Analysis of the Impacts of an Environmental Traffic Management System on Vehicle Emissions and Air Quality

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Introduction

Environmental traffic management systems (ETMS) are implemented to improve air quality in urban streets. They allow for a situation-related control of light signal systems to optimise road capacities and enhance traffic flow in street sections. Therefore, they are equipped with mitigation strategies and continuously provided with traffic and air quality data. In this context, it is usually presumed that improving the traffic flow results in lower vehicle emissions and thus in lower pollutant concentrations, provided that the vehicle intensity does not change.

In order to verify this assumption and to quantify potential effects, a test case has been set up in Cologne, Germany. The Cologne clean air plan 2006 reports NO_2 limit value exceedances at several monitoring stations and pollutant concentrations close to the limit values throughout the inner city. A low emission zone has been established for Cologne on January 1st, 2008, as a first step to improve air quality. Additionally, it is planned to install an ETMS for two heavily trafficked areas of Cologne. One of the two areas was chosen as a test case for which modelling was carried out in advance to assess the impacts of the ETMS on traffic-induced emissions and air quality. This paper describes the modelling procedure and discusses the outcome.

The test case

The test case was set up for Clevischer Ring in Cologne-Mülheim, 4 km north east of the Cologne Main Station. An air quality monitoring station is located in this part of Clevischer Ring, in a typical street canyon with buildings on both sides. Four traffic scenarios were modelled, a base scenario and three ETMS scenarios:

1) Base Scenario: typical hour with maximum traffic load, based on measured traffic data

2) Scenario 1: improved, traffic-dependent control and coordination of light signal systems

3) Scenario 2: scenario 1 plus gatekeeping at the southern, northern and western inlet

4) Scenario 3: scenario 2 plus restriction of existing public transport priority

The impact of the different scenarios on air quality was analysed for meteorological conditions under which the pollutant load resulting from vehicles was expected to be high and therefore potentially harmful. Considered pollutants were NO_X/NO_2 and PM10. In the following, this paper will focus on the NO_X/NO_2 results for the Base Scenario and Scenario 2 for the street section where the monitoring station Clevischer Ring is located.

Modelling

Modelling was carried out in four steps. First, the traffic data for the four scenarios was calculated. Then, the corresponding emissions for the hour with maximum traffic load were determined. Next, dispersion of the pollutants was modelled, based on the calculated emission data and on meteorological data for which the maximum additional pollutant load from traffic was to be expected. Finally, the decrease of the NO_2 annual mean concentration at the monitoring station Clevischer Ring was assessed based on the modelling results. In each step, the impact of the ETMS scenarios was analysed.

Traffic data for the four scenarios was modelled by project partner SIEMENS with VISSIM, a highly detailed microscopic simulation program for multi-modal traffic flow modelling. Figure 1 shows the considered road network which was divided into 11 street sections. Each street section was defined to be located between two light signals. To capture the dynamics within the street sections, three cross sections were assigned to each of them for which traffic data was to be calculated.

VISSIM simulations were then run for each scenario for the hour with maximum traffic load. As the result, VISSIM provided for each direction of traffic time series of fleet composition, vehicle intensity, mean velocity and mean acceleration for each cross section as well as congestion data. The temporal resolution of all time series was 60 s.

Finally, for each street section the VISSIM traffic data of the respective cross sections was evaluated statistically to gain mean hourly values of fleet composition and velocity as well as the standard deviation of velocity.

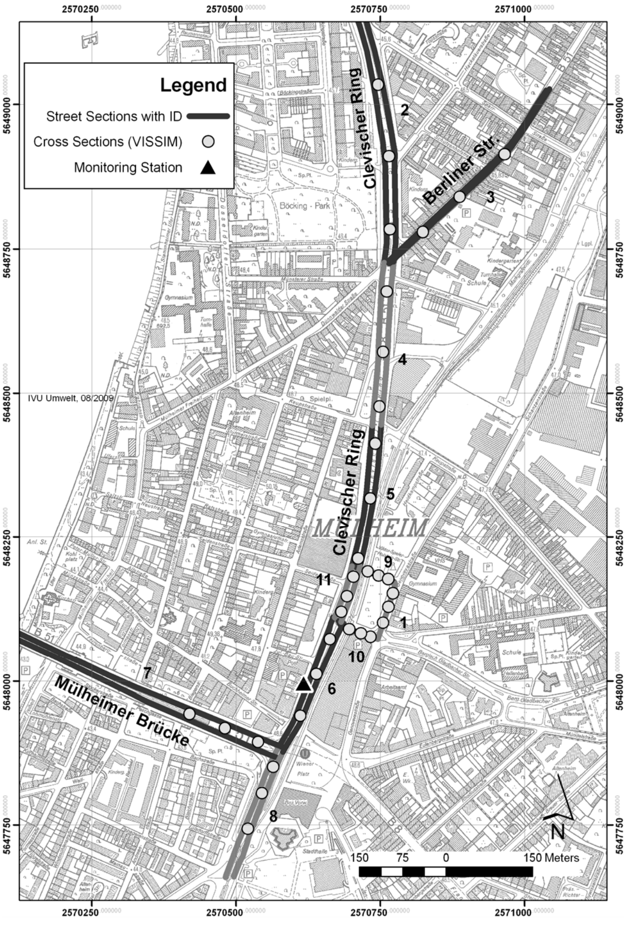

Figure 1: Modelled road network Clevischer Ring with street sections and cross sections.

Table 1 gives exemplarily the traffic data derived from VISSIM results for the Base Scenario and Scenario 2 for street section 6 where the air quality monitoring station is located. For the Base Scenario, the mean velocity of the northbound traffic is only half the mean velocity of the southbound traffic while the standard deviation is nearly twice as much. Applying Scenario 2 obviously improves the traffic flow, as the vehicle intensity increases in both directions compared to the Base Scenario. The mean velocity increases significantly for the northbound traffic and slightly for the southbound traffic while the standard deviation decreases. Scenario 1 and 3 are not shown here as traffic data results differ only slightly from Scenario 2.

The corresponding histograms of mean velocity in Figure 2 show graphically the findings given above. The histogram of northbound Base Scenario street section 6 exhibits a significantly broader and flatter distribution with its center at lower velocities than the southbound histogram. Scenario 2 shifts the distribution of both directions, but mainly of direction North, to higher velocities.

Other street sections, but not all, show a similar behaviour, as will be discussed for the emission data results (Figure 3).

Table 1: Traffic data evaluated statistically from VISSIM results, hour with maximum traffic load for street section 6, Base Scenario and Scenario 2

		Vehicles	Fractions			Velocity (km/h)	
	ID	(veh/h)	HDV	LDV	Bus	Mean	Std. Dev.
Base Scenario	6North	1804	5.0 %	5.5 %	0.2 %	23.7	2.0
	6South	1745	5.0 %	5.5 %	0.1 %	44.2	1.2
Scenario 2	6North	1820	5.2 %	5.3 %	0.2 %	41.9	1.1
	6South	1828	5.1 %	5.3 %	0.2 %	46.0	0.3

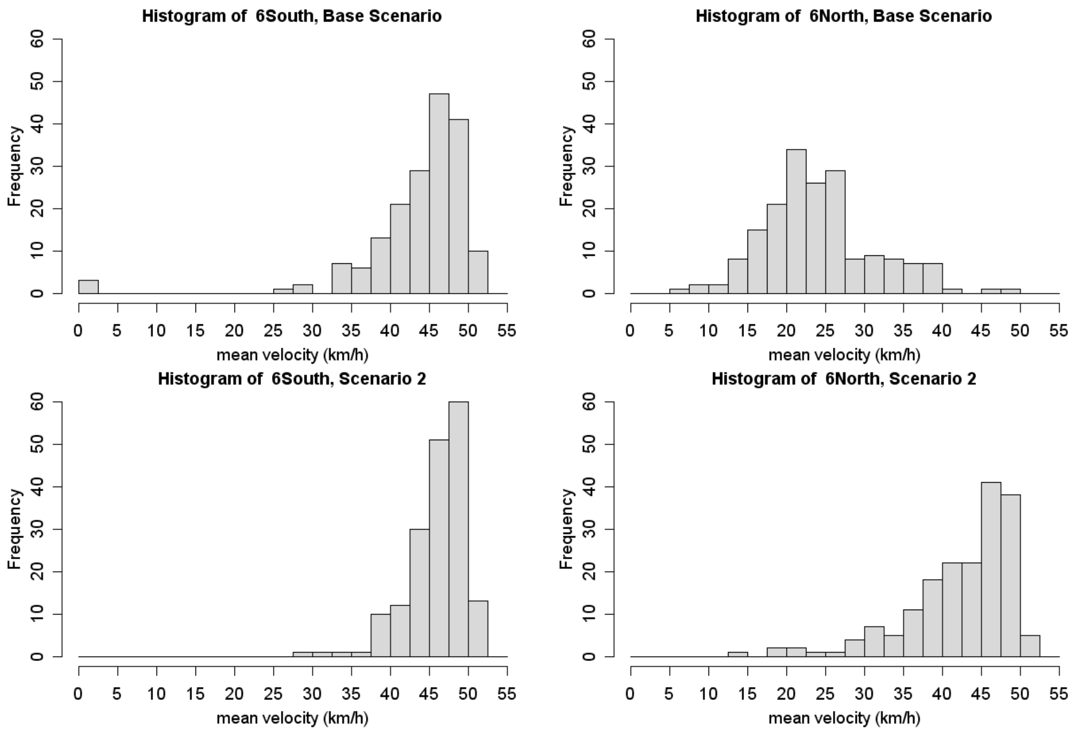

Figure 2: Histograms of mean velocity for street section 6 at air quality station, Base Scenario (top) and Scenario 2 (bottom).

Emission data for the hour with maximum traffic load was calculated for each street section in each scenario with IMMIS$^{em/micro}$ which is a special version of IMMIS^{em} (IVU Umwelt, 2008). Non-exhaust PM10 from abrasion and resuspension processes were determined using the approach by Düring and Lohmeyer (2004). IMMIS$^{em/micro}$ uses a linear combination of driving patterns defined in HBEFA 2.1 (Handbook of Emission Factors for Road Traffic, INFRAS, 2004) to derive traffic situations and emission factors for the traffic data described above. For each street section, the two driving patterns whose mean velocities enclose the mean velocity derived from the VISSIM data are combined such that the weighting factors sum up to unity. Additionally, the fraction of congestion is determined from the VISSIM congestion data. The corresponding emission factor is then calculated from the weighted emission factors of the chosen driving patterns, scaled with the fraction of fluent traffic flow, and the stop&go emission factor, scaled with the fraction of congestion.

Figure 3 shows the absolute values and the relative differences of the calculated NO_X emissions of Scenario 1 – 3 compared to the Base Scenario for each street section. Emissions depend on the chosen driving patterns and stop&go-fraction, on the vehicle intensity and on the fractions of HDV, LDV and busses as given exemplarily in Table 1.

The NO_X emissions of Scenario 1 – 3 decrease significantly for the street sections 5North, 5South, 6North, 8North and 11North at the centre of the considered road network. Lower emissions are also found for 2South, 4South and 9West. Street Section 7East emissions decrease for Scenario 1 and increase for Scenario 2 and 3. This is due to the gatekeeping function of 7East in the latter scenarios which leads to larger stop&go fractions, lower mean velocities and less advantageous driving patterns. Increased emissions are also observed for 7West, 8South, 10East and 11South and to a small degree for 2North, 3West and 4North. Generally, NO_X emissions increase by at most 18 % while they decrease by up to 45 %.

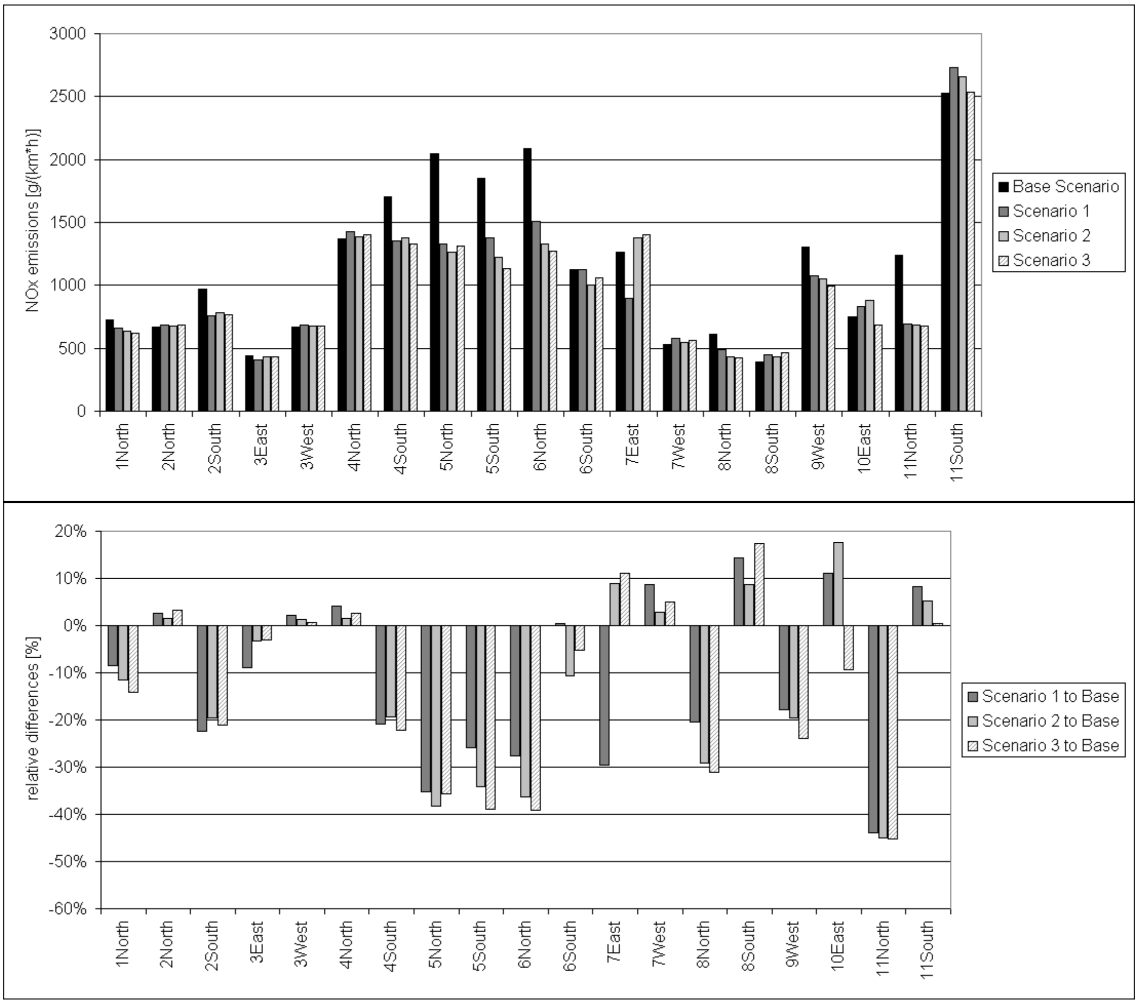

Figure 3: Absolute values (top) and relative differences (bottom) of NOX emissions of Scenarios 1 - 3 compared to the Base Scenario for all considered street sections.

Dispersion modelling was carried out with the three-dimensional microscale model MISKAM 5.02 (Eichhorn, 2008). MISKAM consists of a prognostic, non-hydrostatic wind field model and a Eulerian dispersion model. Buildings are considered in the form of rectangular block structures. The investigation area for the test case has a size of 200 m x 350 m with a horizontal resolution of 1 m. It contains the location of the air quality monitoring station and several street sections of Clevischer Ring (Figure 4). Building data for this area was provided by the Cologne city authorities.

Modelling was performed based on the $IMMIS^{em/micro}$ emission data described above and for meteorological conditions for which the maximum additional pollutant load from traffic was to be expected. Meteorological data and background concentrations were available for 2008 from the Cologne background station Chorweiler. First, the hours of maximum additional pollutant load were identified by analysing the differences of the measured concentration values between the air quality stations Clevischer Ring and Chorweiler. The concentration differences of the identified hours were then correlated with the respective wind directions. Finally, the critical wind direction was defined to be the wind direction for which large concentration differences, i. e. a high additional pollutant load, occured with high frequency. This was the case for a wind direction of 270°. The wind velocity was set to 2.3 m/s which was the annual mean value at Chorweiler in 2008.

Figure 4 shows exemplarily some of the modelling results within the investigation area for the level 1.3 m – 2.0 m above ground. For the Base Scenario, the NO_X additional pollutant load due to traffic reaches its maximum close to the location of the air quality station (Figure 4, left). The respective street section 6 (Table 1) exhibits a canyon-like character and has a large vehicle intensity. North of the building block, concentrations on street section 6 decrease despite of constant emissions as the ventilation improves. Comparing the NO_X additional pollutant load of Scenario 2 with the Base Scenario, relative differences show a drop of concentrations of up to 40 % for street section 6 within the street-canyon area (Figure 4, right). Slight increases up to 5 % are observed for street section 11South in the northern part of the investigation area, for 10East and for 7East. For these street sections, emissions are larger in Scenario 2 than in the Base Scenario (Figure 3).

Figure 4: Left: NO_X additional pollutant load due to traffic emissions under critical wind direction 270° for Clevischer Ring at level 1.3 m – 2.0 m, Base Scenario. Right: Relative differences of NO_X additional pollutant load, Scenario 2 to Base Scenario.

The results described above are valid for an hour with maximum emissions under unfavourable meteorological conditions. Following the approach of Diegmann and Wiegand (2007), the impact of Scenario 2 on the NO_2 annual mean concentration in 2008 compared to the Base Scenario was assessed by assuming that Scenario 2 was implemented as a temporary measure under these conditions:

1) the measure was active only between 5 a.m. and 10 p.m.

2) the measure was activated as soon as the measured NO_2 hourly mean concentration at the monitoring station Clevischer Ring reached A: 60 µg/m³, B: 70 µg/m³, C: 80 µg/m³

3) when activated, the additional pollutant load due to traffic was reduced by 23.7 % compared to the Base Scenario, with 23.7 % being the reduction derived from the MISKAM modelling results for Scenario 2 and the Base Scenario at the location of the monitoring station.

The hourly NO_2 time series 2008 measured at Clevischer Ring was modified according to these parameters and the annual mean value was calculated. The results as well as the fraction of hours in a year for which the measure was to be activated are given in Table 2.

Table 2: Results for Scenario 2 implemented as a temporary measure

Case	A: 60 µg/m³	B: 70 µg/m³	C: 80 µg/m³
fraction of time with activated measure	45 %	36 %	26 %
potential reduction of NO_2 annual average	9.0 %	7.8 %	6.1 %

Conclusions

Modelling the four scenarios and analysing the results led to the following conclusions:

Modelling confirmed that under meteorologically unfavourable conditions the maximum additional pollutant load due to traffic occures close to the location of the monitoring station Clevischer Ring.

Enhancing the traffic flow results in a significant decrease of traffic emissions at the hot spot Clevischer Ring (street section 6) as well as for the considered street sections in total. At the same time, vehicle intensity increases slightly for most street sections (Scenario 1: up to 10 %, Scenarios 2 and 3: up to 5 %).

Scenario 1 leads to a significant decrease of the additional pollutant load within the investigation area and thus improves the air quality situation. Scenario 2 improves the situation further, mainly close to the monitoring station Clevischer Ring. For Scenario 3, concentrations decrease only in some parts of the investigation area compared with Scenario 2, mainly in the northern part. In the southern part and at the monitoring station concentrations increase slightly.

The significantly improved air quality situation at the monitoring station Clevischer Ring for Scenarios 1 to 3 compared to the Base Scenario goes along with minor increases of the additional pollutant load in non-critical areas.

Based on the modelling results for meteorologically unfavourable conditions and a theoretical approach, the potential of Scenario 2 to reduce the NO_2 annual mean concentration at the monitoring station Clevischer Ring was assessed to be 6 % to 9 % for 2008, depending on the parameters of the mitigation strategy.

The results presented here indicate that ETMS may be a worthwhile measure to improve the air quality in heavily trafficked areas. It may be noted that emission modelling was based on HBEFA 2.1 which was in effect at the time of the investigation and which preceeds HBEFA 3.1 now available since February 2010. So far it appears that emission calculations based on HBEFA 3.1 will increase the traffic-induced fraction of the pollutant load. Thus, the ETMS scenarios studied here may be even more effective. In any case, the effect on the surrounding road network should be considered carefully to avoid inducing new hot spots by eliminating existing ones.

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