

# Estimation of Air Quality at Trier, Germany - a Case Study with STREET 5.

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**Abstract:** In the course of the European Council Directive on permissible air pollutant limit values, valid starting from 2005 there is an urgent call for action, particularly for fine dust (PM<sub>10</sub>). Current investigations (Junk & Helbig 2003, Reuter & building Mueller 2003) show that the limit values in certain places in congested areas are exceeded. Only if it is possible to locate these Hot Spots purposeful measures to reduce the ambient air pollution can be conducted. For an efficient identification of these Hot Spots complex computer models or establishing special measurements networks are too expensive. Using the statistical model STREET 5,0 (KTT 2003) a cost-effective screening of the air pollution situation caused by the traffic can be done. STREET is based on the 3-dimensional micro-scale non-hydrostatic flow- and dispersion model MISCAM (Eichhorn 1989). The results of over 100.000 different calculations with MISCAM are stored in a Database and these results are used to calculate the emissions with STREET. In collaboration with the city council more than 100 streets were investigated, mapped, and calculated. A special urban climate measuring network supplies the necessary meteorological input data about the wind field and precipitation events in the valley of the Moselle. Information about road width and road orientation as well as building density were derived from aerial photographs. Traffic censuses and mobile air pollutants measurements with our instrument van supplied the remaining input data. We calculated the mean annual air pollutant concentrations for NO<sub>2</sub>, NO, CO, SO<sub>2</sub>, O<sub>3</sub>, benzene as well as PM<sub>10</sub>. A comparison of the model results with the values obtained from the stations of the central emission measuring network of Rhineland-Palatinate (ZIMEN annual report 2002) show very good agreements. The model was not only used to calculate the annual air pollutant but also for urban planning and management. The absolute level of the air pollutant is mainly dependent on the amount of traffic in the street canyons. Therefore different case-scenarios with varying quantity of traffic were calculated for each street. Furthermore the model can be used to find the maximum tolerable numbers of cars for a street without exceeding the air pollutant thresholds.

**Keywords:** modelling; PM<sub>10</sub>; traffic emissions; urban air pollution

## 1. INTRODUCTION

The current environmental situation is the product of a long historical process. The increasing and rapid growth of cities and the corresponding rise in industrial and traffic density, are making it ever more important to ensure that air quality is adequate. In Germany the level of motorisation, i.e. the number of vehicles per 1.000 inhabitants, has been rising for years. The traffic sector is one of those areas which place a strain on the environment resulting from road construction, consumption of raw materials and the emission of air pollutant substances. Of all means of transport

the private car is responsible for the largest amount of environmental pollution by far. The direct effects of this are felt most by those who live in cities. For decades air pollution, in particular in conurbations, has been the subject of many studies. Thanks to successful emission reduction measures and strategies implemented in recent years the classic air pollutants NO<sub>x</sub>, SO<sub>2</sub>, CO and O<sub>3</sub> are showing stagnating (O<sub>3</sub>) or even negative trends (SO<sub>2</sub>). The pollution of the air by general dust (TSP) has fallen considerably in the last few years. New studies are showing, however, that the element of fine particulate matter (PM<sub>10</sub>, particulate matter with an aerodynamic diameter <

10 µm) is constantly increasing in importance. The reduction in particulate pollution is due above all to the reduction in the proportion of coarse particles. The proportion of fine particulate matter remains constant or is even on the increase. To what extent particles can penetrate the various areas of the lungs and be deposited there depends on the one hand on their physical characteristics and on the other on breathing patterns and the anatomy of the lung, which is subject to change as the result of growth, ageing or illness. A detailed presentation of the medical effects, including the increased frequency of mutations, appears in Heinrich (2000). As early as 1997 Wordley et al. referred to a significant increase in hospital admissions at times of intensified emissions of fine particulate matter. Direct connections between higher daily mortality rates and fine particulate matter concentrations have been analysed and documented in the USA by Lipfert et al. (2000), Klemm et al. (2000) and Samet et al. (2000). Comparable results are presented by Hoek et al. (2000) for the Netherlands. Because of the immediate relevance to health of fine particulate matter which can enter the lungs and act as a carrier for substances which are detrimental to health such as polycyclic aromatic hydrocarbons (PAK) or heavy metals, new limits for fine particulate matter have been imposed by the EU. These will come into effect in 2005. Since 1 January 2001 continuous PM<sub>10</sub> measurements have been taken in the air-quality monitoring networks of the individual federal states of Germany. In Rhineland-Palatinate air pollution is measured by the central emission monitoring network (ZIMEN). Statistical analyses of the ZIMEN data by Junk & Helbig (2003) indicate values exceeding the future limits at various locations close to traffic in Ludwigshafen, Mainz and Trier.

With a surface area of approx. 117 km<sup>2</sup> and a total of 100,234 inhabitants, the city of Trier has a population density of 856 E/km<sup>2</sup>. The city's main residential areas are on the lower slopes of the Mosel valley (140 m above sea level), which runs from NE/SW. In a direct comparison with other conurbations in Rhineland-Palatinate (Koblenz, Kaiserslautern), Trier shows the highest PM<sub>10</sub> pollution in spite of the fact that it has a low level of industrialisation and population density (Helbig & Junk 2003). It was these facts that indicated the necessity of a general screening of PM<sub>10</sub> pollution in the city. If in future (from 2005) certain critical limits are reached or exceeded, measures will have to be taken at short notice to reduce air pollution.

In cooperation with the city of Trier and using the STREET 5.0 statistical model, the mean annual pollution of the air with NO<sub>2</sub>, PM<sub>10</sub> and benzene was calculated for all streets in the city, so that hot

spots and critical points could be identified for more detailed analysis later.

The model also offers the possibility of calculating different scenarios. For example it enables the calculation of the maximum daily traffic volumes which are permissible before the limits are exceeded. In the present study a number of scenarios were calculated and their effects on pollutant concentrations were examined:

- Scenario - "Zero case"
- Scenario - "Private transport"
- Scenario - "Public transport"
- Scenario - "Optimised public transport"

## 2. MODEL DESCRIPTION

STREET 5.0 is an efficient and inexpensive instrument which provides a simple method of evaluating air pollution caused by traffic emissions in inner-city areas.

It is a static model which was originally developed on behalf of the Baden-Württemberg department of the environment and is today distributed by KTT Umwelttechnik und Software GmbH, Dr. Kunz Saarbrücken. The basis for the screening model is 3-dimensional flow and dispersion calculations using the MISKAM mesoscale model. The model calculates quasi-stationary wind and turbulence fields on the basis of pre-defined approach-flow directions. More than 100,000 different configurations involving varying meteorological ancillary conditions and street geometries were calculated and then recorded to form a data base in STREET. The computational grid for calculating the simulation was fixed at 60 x 60 x 20 grid points. The horizontal and vertical grid spacing was 2 m for all simulated street categories. In order to minimise marginal effects, the outer horizontal 7 to 10 grid points were not arranged equidistantly. This produced, depending on street category, an area for calculation of 280 m – 320 m, with only the core area of the computational grid, where the grid points are equidistant, being used for evaluation purposes. The atmospheric stability is described by means of a vertical temperature gradient which can be defined in advance. Depending on this stability the emitted air pollutants are mixed with the ambient air at different speeds. Where stability is high the dilution takes place very slowly, while unstable layering leads to rapid dilution. Assuming typical configurations for streets and crossroads, mean annual and 98 percentile values are calculated on the basis of current emission factors. The emission factors which are required for the calculations are taken from the UBA handbook (1999 edition) and permit calculations to be made up to the year 2020.

For more detailed information on the MISKAM model cf. Eichhorn 1989.

### 3. INPUT DATA FOR THE CALCULATIONS

#### 3.1 Meteorological data

The conditions which govern the spread of pollutants depend primarily on the extent of the stability, wind direction and wind speed, combined with precipitation factors. In particular for cities which are situated in a valley, of which Trier is an example, air-flow conditions play a decisive part. Studies by Helbig & Junk (2003) show that during autochthonous weather situations, low wind speeds can lead to rising contamination of the air with pollutants in the Trier area. The necessary input data for creating the models is supplied by the special measuring network of the climatology department of Trier University. Because of its situation on the Petrisberg, a hill 100 m above the Mosel valley, it was not possible to use the wind

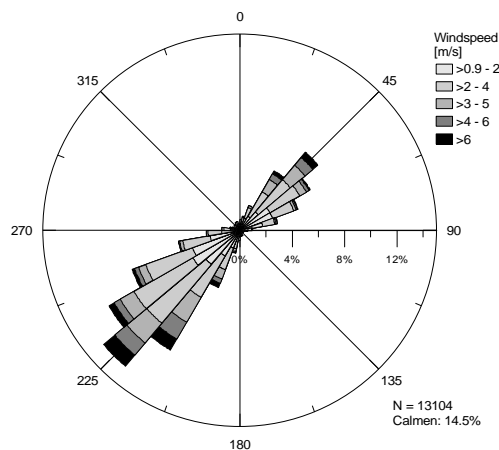


Figure 1: Rel. Frequency of 1h values of the windvector at Niederkircher Str., 2002-2003

measurements of the German weather service's climatic station at Trier-Petrisberg. The wind direction and wind speed were measured at an exposed wind mast 10 m above ground in the Mosel valley to the west of the town. Figure 1 shows the mean wind vectors for the years 2002 and 2003. As a further meteorological parameter, the number of days with precipitation  $\geq 1$  mm are required as input for the model. Wet deposition, in other words the deposit of atmospheric microelements by precipitation (rain, fog, hail or snow), marks the whole process from cloud formation to precipitation (GUDERINA, 2000). For the present calculations the data of the German weather service's climatic station at Trier-Petrisberg was used. The higher the number of days with precipitation, the greater is the purification potential resulting from wet deposition. For this

reason trend analyses were used to see if the Trier-Petrisberg weather station had observed an increase in the days with precipitation over the last 30 years. Although a slight increase in such days with precipitation  $\geq 1$  mm has been observed, this linear trend is not statistically significant.

#### 3.2 Topographical information and traffic data

In addition to the meteorological data, detailed information about street geometry, street orientation, number of lanes and the type of surrounding buildings is required. In addition details about the road surfaces have to be provided. The required information in relation to road surface and height of the surrounding buildings was obtained by surveying and mapping. Information about the number of lanes, road types and surrounding buildings was derived from digital aerial photographs of the city of Trier. The sections of road which were to be modelled were digitalised on the basis of topographical maps with a scale of 1:5000. All the necessary data sets were stored as attribute datasets in ARCGIS. The validity of the calculations depends to a large extent on the accuracy of the data about daily traffic volumes (DTV), the proportion of lorries, the proportion of traffic jams and the mode of driving. The driving mode describes the time sequence of different speeds and engine conditions (idling, acceleration, constant speed). Eight different driving modes can be selected in the model. In addition the percentage of traffic jams can be indicated. A traffic jam proportion of 25% represents 6 hours of traffic jams within 24 hours.

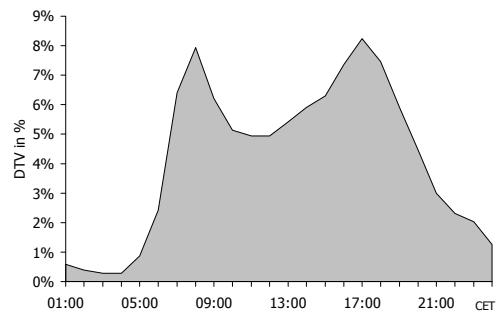


Figure 2: standardised distribution patterns of daily traffic volumes in percent

The average daily traffic volumes were established by means of traffic surveys (Fig. 2). Traffic surveys can either be carried out by automatic equipment, or the daily traffic volume can also be calculated on the basis of relatively short survey times by means of standardised distribution patterns (VERTEC GmbH, consulting engineers for traffic planning and technology, Koblenz).

#### 4. RESULTS OF THE MODELLING

As an example the results and evaluations for 13 streets where detailed traffic surveys were carried out in the summer of 2003 are discussed here. The concentrations which were calculated are shown in Table 3. The pollutant SO<sub>2</sub> is not included in the evaluation, because for all 175 streets which were analysed the values were significantly below the limit value of 20µg/m<sup>3</sup>.

For all pollutants Lindenstraße shows the highest concentrations, which lead to classification in the category 'limits clearly exceeded'. The reasons for these increased values are to be found in the

#### Zero case prognosis:

For the zero case prognosis no changes are assumed to the existing traffic network or public transport. The data for this scenario are used as reference data.

#### Private transport scenario:

The private transport scenario assumes the implementation of measures regarding the road network which are under discussion for long-term implementation. The inner-city parking space requirement will be met for the most part. As for the zero case prognosis, the pedestrian and cycle-path network as well as the local public transport system remain without any significant change.

Table 1: Calculated annual means of Benzene-, NO<sub>2</sub> und PM<sub>10</sub> for selected streets, 2003

Street Name	DTV [Kfz/24h]	Benzene [µg/m <sup>3</sup> ]	NO <sub>2</sub> [µg/m <sup>3</sup> ]	PM <sub>10</sub> [µg/m <sup>3</sup> ]
Saarstr.	13.000	7,7	58	48
Hindenburgstr.	9.500	4,1	42	37
Im Avelertal	17.100	3,0	30	29
Olewigerstr.	23.000	3,9	40	34
Hohenzollernstr.	6.400	4,4	37	34
Kaiserstr.	13.300	5,1	41	37
Luxemburgerstr.	32.500	4,8	53	38
Ostallee	17.500	6,5	49	44
Schellenmauer	14.200	4,2	42	35
Pacelliufer	38.700	5,7	47	44
Matthiasstr.	12.000	7,2	57	47
Zurmaiener Str.	36.100	3,5	37	33
Lindenstr.	17.900	7,9	59	53

grey: Range of values below the limit

bold: Range of uncertainty

normal: Range of values below the limit

building structure which encloses the street, and the presence of traffic lights.

Classification in the category 'clear range below limits' was only achieved for the benzene concentrations calculated for the Neue Zurmainer Str. and Im Avelertal. Although both street sections show considerably different DTV values, the better air-flow situation resulting from the fact that only one side is built up and fewer hold-ups with a proportion of traffic jams of only 5% and 3% respectively have a positive effect on emission concentrations.

As part of earlier studies, plans were made on behalf of Trier city council covering the whole traffic network (road and local public transport network). These plans incorporated all the planning measures which were under discussion for short, medium and long-term implementation. On the basis of these measures it has been possible to calculate various scenarios for the planning year 2010 and to derive from this future traffic volumes.

#### Public transport:

With the public transport scenario the assumption is that there will be short or medium-term measures implemented in the road network, extension and improvement of the public transport infrastructure and changes to the pedestrian and cycle-path network. In addition there will be an increase in Park & Ride (P+R) facilities and the conversion of long-term parking in the old town to short-term and residential parking.

#### Optimised public transport:

The last scenario describes the case of optimised promotion of local public transport. There will only be few additions and extensions to the road network - on the contrary, there will be increased restrictions. The rail network will play an increased role as the backbone of local transport operations.

As with the public transport scenario, the planning will include measures for improving the pedestrian and cycle-path network. The existing P+R facilities will be expanded and both in the old town

and its outer areas there will be restrictions on the space available for long-term parking. By means of such so-called 'soft' measures (PR work/advertising, improved information flow, image, service, convenience...) the transport facilities offered by the environment department will be reinforced. There will be nine more P+R sites. With this scenario the biggest changes will be in the form of extensions to the public transport services.

The 'Zero case prognosis' was taken as the reference point for the comparative changes in emission concentrations to be expected for the 'Private transport', 'Public transport' and

The mean annual limit for NO<sub>2</sub> emission concentrations as defined by the council of ministers on 22 April 1999 in EU Guideline 1999/30/EG concerning limits on sulphur dioxide, nitrogen dioxide, nitrogen oxide, particles and lead in the air is 40 µg/m<sup>3</sup>. In addition a mean hourly limit of 200 µg/m<sup>3</sup> must not be exceeded more often than 18 times per year.

In the case of NO<sub>2</sub> concentrations, approx. 80% of the roads are within the range of uncertainty. Here action must be taken to ensure that the limits imposed by the EU can be observed.

The most serious aspect is the way in which limits are exceeded in the case of PM<sub>10</sub> concentrations.

Table 2: Results of the calculation of pollutants for the various scenarios in relation to the planning year 2010

	Benzene		NO <sub>2</sub>		PM <sub>10</sub>	
	Range of values below the limit (≤ 3.7µg/m <sup>3</sup> )	Range of uncertainty (3.8 – 6.1 µg/m <sup>3</sup> )	Range of values below the limits (≤ 28µg/m <sup>3</sup> )	Range of uncertainty (29-50µg/m <sup>3</sup> )	Range of uncertainty (15-25 µg/m <sup>3</sup> )	Range of values over the limits (≥ 26µg/m <sup>3</sup> )
Zero case	78%	22%	20%	80%	2%	98%
Private transport	78%	22%	22%	78%	2%	98%
Public transport	83%	17%	20%	80%	2%	98%
Optimised public transport	83%	17%	21%	79%	2%	98%

'Optimised public transport' scenarios. For purposes of calculation with STREET 5 a total of 175 streets were selected because data was available for these covering all four scenarios.

In the analysis of the emission concentrations calculated for the year 2010, only the pollutants benzene, PM<sub>10</sub> and NO<sub>2</sub> were included.

The calculation of the pollutants was based on the background pollution data contained in the handbook 'Emission factors in road transport' (1999 edition) published by the Federal Department for the Environment in Berlin. This leads to a potential weak point in the calculations. In an ideal case, regionally specific values were to be established in individual situations for the various background pollution levels caused by individual pollutants. Table 4 contains the results for the individual scenarios.

The mean annual limit (reference year 2010) as defined by the council of ministers on 16.11.2000 in EU Guideline 2000/69/EG concerning limits on benzene is 5µg/m<sup>3</sup> benzene. Altogether it can be seen that the forecast benzene pollution for the majority (78% - 83%) of the roads tested lies within the clear range below the limits. In addition, the values for those roads which fall within the range of uncertainty almost all lie below the limit of 5µg/m<sup>3</sup> at 3.8 µg/m<sup>3</sup> to 5.1 µg/m<sup>3</sup>.

However, this is caused in particular by the high levels of background pollution. It also becomes clear that the various scenarios do not effect any great changes in the concentration of pollutants. For purposes of reducing benzene pollution the best solution seems to be the measures which are planned to strengthen local public transport. No statistically significant effect could be indicated for the planned measures on PM<sub>10</sub> concentrations.

## 5. DISCUSSION

The results of the calculation show that on the basis of the mean values for both NO<sub>2</sub> and benzene, it is not to be expected that the limits will be exceeded significantly. In the case of NO<sub>2</sub> hourly limits it must be expected that the limits will be exceeded on some roads where there is heavy traffic. Here the main advantage of the screening model becomes apparent. Closer studies involving greater time and cost will only have to be carried out at these few selected points.

The situation with regard to fine particulate matter pollution is very different. On all roads it is highly probable that the limits will be exceeded. Established reduction strategies will have to be tested for their application to the Trier area and their potential for reducing levels. In addition, to

create an effective improvement in air quality, further non-traffic sources must be identified in the region and their contribution to the overall pollution level needs to be quantified. The results of the various scenarios, (private traffic, public transport and optimised public transport) show that the targeted promotion and expansion of local public transport, with the resultant reduction in overall traffic volumes, can make a contribution to ensuring that the limits can be met

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