Einsatz eines Verkehrsmanagement-Systems zur Reduzierung der Schadstoffbelastung (Application of Traffic Management Systems to Improve Air Quality)

Volker Diegmann, Günter Gässler, Florian Pfäfflin, Anna Mahlau

IVU Umwelt GmbH, Emmy-Noether-Straße 2, D-79110 Freiburg, vd@ivu-umwelt.de

ABSTRACT

Traffic management systems are commonly used to optimize traffic flow in urban areas, e.g. to prevent traffic congestion. However, the regulation of traffic flows can also be used to control traffic induced emissions and therefore affects air quality. To use a traffic management system as an instrument for the benefit of air quality, the application requires reliable information about the current air pollution along all major traffic routes. This can be provided by the online modeling system IMMIS^{mt}. The system consists of a combination of linked air quality models using online traffic, weather and pollutant concentration data to monitor the citywide distribution of pollutants within the streets. In addition, it can be operated in offline mode with archived data to assess various regulation scenarios. Thus IMMIS^{mt} enables traffic management systems to be used as Environmental Traffic Management System.

In recent years, the application of Environmental Traffic Management Systems has been subject to extended research. Within the framework of the project "iQ mobility" IMMIS^{mt} was used to develop situation-related operational control measures and to monitor the current air pollution for the City of Berlin. The quality of the monitoring system, the efficiency of measures in reducing NO_2 and PM_{10} and the practicability of the system were tested in a field study in autumn 2007. More recent studies conducted in Braunschweig within the project of UVM-BS show that IMMIS^{mt} can be used operationally to assess and validate the effects of traffic management measures on air quality.

INTRODUCTION

The benefits of Traffic Management Systems (TMS) in urban areas are widely known. In general, a TMS is an instrument for larger cities that helps managing road works, big events or unforeseeable situations like accidents. Further, it allows for a situation-related control of traffic signals and can be used to optimise road capacities in order to improve traffic flow and quality.

Stricter limit values for air pollutants, demanded e.g. by the EC directive (EC, 2008), require to reduce environmental effects of traffic within urban areas. Because measures of a TMS influence traffic load and flow, they have a certain impact on air quality, especially for traffic related pollutants such as PM_{10} or NO_2. Thus, traffic management systems can be used to improve air quality (Diegmann, 2008 and Tullius, 2003). The extension of traffic management by air quality strategies such as decreasing traffic related emissions within critical segments will lead to an Environmental Traffic Management System (ETMS).

Focusing on a single street section, the reduction of traffic related emissions can be achieved by a number of measures like speed limits, reducing traffic control stops, preventing disturbances due to lane blocking (e.g. while delivering goods) and finally by partial or full road closure (Diegmann, 2008).

Before implementing measures to manage air quality, the range of their effects in space and time need to be understood. The following aspects should be considered before taking action:

- What is the efficiency of the measure?
- What are the side effects?
- Is it possible to shift high emissions and/or concentrations to non-sensitive areas?
- When is the best time to apply the measure?

Answers to these questions can be obtained from an air quality monitoring system providing online citywide information of the pollutant concentrations.

Conventional monitoring systems based on regular pollutant concentration measurements can only assess air quality at the point of measurement but do not provide information on the spatial distribution of pollutants. However, air quality problems are generally widely distributed in a city. The highest values of pollution are mostly found along major roads within street canyons where concentrations will vary from segment to segment according to the local traffic (e.g. volumes, driving pattern…) or dispersion conditions (e.g. orientation, height, width, porosity of buildings). Measurements at all potential hot spots are not feasible. Thus, air quality monitoring covering all relevant streets can only be achieved with air quality models.

For this purpose, the monitoring system IMMIS^{mt} was developed (Diegmann, 2002 and Diegmann et. al., 2004). This validated system is capable of quickly calculating concentration values at a given point within a street canyon on a micro scale basis using a canyon box model with online traffic data and can therefore be used to monitor air quality in all relevant streets in a city.

SYSTEM DESCRIPTION

Design

IMMIS^{mt} consists of numerous components, whose cooperation is described referring to Figure 1. The core of IMMIS^{mt} consists of three models, forming a modeling chain to calculate traffic-induced emissions, urban and local dispersion. The control of the data flow between the models is coordinated by software components controlling the temporal sequence of the overall system, which includes data supply, start of the models, data transmission to the archive and data export of the results to further clients (e.g. map clients).

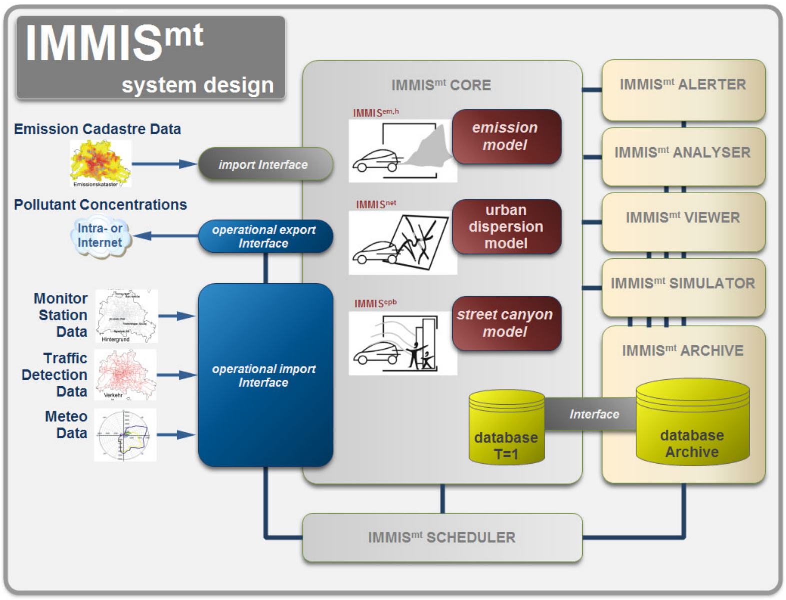

Figure 1: System desgin

All the input and output data is passed through an adjustable interface, capable of controlling various data transmission techniques like SOAP, ASCII, or HTTP. The internal data storage structure is realized by a local or a client-server database (e.g. Oracle). The database stores all static data (e.g. road and canyon geometries, emission cadastre data) as well as all dynamic data for the current modeling interval. The system-archive is based on a client/server database and holds the total input and output data of all computations. Together with the simulator module the stored computations can be repeated, if desired with changed conditions. This allows for the analysis of scenarios e.g. for planning traffic control measures and is a good basis to develop further improvements of the models.

Data Requirement

Online Data

The system is mainly driven by traffic data. Each street segment is characterized by a default traffic situation. If the current situation can be derived from velocity profiles of the detected traffic data, this information can be updated for each time step. The dispersion models use meteorological data such as temperature, wind data and stability class. Available data from air quality monitoring stations are used to derive background concentrations. The interval at which the online data should be provided depends on the temporal resolution of the results. In most cases an hourly interval will be adequate.

Static Data

To account for urban background concentration, emissions of the main sources like industry, shipping, rail traffic, off-road traffic and domestic combustion, usually available from an emission cadastre, are required for the regional dispersion model. The modeling approach on the micro scale requires a parameterisation of the major roads. All street segments with adjacent buildings, called sections, are described by their width, height and porosity (gaps between the buildings). Within each section, one or more points where concentrations are to be calculated can be defined.

Modeling Control

The modeling of the total concentration at a hot spot in a street canyon needs to account for regional background caused by long distance transport, urban background caused by the urban emission sources and the "additional concentration" caused by the road traffic in the street canyon itself. The data flow of the modeling process for each time step is described as follows: Based on incoming traffic data, the emissions of the major roads are determined by the emission model IMMIS^{em} (IVU Umwelt 2008a). Together with emissions of other urban sources the citywide spatial distribution of air pollution is calculated using the urban dispersion model IMMIS^{net} (IVU Umwelt 2008b). This provides the urban background concentration for each section and for the location of the air quality monitor stations. The regional background can then be determined as difference between the observed concentration at the background station and the urban concentration modeled for the station. Finally the micro scale model IMMIS^{cpb} (Yamartino, R. J., Wiegand, G. 1986) is applied to assess the additional concentration within each street canyon by the Canyon Plume Box approach using meteorological and local emission data. To determine NO_2 values out of the NO_x results, IMMIS^{mt} is able to provide different methods ranging from simple rational techniques based on measurements to complex photochemical models.

RESULTS AND DISCUSSION

Validation

Within the project iQ mobility (2007), the monitoring system IMMIS^{mt} was set up to monitor the city centre of Berlin. The "Leipziger Strasse", a typical street canyon with approx. 42000 vehicles a day, was chosen as test field to validate the system for a period of several weeks. Figure 2 shows the modeled NO_x concentration compared to the measured values together with the modeled stop&go-fraction for a time span of 3 weeks in autumn 2007.

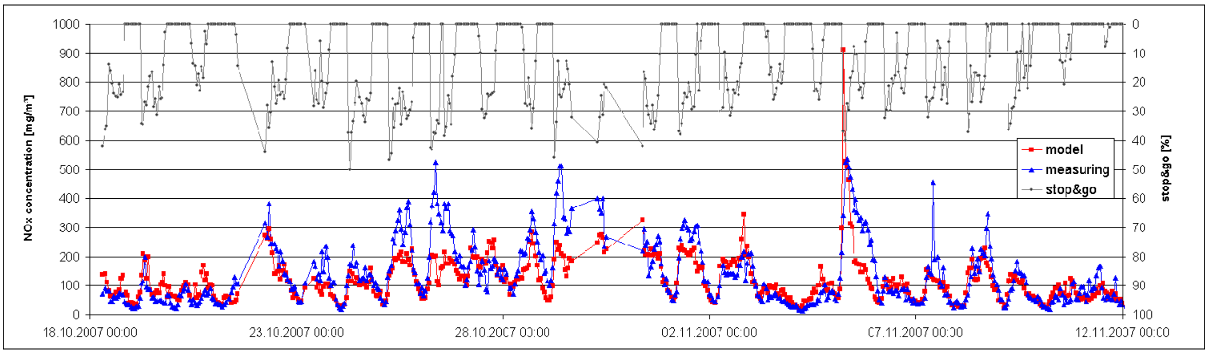

Figure 2: Total NO_x concentrations in the Leipziger Strasse (modeled and measured) and modeled fraction of stop&go

The figure shows that there is a good match of the model results with the diurnal patterns of the measured concentrations. The rise in the NO_x concentrations correlates highly with the increase of the traffic stop&go fraction indicating congested situations. A regression analysis of modeled versus measured concentrations gives a coefficient of determination (R^2) of 0.56 for the hourly NO_x values of the evaluated period. For PM_{10} the coefficient rises up to 0.7. The measurements are underestimated both for NO_x and PM_{10} leading to a regression gradient of 0.54 and 0.77, respectively. Deviations in modeled NO_x-concentrations are likely due to the emissions factors that are taken from the Handbook Emission Factors for Road Transport (HBEFA, 2004). A new revision of the handbook to be published this year will give higher NO_x emission factors. Another relevant source of uncertainty is the stop&Go fraction. This parameter significantly affects NO_x-emissions and had to be modeled in the test case as no measured data on stop&go was available. For PM_{10}, the correlation is heavily influenced by the methodology to model non-exhaust emissions and its uncertainties.

Within in the scope of the Project UVM-BS in Braunschweig (UVM-BS, 2008), founded by the German Ministry of Transport, Building and Urban Affairs, $IMMIS^{mt}$ was set up to monitor citywide air quality effects of traffic management measures. During the test periods of the project, $IMMIS^{mt}$ shows similar qualities in reproducing measured concentrations. Here the coefficient of determination for PM_{10} for the 24 hour moving average was 0.9 with a small tendency of the model to overestimate. NO_x concentrations were, as in Berlin, underestimated with a coefficient of determination of 0.6. Here, deviations are most likely due to the same reasons as in Berlin.

Potential of Measures

The evaluation of the field test for Berlin demonstrates that, in accordance with expectations, meteorological conditions have a high influence on the additional concentrations in the canyon. The concentrations at the south side of the street section, which is oriented east-west, were found lowest with wind from the west, whereas wind from the south resulted in higher concentrations (see figure 3).

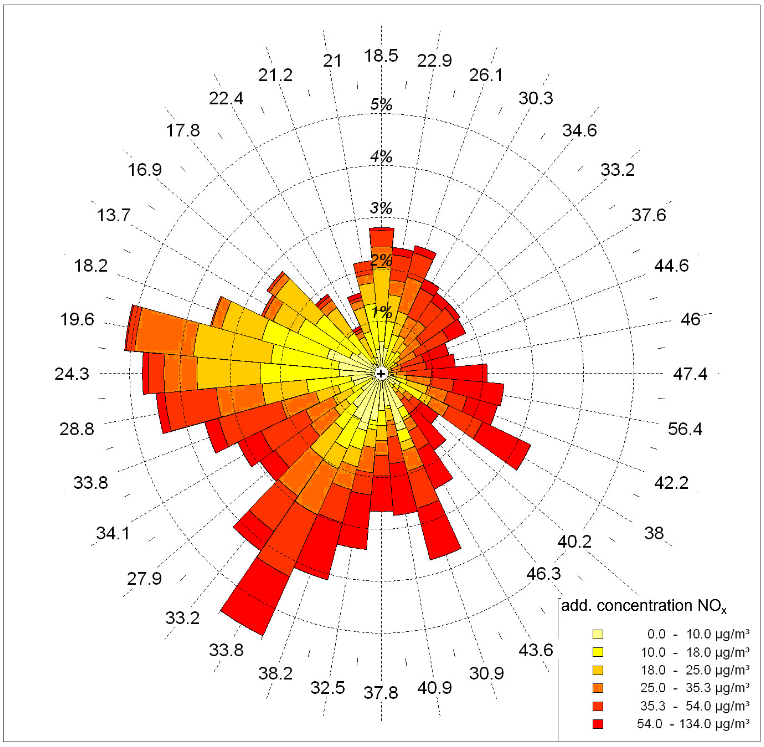

Figure 3: Concentration wind rose Leipzigerstrasse

The quality of traffic flow has a great influence on the concentration level. It can be shown that the Level of Service (LOS), which describes the quality of traffic flow (HBS 2001), is highly correlated with the observed additional concentration. First assessments suggest that an improvement of the LOS by one stage during critical meteorological situations could lower the annual mean value for the additional concentration of NO_2 by approximately 10%.

Monitoring

Measures controlling traffic flow will often have a more or less intense impact on the surrounding road network. Therefore, it is necessary to observe the effects on air quality in a larger area. Thus, the monitoring system $IMMIS^{mt}$ currently covers an area of approx. 24 km² containing 116 km of major roads in length in the city centre of Berlin.

During the field tests in Braunschweig within the UVM-BS-Project, IMMIS^{mt} was used to monitor citywide air quality effects of traffic management measures. The measures were designed to reduce the traffic passing the local hotspot at Altewiekring by 6 and 12%, respectively. Each measure was applied for four weeks. During the test periods IMMIS^{mt} continuously (every hour) provided the air quality information for all street sections with available traffic detection. After recording online results during the test periods, IMMIS^{mt} was used in an offline mode to model a base scenario with traffic data from the corresponding four weeks from the previous year while retaining both meteorological conditions and the conditions influencing background concentrations. By comparing these two datasets for each measure, the effects of the traffic management measures on air quality can be analyzed.

The focus of the draft results presented is on the second, more strict measure. The analysis of the differences for the traffic detection values shows that the design of the measure was appropriate as the detection recorded 14.3% less traffic compared to the corresponding period in 2008. The reduced traffic volumes caused a drop of the stop&go fraction by 62% (see graph in figure 4). This leads to a modeled reduction of approximately 17% for the emissions in the street both for NO_x and PM_{10}. Thus, by applying the measure, the mean of the additional concentration (caused by traffic within the Altewiekring) is reduced by 12.2% for NO_x and 12.8% for PM_{10}. The mean of the total concentrations in the Altewiekring was reduced by 10.2% for NO_x and by 4.2% for PM_{10}.

Evaluating the effect of the measure on a larger scale shows a city wide effect of the locally applied measure. The map in figure 4 shows the relative difference of mean additional concentrations of NO_x with and without the measure for all road segments with hourly online traffic data. Benefits for air quality can be seen in the Altewiekring itself and in its surrounding streets. On the other hand, due to the shifted traffic volumes, there are increases of concentrations at other locations. However, the benefits with a maximum reduction of 15.6% at the local hot spot outweigh the “costs” in other, less sensitive areas.

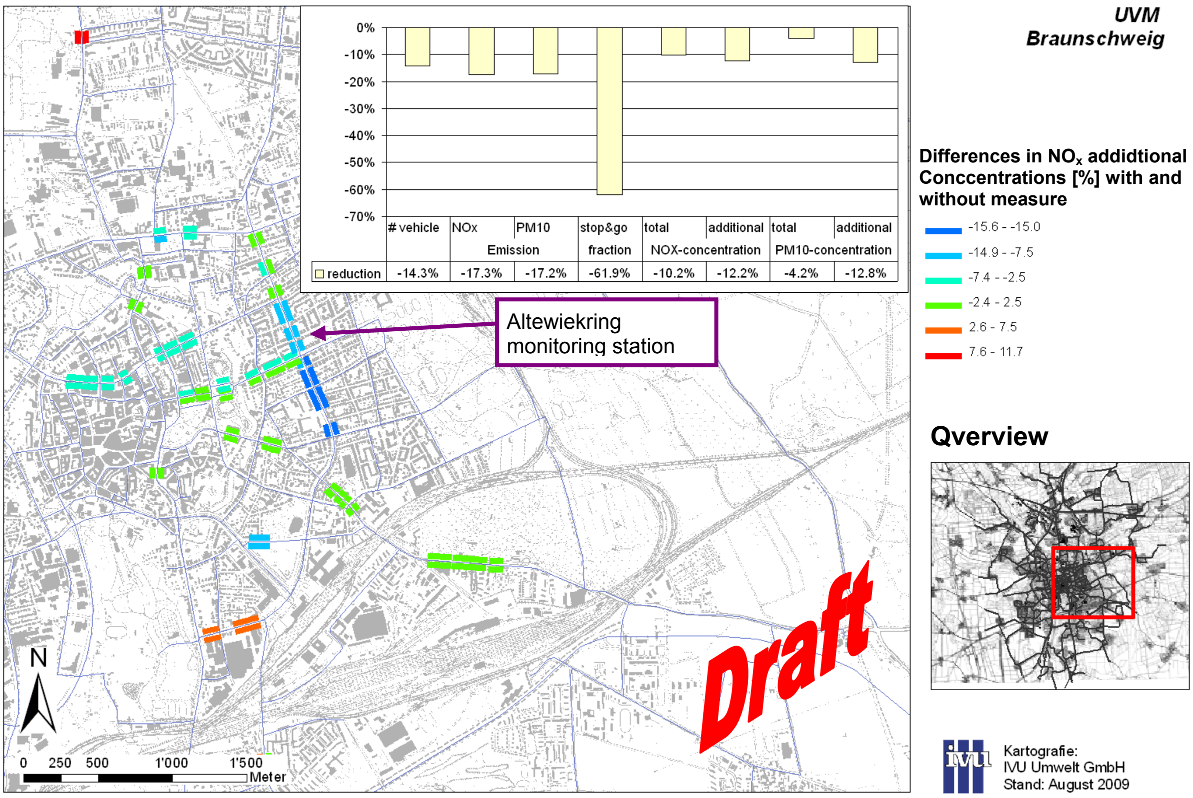

Figure 4: Differences of emissions and concentrations in Altewiekring and map of differences of NO_x additional concentrations with and without implementation of the measure for all road sections with hourly online traffic data

Conclusion and Outlook

Traffic management systems (TMS) are being used in a growing number of cities. The motivation is primarily to reduce travel times and optimise road capacities. However, there is a potential for a TMS to reduce air pollution. To use a TMS for environmental traffic management, it needs to be extended by an online air quality monitoring system to assess the situation in hotspots and surrounding areas. For this purpose, IMMIS^{mt}, a validated, technically mature system, is currently used in the city centre of Berlin and Braunschweig. Implementing local traffic related measures in order to improve air quality might lead to negative effects at other locations in the network and the challenge is to design traffic management measures without provoking further hot spots areas. Therefore, tools for planning of traffic management measures as well as the monitoring of the air quality while applying measurements are inevitable.

Currently, it is intended to enlarge the area monitored by IMMIS^{mt} in Berlin to cover the entire city including the adjacent City of Potsdam. In preparation for an implementation of an ETMS in the City of Cologne, the efficiency of operational traffic control measures is currently being analysed.

References

Diegmann, V. 2002. Online Environmental Monitoring for Berlin/Germany. S. 293-300. In: Pischinger (Hrsg.). 11th International Symposium „Transport and Air Pollution", 19.-21.6.2002 in Graz. VKM-THD Mitteilungen Heft 81-II. Verlag der technischen Universität Graz. ISBN 3901351590.

Diegmann, V. 2008. Der Einfluss des Straßenverkehrs auf die Luftschadstoffbelastung und Potenziale von temporären Minderungsmaßnahmen im Verkehr. Tagungsband der HEUREKA '08, Optimierung in Verkehr und Transport, FGSV Verlag, Köln.

Diegmann, V., Annecke, R., Mahlau, A. 2004. Echtzeit-Screening-System zur stadtweiten Berechnung der Schadstoff- und Lärmbelastung auf Basis von Verkehrsdaten. S. 85-89. In: Strobl, Blaschke, Griesebner (Hrsg.). Angewandte Geoinformatik 2004 - Beiträge zum 16. AGIT-Symposium Salzburg. Wichmann Verlag, Heidelberg. ISBN 3879074062.

EC. 2008. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. Official Journal of the European Communities L152/1.

iQ mobility. 2007: http://www.iqmobility.de.

IVU Umwelt. 2008a. IMMIS$^{em/luft}$ – Handbuch zur Version 4.0; IVU Umwelt GmbH; Freiburg, 2008 (http://www.ivu-umwelt.de/upload/download/handbuecher/immis40.pdf).

IVU Umwelt. 2008b. IMMIS^{net} – Handbook, Version 3.3; IVU Umwelt GmbH; Freiburg, 2008 http://www.ivu-umwelt.de/upload/download/handbuecher/immisnet_arcgis_3.3_en.pdf).

IVU Umwelt. 2008c. IMMIS^{mt}– Handbuch zur Version 2.0. IVU Umwelt GmbH, Freiburg.

HBEFA, 2004: Handbook Emission Factors for Road Transport; version 2.1; Feb. 20004

HBS. 2001. Handbuch für die Bemessung von Straßenverkehrsanlagen (HBS 2001). Forschungsgesellschaft für Straßen und Verkehrswesen, Köln, Januar 2002,ISBN 3937356444.

Landeshauptstadt München (Hrsg.). 2003. MOBINET Abschlußbericht 2003 – 5 Jahre Mobilitätsforschung im Ballungsraum München; Leitprojekt Mobilität im Ballungsraum München - gefördert vom Bundesministerium für Bildung und Forschung; München.

Tullius. 2003. http://www.berlin.de/sen/umwelt/luftqualitaet/de/download/heaven_ergebnisse.pdf.

UVM-BS. 2008. Umweltorientiertes Verkehrsmanagement Braunschweig im Auftrag des BMVBS im Rahmen der Förderinitiative „Mobilität 21 - Kompetenznetzwerk für innovative Verkehrslösungen (see www.uvm-bs.de).

Yamartino, R. J., Wiegand, G. 1986. Development and Evaluation of Simple Models for the Flow, Turbulence and Pollutant Concentration Fields within an Urban Street Canyon; Atmospheric Environment Vol.20, No.11, pp 2137-2156, 1986.