# A monitoring system to control effects and effectiveness of traffic measures in urban areas

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## Introduction

Within a project on environmental traffic management in Braunschweig, Germany, ("UVM Umweltorientiertes Verkehrsmanagement Braunschweig") a monitoring system has been installed as part of an environmental traffic management system (ETMS). This paper describes the layout, the application and the validation of the monitoring system.

The effectiveness of implemented traffic measures for a selected hotspot as well as the side effects were assessed by comparing modelling results based on identical input data but using traffic data without any measures in one case and with reduced traffic in the other case. The results emphasise the importance of a monitoring system that offers the possibility to assess and control the consequences of traffic measures within the entire road network.

During the project, differences between results of the monitoring system and measurements were observed. It will be shown that these may be attributed to some degree to the emission factors of HBEFA 2.1 (INFRAS, 2004) which was used as the basis for emission modeling.

## Motivation

European air quality limit values for PM10 and $NO_2$ are still exceeded in a number of cities in Germany and Europe. Vehicle emissions have been identified to play an important role in these limit value exceedances. Thus, clean air plans are usually focusing on traffic measures to improve air quality. Typical measures are low emission zones, traffic bans for heavy duty vehicles, speed limits or road traffic reduction, with the spatial extent ranging from a single street section up to the entire city center. These measures may be installed either permanently or temporarily.

In the context of quality assurance the effectiveness of the implemented traffic measures with respect to air quality improvement needs to be monitored. Additionally, it is important to control side effects on other street sections of the road network to prevent the emergence of new hot spots. In the case of an environmental traffic management system (ETMS), reliable traffic and air quality data are continuously needed as well (Diegmann and Gässler, 2009).

However, measured air quality data is usually not detailed enough for these purposes due to the limited number of measurement stations available along the considered road network. Instead, a monitoring system based on a modelling system that provides concentrations within all relevant street canyons may be used to gain the necessary information on air quality along the road network.

## Monitoring system

The environmental monitoring system installed in Braunschweig is an implementation of $IMMIS^{mt}$. The core of $IMMIS^{mt}$ consists of three models, forming a modeling chain to calculate traffic-induced emissions, urban and local dispersion. 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).

All input and output data is passed through adjustable interfaces that are capable of controlling various data transmission techniques like SOAP, ASCII, or HTTP. The internal data storage structure is realized with 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's archive is based on a client/server database and stores the total input and output data of all computations. 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.

Data requirement: The system is mainly driven by traffic data. Each street segment is characterized by a default traffic situation. This information can be updated for each time step in which the current situation can be derived from velocity profiles of the detected traffic data. 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. To account for the variation of urban background concentration, emissions of main sources like industry, shipping, rail traffic, off-road traffic and domestic combustion, usually available from an emission cadastre, are used for the urban dispersion model. The modeling approach on the micro scale requires a parameterization of the major roads. All street segments with adjacent buildings, called sections, are described by their width, height and porosity.

Modeling control: The modeling process calculating the total concentration at a hot spot in a street canyon needs to account for the regional background caused by long range transport, the urban background caused by the urban emission sources and the additional pollutant load caused by the road traffic in the street canyon itself.

Based on incoming traffic data, emissions of the major roads are determined with the emission model $IMMIS^{em}$ (IVU Umwelt, 2008). Together with emissions of other urban sources, the citywide spatial distribution of air pollutants is calculated using the urban dispersion model $IMMIS^{net}$ (IVU Umwelt, 2008b). This provides the urban background concentration for each section and for the locations of air quality monitoring 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 and Wiegand, 1986) is applied to assess the additional concentration due to traffic within each street canyon with the Canyon Plume Box approach using meteorological and local emission data. To derive $NO_2$ values from the calculated $NO_X$ concentrations, $IMMIS^{mt}$ provides different methods ranging from simple statistical techniques based on measurements to photochemical models.

## Application

The monitoring system was installed in street sections throughout the Braunschweig city center. Street sections of the northern and eastern inner ring road have already been identified in the Braunschweig clean air plan (Braunschweig 2007) to have a high traffic and pollutant load. These findings were confirmed by recalculation with a screening model (Figure 1).

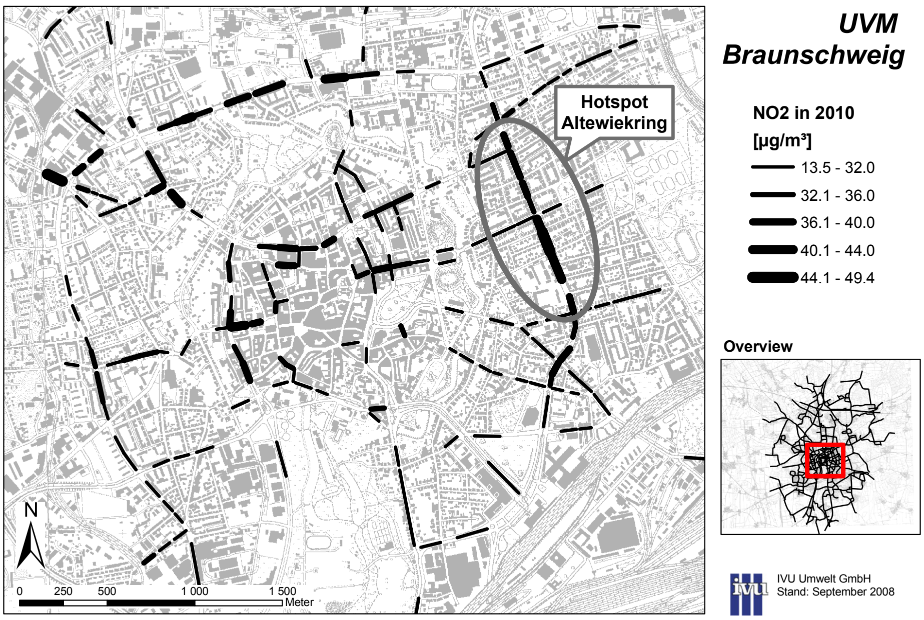


Figure 1: Recalculation of the $NO_2$ annual mean values for street sections in the city center of Braunschweig based on the Braunschweig clean air plan (Braunschweig 2007).

The Altewiekring, a part of the eastern inner ring road, was chosen as the hot spot to which traffic measures were applied. A monitoring station was installed there to provide air quality data for validation purposes. The traffic intensity in this part of the Altewiekring is about 38000 veh/day on weekdays, with hourly maximum values of 2200 veh/h. The annual mean values of the hot spot measurements in 2009 were 23 µg/m³ for PM10 and 52 µg/m³ for $NO_2$. The recalculation with a screening model based on the Braunschweig clean air plan predicted annual mean values of 30 µg/m³ for PM10 and 44 µg/m³ for $NO_2$ in 2010.

After implementing the system, monitoring was performed for several month in 2009, including a time period without any traffic measures and two time periods with traffic measures, in the following referred to as test phase 1 and 2. Hourly pollutant concentrations were calculated with IMMIS$^{mt}$ for the Braunschweig road network, based on online traffic data, emissions from sources other than traffic (e. g. domestic combustion, industry), background concentrations and meteorological data.

## Validation

Modelling results from IMMIS$^{mt}$ were validated with the measured data from the monitoring station at the hot spot in Altewiekring. The modeled time series of PM10 daily mean values are in overall good agreement with measured values (Figure 2, top). The corresponding coefficient of determination calculates to very good 91 % (Figure 3, left). It should be kept in mind that the PM10 concentration measured and modelled at the hot spot is mainly influenced by the regional background concentration which is not part of the modeling procedure.

The modeled time series of $NO_X$ hourly values agree very well with measured values in some parts (Figure 2, bottom). Maximum concentrations e.g. on 4 April 2009 or 19 May 2009 are well modeled. The overall characteristics of the measured time series is met by the model as well. However, the model often underestimates maximum concentration values. The coefficient of determination is 60 % (Figure 3, right) which is low compared to the PM10 result. This may be explained by the larger fraction of urban background und additional pollutant load due to traffic, both part of the modeling procedure. The averaging period which is a day for PM10 and an hour for $NO_X$ may play a role as well because there is less variability associated with longer averaging periods.

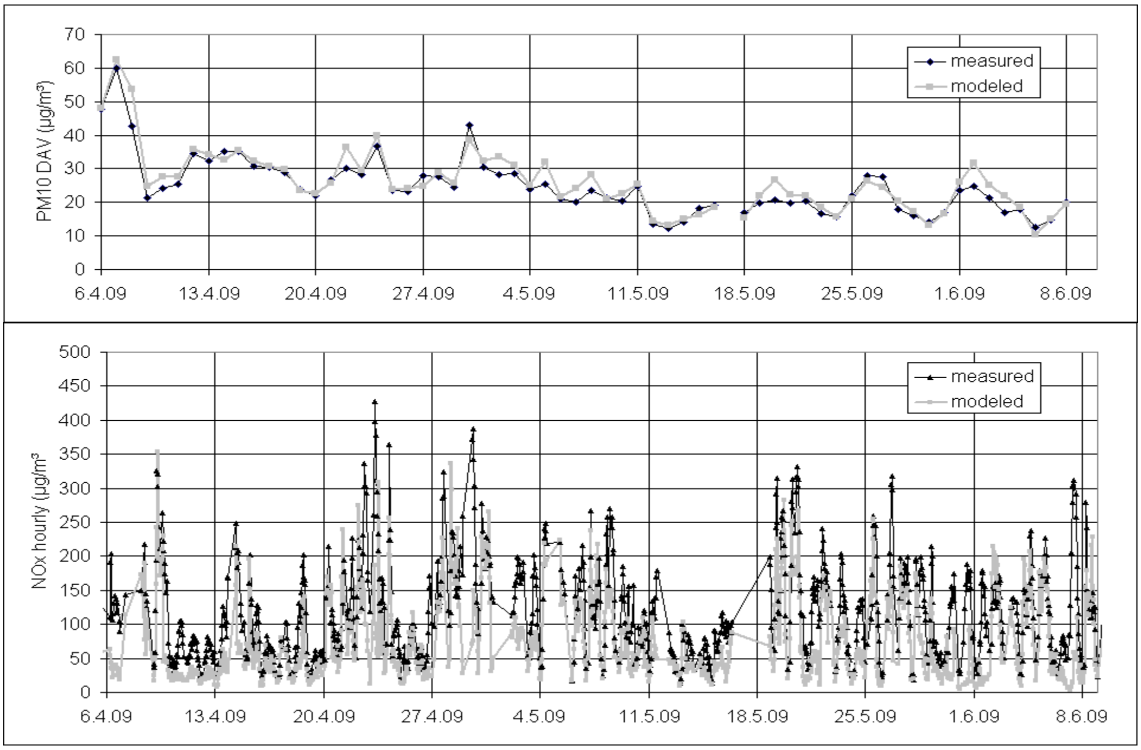


Figure 2: Time series of modeled and measured PM10 daily mean values (top) and $NO_X$ hourly values (bottom).

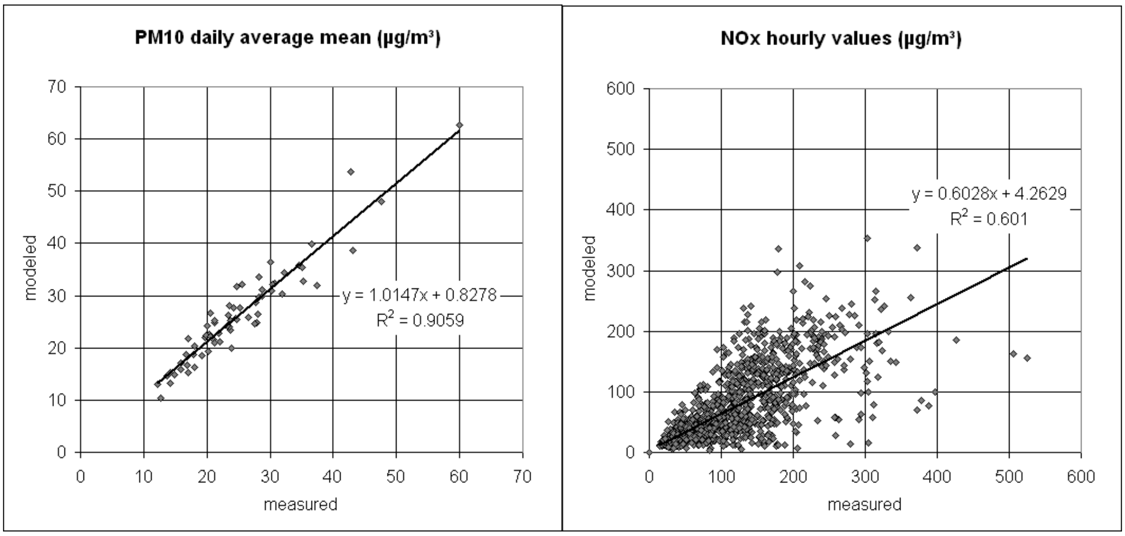


Figure 3: Scatterplot and regression analysis of modeled vs. measured data for PM10 daily mean and $NO_X$ hourly values.

Table 1 shows measured and modelled PM10 and $NO_X$ concentrations, averaged separately over the time period of each test phase and over both time periods. While measured PM10 concentrations are overestimated slightly by 5 % to 7 %, $NO_X$ concentrations are under-estimated significantly by 34 % to 35 %. Thus, $NO_X$ model results just missed the data quality objectives for ambient air quality assessment required by the EU directive 2008/50/EC (EU, 2008) which allow a deviation of 30 % for the $NO_X$ annual average.

It is widely accepted that the $NO_X$ emission factors of HBEFA 2.1 (INFRAS, 2004) are in parts significantly too low. Current calculations based on the just published HBEFA 3.1 (INFRAS 2010) show $NO_X$ emissions increasing up to 30 %. Hence, the $NO_X$ underestimation of the modeled data may be attributed to a large degree to the emission factors of HBEFA 2.1 which was used as the basis for emission modelling in this study. The concurrent increase of HBEFA 3.1 PM10 emissions indicates the necessity to revise the currently used approach for modeling non-exhaust emissions according to Düring and Lohmeyer (2004).

Table 1: Comparison of average values for measured and modeled PM10 and $NO_X$

| Substance | Period | ID | Measurement (µg/m³) | Model result (µg/m³) | Deviation (Mod-Meas)/Meas |
|---|---|---|---|---|---|
| PM10 | 06.04. - 10.05. | test phase 1 | 29.3 | 31.2 | 6.6 % |
| | 11.05. - 09.06. | test phase 2 | 18.7 | 19.7 | 5.4 % |
| | 01.04. - 09.06. | test phase 1+2 | 24.7 | 26.1 | 5.6 % |
| $NO_X$ | 06.04. - 10.05. | test phase 1 | 117.9 | 77.2 | -34.5 % |
| | 11.05. - 09.06. | test phase 2 | 117.1 | 76.3 | -34.9 % |
| | 01.04. - 09.06. | test phase 1+2 | 117.2 | 76.1 | -35.1 % |

## Results

As described above, the simulator module of IMMIS$^{mt}$ offers the possibility to repeat stored calculations using the same input data but replacing the traffic data. This allows to determine the effects of traffic measures on the pollutant load while keeping all other conditions constant. In the following, the paper will focus on the results for test phase 2.

Figure 4 shows the effects of the traffic measures implemented for Altewiekring at the hot spot site. Vehicle intensity was reduced by 14 %. Traffic-induced emissions decreased even more, they were reduced by 17 %. The disproportionate decrease of traffic emissions compared to vehicle intensity is due to improved traffic flow with less stop&go-situations. In combination with the meteorological conditions prevailing during test phase 2, reduction of the additional pollutant load due to traffic was calculated to 13 % (PM10) and 12 % ($NO_X$). This results in a decrease of total concentrations by 4 % (PM10) and 10 % (NOX).

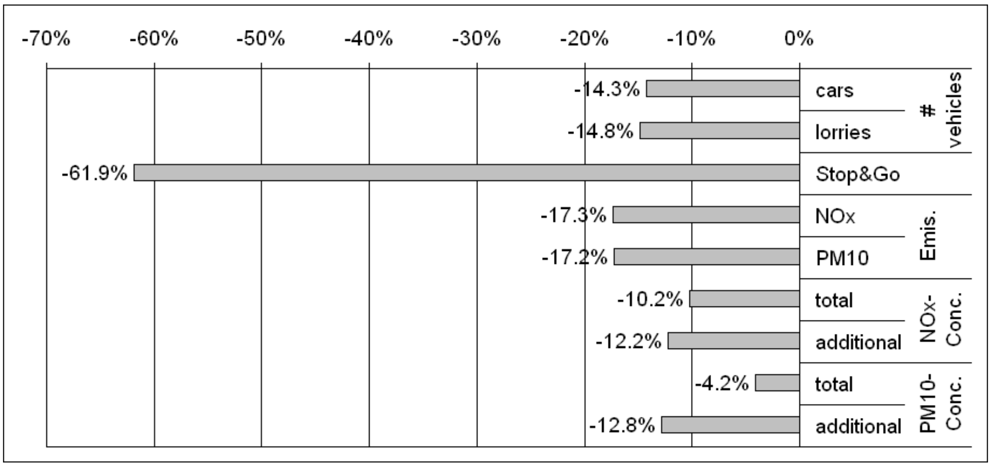


Figure 4: Effects of implemented measures on traffic load, traffic-induced emissions and pollutant load.

Figure 5 shows the differences of $NO_X$ total concentration in the monitored street sections which result from implementing traffic measures for the hot spot site Altewiekring. The differences are calculated from modeling results for test phase 2 and from results for modeling test phase 2 with the traffic data replaced with data for the same period in the previous year when no traffic measures were applied. $NO_X$ total concentration decreases by up to 14.4 µg/m³ and increases by up to 1.5 µg/m³. Relative differences between $NO_X$ total concentration with and without traffic measures implemented vary between a reduction of 16 % and an increase of 6 %.

PM10 total concentration decreases by up to 2.2 µg/m³ and increases by up to 0.3 µg/m³. The relative differences of PM10 additional pollutant load due to traffic decrease by up to 16 % and increase by up to 20 %. The maximum increase of the additional pollutant load occurs in the street section representing Hamburger Straße. Due to the low fraction of the pollutant load with respect to the total concentration the relative differences of PM10 total concentration vary only between a reduction of 8.5 % and an increase of 1.9 %.

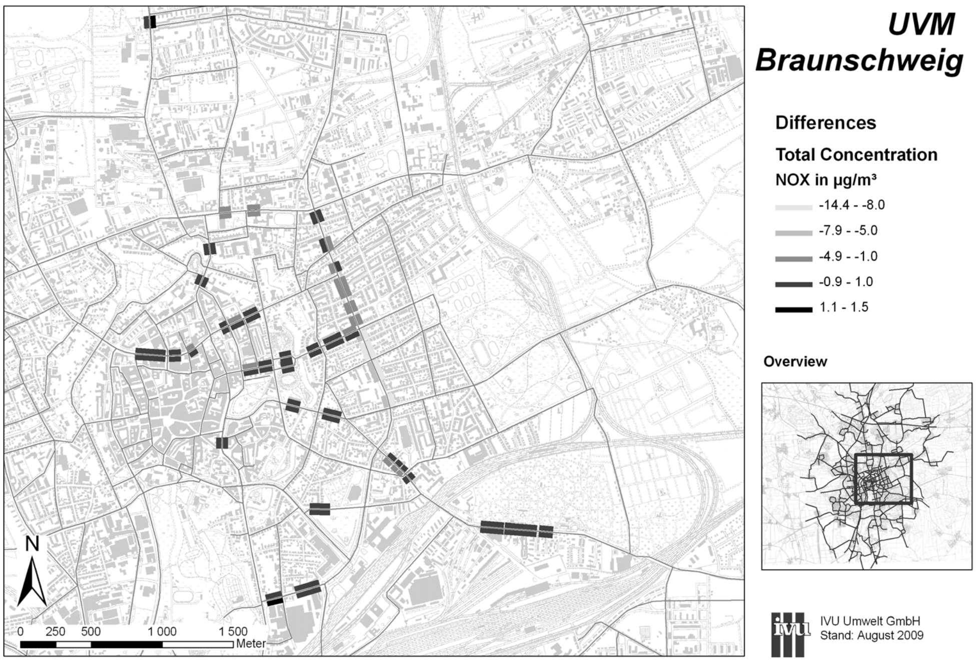


Figure 5: Effects of implemented measures on $NO_X$ total concentration in street sections.

## Conclusions

A model and data base supported monitoring system continuously controls the current traffic and air pollutant load. Hence, it allows to investigate the effects and effectiveness of traffic measures on air quality in urban areas while being much more cost-effective than measurements. Additionally, it offers the possibility to validate the implemented models and their input data.

Within the project "UVM Braunschweig", the implemented traffic measures reduced traffic at the hot spot site Altewiekring by 14 %. This induced a decrease of the calculated additional pollution load due to traffic by up to 13 % (PM10) and 12 % ($NO_X$). Considering the polluter fractions, this results in a decrease of total concentrations by 4 % (PM10) and 10 % (NOX). Side effects within the monitored street sections are mostly positive or neutral. However, impairment of air quality in a few street sections highlights the necessity of monitoring the pollutant situation within the relevant road network.

Validation of the model part of the monitoring system shows a significant underestimation of $NO_X$ total concentration. This was attributed to the $NO_X$ emissions factors of HBEFA 2.1 which had been the basis for emission modeling. Comparison with emission factors of HBEFA 3.1 for a mean traffic situation at the hot spot site showed an increase of $NO_X$ emissions by 30 %.

## Acknowledgements

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