06    1.705E-06      104           1     112.8       86.3
       4          1.237     2.599E-05   1.624E-06    1.098E-06       68           0     113.9       84.8
…
      22          5.125     1.087E-04   6.746E-06    4.514E-06      281           3     110.5       87.2
      23          3.841     8.107E-05   5.043E-06    3.371E-06      212           2     110.7       87.1
      24          2.754     5.820E-05   3.621E-06    2.425E-06      152           1     111.0       87.2
```

File: UBM_1_NO2NOxO3.dat

```
Caclulations with the back ground model - UBM          (Line 1-6 is not read)

Data in µg/m3. NOx is given in  NO2 units

    DATE        HR    NOx      NO2      O3    Global_radiation
   yymmdd       hh   µg/m3    µg/m3    µg/m3    W/m2
    30101        1  14.403   12.270   62.121     0.0       (free format)
    30101        2 -99.000  -99.000  -99.000     0.0
    30101        3 -99.000  -99.000  -99.000     0.0
    30101        4 -99.000  -99.000  -99.000     0.0
    30101        5 -99.000  -99.000  -99.000     0.0
```

…….

…

Note:

-99 indicates missing values

Ingenieurbüro Lohmeyer

GmbH & Co. KG

Appendiks 4: Proposal from a German Consulting Company

Ing.-Büro Lohmeyer GmbH & Co. KG. Mohrenstraße 14. 01445 Radebeul

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Büroleiter: Dr. rer. nat. Ingo Düring

DK-4000 Roskilde (Dänemark)

70341-06-07-HL 04.12.2006

Development of SELMA^{GIS} for OML-Highway and UBM
Offer

Dear Mr. Ketzel,

Based on the results of the visit of Mr. Lorentz to Roskilde (October 2006) we offer the following services.

1 Title

Development of SELMA^{GIS} for OML-Highway and UBM

2 Task

The National Environmental Research Institute of Denmark (NERI) is using various programs for air quality modelling. The programs runs under different software environments. To increase the efficiency of the work with dispersion models, NERI needs one graphical user interface (GUI) helping the users to prepare and evaluate input/output data and to start the programs as well.

A way to accommodate all air quality modelling programs in one system is to implement them in to the GIS based air quality system SELMA^{GIS} [1] developed by Lohmeyer (LOH).

3 Procedure

We offer to extent SELMA^{GIS} with the local scale model OML-Highway and the Urban Background Model UBM.

---

[1] http://www.lohmeyer.de/Software/SELMAGIS-AG9-english.htm

Ingenieurbüro Lohmeyer
GmbH & Co. KG,
Sitz ist Karlsruhe (KA),
Registergericht KA, HRA 4948
Prok.: Dr.- Ing. Wolfgang Bächlin

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BIC (SWIFT): SOLADES1MEI
USt - IdNr.: DE813768755

SELMA^{GIS} is a modular software package which runs under ArcMap™ and is part of the geographical information system (GIS) ArcGIS™ ArcView 9.1 supplied by ESRI. ArcMap™ is a Windows based GIS. Its user interface is according to Windows principles (e.g. drag and drop). All modules of SELMA^{GIS} are plug-ins under ArcMap™ and can be activated by menus and buttons. The following modules of SELMA^{GIS} are available at this time:

- Emission Factory/Emission Database for all emission source types (point, area and line sources)
- Digitising Tool for digitising emission sources and its attributes.
- Meteorology Factory for preparing meteorological input data.
- Terrain Factory for preparing elevation model and land use data
- AUSTAL2000[2]
- MEMO and MUSE[3]

The actual schematic dataflow and model structure which is in use at NERI for highway calculations is illustrated in **Figure 3.1**. Both the present “pilot version” and the planned SELMA^{GIS} version are indicated.

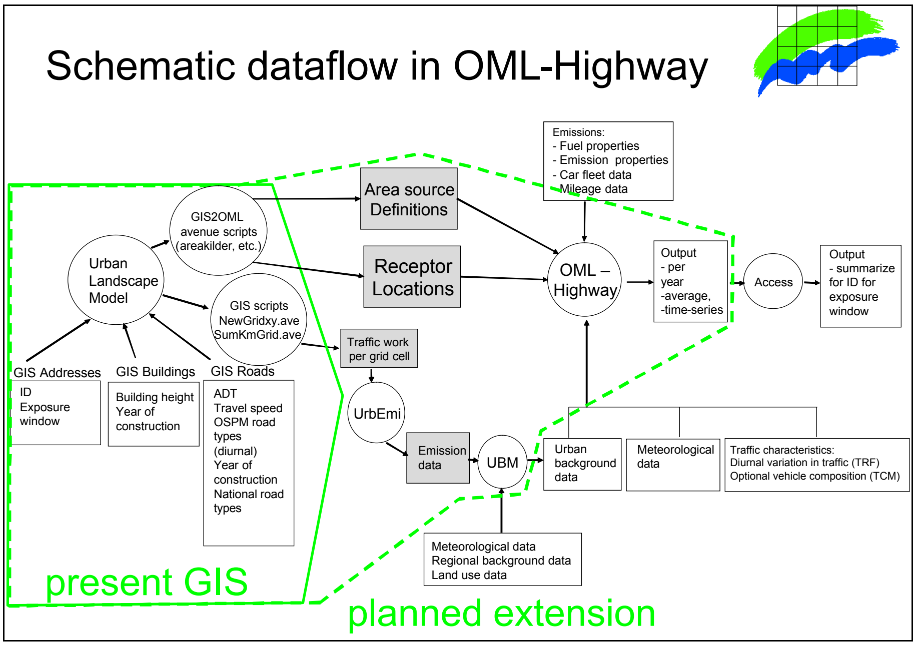


Figure 3.1: Structure of the OML-Highway-GIS combination. The full/ dashed lines indicate the present / planned GIS integration.

---

[2] AUSTAL2000 is the official German Federal Environmental Agency air pollution dispersion model and meets the demands contained in appendix 3 of the German "Technical Instruction Clean Air" (TA Luft).

[3] MEMO and MUSE are models from the Laboratory of Heat Transfer and Environmental Engineering, Aristotle University Thessaloniki, Greece. Head Director of the Laboratory is Prof. Dr.-Ing. Nicolas Moussiopoulos (http://www.envirocomp.org/html/meetus/moussio.htm).

In the Following tables the programming work is listed. More details will be defined in a document “System Specification” after the order is placed.

OML-Highway	
Task	**Solution**
Create Receptor locations from GIS to OML-Highway. Receptor location are defined in a ASCII file for OML.	o With Terrain Factory of SELMA^{GIS} (exists already) it is possible to define calculation grids. The format of the calculation grids will be adapted to UBM and OML-Highway. o It will be programmed the possibility to define free receptor points in ArcMap^{TM} for OML-Highway o For street sources it will be programmed a function which is able to define receptor points for OML-Highway in different distances positioned on a line which is orthogonal to the street.
Program a possibility to digitise Street lines for OML-Highway	o Under the SELMA^{GIS}’s Digitising Tool it will be programmed a digitising tool to define street sources and his attributes for OML-Highway as shape files.
Define input data and Start OML-Highway	o Programming the SELMA^{GIS} Navigator OML-Highway ✓ It will be programmed an import for area source definitions from Urban Landscape model to OML-Highway, which is able to transform street lines to street areas. Therefore the avenue script “areakilder” will be translated to Delphi. ✓ Defines file names for time series of urban background concentrations (with spatial varying in the model area) from UBM, meteorological and

OML-Highway	
Task	**Solution**
	traffic characteristics ✓ Start Button optionally preparing project directory
Convert Results from OML-Highway to GIS-Format	○ Programming SELMA^{GIS} result Dialog. ✓ It creates Shape files and imports it to ArcMap^{TM}. In each Shape file will be stored the position of the receptor point, the annual mean concentration and a link to the time series ASCII file which comes from OML-Highway. ✓ The time series can be shown in a chart by clicking on the receptor point in ArcMap^{TM}.

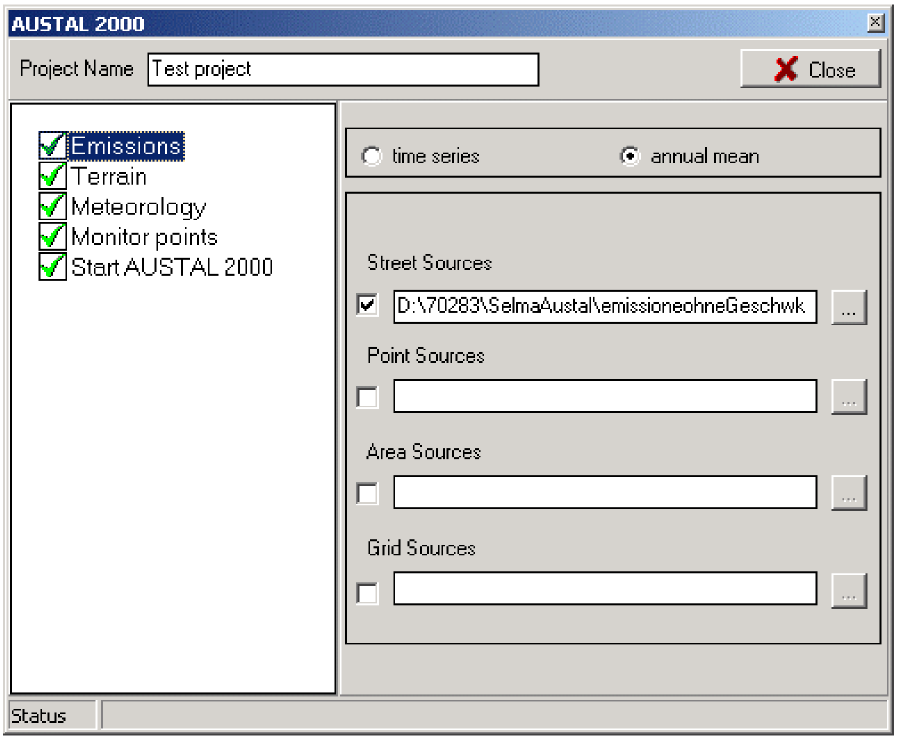
Urban Emission Model (UrbEmi)	
Task	**Solution**
Generating Emission data from Urban Landscape Model for UBM	○ Programming an converting function from the Urban Landscape Model to Emission data files for UBM using UrbEmi under the SELMA^{GIS} Emission Factory ✓ Export Data from the Urban Landscape Model to an array with traffic work per Grid Cell. Therefore the Avenue scripts “NewGridxy.ave” and “SumKmGrid.ave” from NERI will be translated to Delphi. ✓ Start UrbEmi using the traffic work array. The result is a emission data Shape file which can imported with the UBM Navigator.

Urban Emission Model (UrbEmi)	
Task	**Solution**
Generating Emission data for UBM.	○ Implementing the GUI of UrbEmi to the Emission Factory of SELMA^{GIS}. It is visible only for experts.

Urban Background Model (UBM)	
Task	**Solution**
Defining input data and Start UBM	○ Programming the SELMA^{GIS} Navigator UBM ✓ Defines file names for time series of regional background concentrations (one for the entire model area), emission data shape file from UBM and meteorological characteristics ✓ Start Button optionally preparing project directory
Converting Results from UBM to GIS-Format	○ Programming SELMA^{GIS} result Dialog. ✓ It creates Shape files and imports it to ArcMap^{TM}. In each Shape file will be stored the position of the receptor point, the annual mean concentration and a link to the time series ASCII file which comes from OML-Highway. ✓ The time series can be shown in a chart by clicking on the receptor point in ArcMap^{TM}.

Navigator

The GUI for OML-Highway and UBM will be implemented under a SELMA^{GIS} navigator surface as it exists for AUSTAL2000 (**Figure 3.2**).



Project Name: Test project

○ time series ● annual mean

Street Sources
☑ D:\70283\SelmaAustal\emissioneohneGeschwk

Point Sources
☐

Area Sources
☐

Grid Sources
☐

Figure 3.2: AUSTAL2000 Navigator in SELMA^{GIS}

The Navigator defines all input data (e.g. file names) and parameters to start the calculation of the respective dispersion model. At the left side the navigator implements a table of Content (TOC) with which it is possible to switch between different definition areas (e.g. Emissions to define emission input files). All input data and other parameters will be checked for plausibility. Only if the plausibility check is O.K. the user is able to start the calculation.

The navigator is able to start the dispersion calculation directly from ArcMap. Alternatively the navigator prepares all input data and parameters under a project directory for starting the calculation separately on an other computer.

It will be programmed a navigator separately for UBM and OML-Highway. The programs OML-Highway and UBM are programs without GUI at this time, therefore it is not possible to reuse GUI's of them.

Interface LOH - NERI

The programming work is using SELMA^{GIS} components and trying to reuse most of the existing models interfaces in there native programming language. The main programs of OML-Highway and UBM from NERI will be supplied as dynamic link libraries (DLL's) which will be called from SELMA^{GIS}. The calling of the DLL's will be defined as fixed interfaces, which are fixed in the document System Specifications. By this way it possible change the main source code of the DLL's but the implementation in SELMA^{GIS} must not be changed. Also the source code of the DLL's can be programmed with different compiler languages (Fortran, Visual Basic, Delphi etc.).

The navigator for OML-Highway and UBM and the component for UrbEmi will be programmed as different DLL's which can run as a stand alone program. This is useful for testing them and to enable NERI to change the source code for this components.

Online help

The online help will be implemented for each GUI by pressing the key F1. LOH produce a online help only for GUI which are programmed from LOH. LOH will make the programmers work and the description of the handling of the GUI. Explanations for UrbEmi, UBM and OML-Highway has to be made by NERI.

Installation

SELMA^{GIS} will be delivered as a installation for windows.

Testing

The testing process will be divided between the programmer and different testing person. Therefore all programmed components from LOH will be tested by NERI.

Dokumentation

SELMA^{GIS} OML-Highway and UBM will be descried in different documents:

- System Specification
- Manual
- Code documentation.

In the System Specification it will be written the detailed functionality and interfaces of SELMA^{GIS} OML-Highway and UBM. The System Specification will be agreed with NERI.

The manual describes the graphical user interface (GUI) and the required data formats. LOH will write the manual for components programmed by LOH it. NERI writes the entire manual by using the parts written from LOH. The manual should be used as a base for the online help. Therefore it should be structured that it is possible to use chapters for linking them to components of the GUI.

To enable NERI to continue the programmers work the source code will be given to NERI as a Borland Delphi 6.0 Professional project. NERI will get only the source code for the navigator of OML-Highway and UBM and the UrbEmi component. The source code is described in the source code documentation.

Licensing

SELMA^{GIS} will be licensed as a base module. The implemented models will be licensed separately. The Base module SELMA^{GIS} will licensed by Lohmeyer GmbH an Co. KG and the models OML-Highway and UBM by NERI. Terms of selling and distributing will be defined in a separate contract.

4 Our service

4.1 Adapting Terrain Factory of SELMA^{GIS} to UBM and OML-Highway.

4.2 Programming the possibility to define free receptor points in ArcMap^{TM} for OML-Highway.

4.3 Programming a function which is able to define receptor points for OML-Highway in different distances positioned on a line which is orthogonal to the street.

4.4 Programming a Digitising Tool for street sources and his attributes for OML-Highway.

4.5 Programming the SELMA^{GIS} Navigator OML-Highway

4.6 Programming SELMA^{GIS} result Dialog for OML-Highway

4.7 Programming an converting function from the Urban Landscape Model to Emission data files for UBM using UrbEmi under the SELMA^{GIS} Emission Factory.

4.8 Implementing the GUI of UrbEmi to the Emission Factory of SELMA^{GIS}.

4.9 Programming the SELMA^{GIS} Navigator UMB

4.10 Programming SELMA^{GIS} result Dialog for UBM.

4.11 Programming online help for SELMA^{GIS} GUI based on the Manual.

4.12 Writing System Specification

4.13 Writing Manual for SELMA^{GIS} (only for components programmed by LOH)

4.14 Writing Code documentation.

5 Participation of NERI

NERI is responsible for the following points:

- Supplying all documentation and example files for UrbEmi, UBM and OML-Highway.
- Supplying testing datasets of the Urban Landscape Model
- Programming interfaces which are defined in the document System Specifications
- Testing the SELMA^{GIS}
- Writing the Manual

Included into the costs are 2 meetings in Roskilde and all additional costs and 1 hard copy of the System Specification, the Manual and additional the source code and the installation routine on a CD.

7 Terms

Installment according proceeding the project. Final Settlement after delivering Software.

8 Due dates

The project can be finished after 4-5 month (real working time: 3 month). The due dates will be defined after placing of order.

We hope that our offer meets your expectations. We are looking forward to a further collaboration. In case of any questions, please feel free to contact us.

Sincerely yours

i.V. H. Lorentz

Dipl.-Ing. H. Lorentz

NERI National Environmental Research Institute

DMU Danmarks Miljøundersøgelser

National Environmental Research Institute, NERI, is a part of University of Aarhus.

At NERI's website www.neri.dk you'll find information regarding ongoing research and development projects.

NERI's tasks are primarily to conduct research, collect data, and give advice on problems related to the environment and nature.

Furthermore the website contains a database of publications including scientific articles, reports, conference contributions etc. produced by NERI staff members.

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NERI Technical Reports

NERI's website www.neri.dk contains a list of all published technical reports along with other NERI publications. All recent reports can be downloaded in electronic format (pdf) without charge. Some of the Danish reports include an English summary.

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613 PAH i muslinger fra indre danske farvande, 1998-2005. Niveauer, udvikling over tid og vurdering af mulige kilder. Af Hansen, A.B. 70 s.

612 Recipientundersøgelse ved grønlandske lossepladser. Af Asmun, G. 110 s.

611 Projection of Greenhouse Gas Emissions – 2005-2030. By Illerup, J.B. et al. 187 pp.

610 Modellering af fordampning af pesticider fra jord og planter efter sprøjtning. Af Sørensen, P.B. et al. 41 s.

609 OML : Review of a model formulation. By Rørdam, H., Berkowicz, R. & Løfstrøm, P. 128 pp.

608 PFAS og organotinforbindelser i punktkilder og det akvatiske miljø. NOVANA screeningsundersøgelse. Af Strand, J. et al. 49 s.

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607 Miljøtilstand og udvikling i Viborgsøerne 1985-2005. Af Johansson, L.S. et al. 55 s.

606 Landsdækkende optælling af vandfugle, januar og februar 2004. Af Petersen, I.K. et al. 75 s.

605 Miljøundersøgelser ved Maarmorilik 2005. Af Johansen, P. et al. 101 s.

604 Annual Danish Emission Inventory Report to UNECE. Inventories from the base year of the protocols to year 2004. By Illerup, J.B. et al. 715 pp.

603 Analysing and synthesising European legislation in raletion to water. A watersketch Report under WP1. By Frederiksen, P. & Maenpaaa, M. 96 pp.

602 Dioxin Air Emission Inventory 1990-2004. By Henriksen, T.C., Illerup, J.B. & Nielsen, O.-K. 88 pp.

601 Atmosfærisk kvælstofbelastning af udvalgte naturområder i Frederiksborg Amt. Af Geels, C. et al. 67 s.

600 Assessing Potential Causes for the Population Decline of European Brown Hare in the Agricultural Landscape of Europe – a review of the current knowledge. By Olesen, C.R. & Asferg, T. 30 pp.

599 Beregning af naturtilstand ved brug af simple indikatorer. Af Fredshavn, J.R. & Ejrnæs, R. 93 s.

598 Klimabetingede effekter på marine økosystemer. Af Hansen, J.L.S. & Bendtsen, J. 50 s.

597 Vandmiljø og Natur 2005. Tilstand og udvikling – faglig sammenfatning. Af Boutrup, S. et al. 50 s.

596 Terrestriske Naturtyper 2005. NOVANA. Af Bruus, M. et al. 99 s.

595 Atmosfærisk deposition 2005. NOVANA. Af Ellermann, T. et al. 64 s.

594 Landovervågningsoplande 2005. NOVANA. Af Grant, R. et al. 114 s.

593 Smådyrfaunaens passage ved dambrugsspærringer. Af Skriver, J. & Friberg, N. 33 s.

592 Modelling Cost-Efficient Reduction of Nutrient Loads to the Baltic Sea. Model Specification Data, and Cost-Fynctions. By Schou, J.S. et al. 67 pp.

591 Økonomiske konsekvenser for landbruget ved ændring af miljøgodkendelsen af husdyrbrug. Rapport fra økonomiudredningsgruppen. Af Schou, J.S. & Martinsen, L. 55 s.

590 Fysisk kvalitet i vandløb. Test af to danske indices og udvikling af et nationalt indeks til brug ved overvågning i vandløb. Af Pedersen, M.L. et al. 44 s.

589 Denmark's National Inventory Report – Submitted under the United Nations Framework Convention on Climate Change, 1990-2004. Emission Inventories. By Illerup, J.B. et al. 554 pp.

588 Agerhøns i jagtsæsonen 2003/04 – en spørgebrevsundersøgelse vedrørende forekomst, udsætning, afskydning og biotoppleje. Af Asferg, T., Odderskær, P. & Berthelsen, J.P. 47 s.

587 Målinger af fordampning af pesticider fra jord og planter efter sprøjtning. Af Andersen, H.V. et al. 96 s.

586 Vurdering af de samfundsøkonomiske konsekvenser af Kommissionens temastrategi for luftforurening. Af Bach, H. et al. 88 s.

585 Miljøfremmede stoffer og tungmetaller i vandmiljøet. Tilstand og udvikling, 1998-2003. Af Boutrup, S. et al. 140 s.

584 The Danish Air Quality Monitoring Programme. Annual Summary for 2005. By Kemp, K. et al. 40 pp.

The report outlines the specifications for a new user-friendly Danish highway air pollution model as a tool for environmental impact assessment and mapping of air quality along highways. A prototype of the model was developed earlier based on the regulatory air pollution model OML.

The model was tested previously on Danish measurements and as part of this project also for a Norwegian data set, both showing good performance of the model. The new user-friendly model version will have a close coupling with Geographic Information Systems (GIS) both for creating model input data and visualising model results.

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