*Short Communication*

# Effects of Traffic on $NO_2$ and $PM_{10}$ Emissions in Novi Sad

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## Abstract

Traffic-related emissions depend on traffic volume, traffic flow composition, and fleet age, as well as urban housing density and meteorological conditions. Thus, software technology and high-quality (applicable) input databases are the key prerequisites for multidisciplinary and multiparameter analysis of the impact of traffic on air quality. A series of studies conducted in Novi Sad and the use of modern technology for data measurement and storage enabled improved assessment of the impact on air quality. This paper presents the simulation results pertaining to the influence of traffic on $NO_2$ and $PM_{10}$ emissions at the most heavily congested city streets, based on the surrounding housing and meteorological conditions in Novi Sad.

The results of this type of research have multiple benefits, including application in the development of air quality plans and testing environmental effects of different transport policy measures.

**Keywords:** traffic, urban street environment, meteorological conditions, pollution

## Introduction

Air pollution modeling has received increasing political attention in terms of development of emission abatement strategies, city planning measures, and the identification of human exposure to air pollution. Policy action based on modeling results requires accurate reproduction of the spatial and temporal distribution of air pollutants [1].

Research findings published in recent decades consistently indicate that outdoor air pollution is harmful to human health, and the empirical evidence reveals that traffic is an important contributor to air pollution [2-6]. One of the fundamental problems is the fragmentation of valuable natural areas caused by an abundance of high-traffic roads [7]. The present trend toward increasing traffic volume, and the associated risk of compromising air quality and health, threaten the policy objectives of many countries to achieve pollution levels that tend to decrease harmful effects on human health and the environment [5, 8]. In Europe, high particulate matter ($PM_{10}$) and nitrogen dioxide ($NO_2$) pollution is predominantly encountered in highly-populated areas, where these are recognized as the main contributors. The urban and local sources of $NO_2$ and $PM_{10}$ contribute to air pollution within street canyons in European cities by more than 60% and up to 50%, respectively [9]. An important source of $PM_{10}$ in urban areas is road transport, whereas $NO_2$ is a product of anthropogenic and natural combustion processes and chemical oxidation of nitrogen monoxide (NO). According to the extant study findings, traffic contributes to overall nitrogen oxide ($NO_x$) emissions by approximately 50%. Nitrogen dioxide ($NO_2$) is a very dangerous pollutant due to its high toxicity (nitrogen dioxide is about 4 times more toxic than nitrogen monoxide).

Stationary measurements are the basis of ambient air quality assessments. An integrated approach using both

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measurements and models enhances the quality of spatial information and allows the estimation of air pollutant concentrations in areas that are not covered by monitoring stations [10-12].

Air quality management requires the use of screening and advanced modeling tools capable of projecting roadside pollution levels under a variety of meteorological and traffic conditions. As traffic is the predominant pollution source in many cities, a significant number of models has been developed specifically for the evaluation of its effects on air quality in street canyons [13-16], as well as in a wider city area [17-20].

Dispersion models are employed in estimating the air quality in terms of the boundary values determined by appropriate standards and guidelines. Averaged annual and daily limits are imposed for the protection of human health from urban air pollutants [21]. In 2008 Mensink and Cesemans developed a model that was applied to the street network of the city of Antwerp and its $NO_2$ and $PM_{10}$ estimates were compared with the measurements obtained in 2003 from an urban monitoring station. The results of this validation exercise reveal a very good agreement, i.e. within 15% accuracy [22]. Similar research was conducted in an urban area in southwestern Luxembourg, the results of which indicate that the simulated annual mean $NO_2$ and $PM_{10}$ concentrations are in good agreement with the concentrations reported from the official monitoring location [11]. The results of $NO_2$ modeling on the Copenhagen territory indicated that the modeled concentrations were on average slightly higher than the measured concentrations, as well as that the agreement between the two was better in the rural areas than in densely populated (and thus more traffic-congested) urban areas [23].

Owing to the wide range of studies in significant areas and the implementation of modern technology for data measurement and storage, in Novi Sad, the key prerequisites have been met for the application of advances in software technology for modeling the effects of traffic on pollutant emission levels. This paper presents the simulation results pertaining to the effect of traffic on the $NO_2$ and $PM_{10}$ emission levels at the most heavily used city roads as a function of the pollution levels and meteorological conditions.

## Study Area

Street network development in Novi Sad has historically not accommodated the growing motorization trends, increasing travel demand and freight transport needs. Consequently, the results of the former traffic policies, whereby the problems were solved by stimulating private car usage, is evident in more frequent traffic congestion, life quality degradation in the city, increased pollutant and environmental noise levels, inadequate basic traffic safety elements, degradation of road and land quality, etc. According to the 2009 data [24], private car share (26%) in the overall daily travel distribution significantly exceeds that of public transport (22%).

Motorization levels in the city area is relatively low (250 PA/1000 inhabitants) in comparison with European cities of similar size. However, according to the traffic demand forecast study conducted in 2009 [25], in 2029, 133,000 vehicles will be registered in the same area, which is equivalent to 450 PA/1000 inhabitants. This increase of 64% corresponds to the 2.5% annual growth in the number of private vehicles. In the analyzed period, an increase in

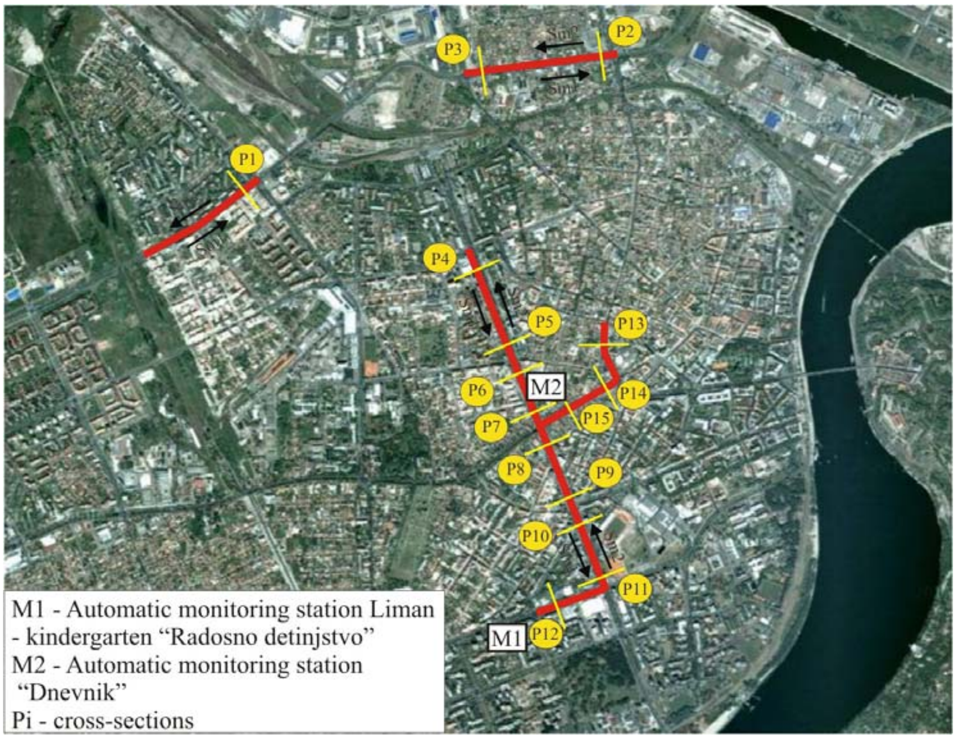


Fig. 1. Locations of the network sections, automated monitoring stations and cross-sections used for modelling.

resident mobility is also expected, and is projected to reach 3.0 trips (including walking) per day in 2029.

Based on the extant and expected changes in traffic demand, the key sections are identified (cross-sections – $P_i$) along the Novi Sad street network, where the data utilized in this work was collected and measurements conducted (Fig. 1).

Cross-sections P1-P3 are located at the city streets comprising the city transit road network, where freight vehicle traffic is permitted. Cross-sections P4-P15 are located on the main city transport routes and belong to the city center street network.

## Methodology

The methodology adopted in this work allows for the projection of annual mean $NO_2$ and $PM_{10}$ levels as a function of traffic and ambient conditions in the studied area. Input parameters consist of data obtained as a part of the NOSTRAM traffic study [24], which have been evaluated and supplemented by another study conducted in 2012, as well as data pertaining to land use and meteorological conditions. In order to obtain the most realistic estimates and calibrate the model for projecting the traffic effects on $NO_2$ and $PM_{10}$ pollutant emissions, mean annual pollutant levels, obtained in 2011 at automatic monitoring stations in (Fig. 1) [26], were used as simulation inputs. The most widely adopted modeling practice is based on using background concentrations obtained from measurements at urban locations that are not directly affected by local pollutant emission sources.

In addition to meteorological conditions, emission factors of the fleet and the measured $NO_2$ and $PM_{10}$ values sourced from two automatic monitoring stations, all other data collected by special surveys were further processed and adapted for calculation and simulation using the PROKAS software package.

The output of the data processing and preparation pertaining to the traffic intensity and composition within the city territory were:

- annual average daily traffic – AADT
- traffic flow composition (% freight vehicles)
- traffic conditions
- temporal distribution of the number of vehicles during the day

Emission factors pertaining to the pollution incurred by the fleet vehicles were obtained within the scope of the Twinning project. They were established based on the forecasted changes in the fleet composition for specific time intervals, i.e. years 2010, 2015, and 2020. The factors were generated from the Manual of Road Transport Emission Factors [27] and represent fleet emission levels (mg/s) depending on:

- vehicle type (personal and freight transport)
- road type (urban or rural, imposed speed limit, and typical traffic flow density)
- emission type (cold start, evaporation, or hot emission)
- fleet composition (forecast changes in the fleet composition across time intervals, motor types, motor capacity, fuel type, etc.)
- pollutant type ($NO_x$, $NO_2$, $PM_{10}$, etc.)

Georeferenced boundaries and information on building height were used for the calculation and selection of land use input parameters. Depending on the street profile shape (free, L or U profile), the building height/profile width ratio, and the percentage of the openings between the buildings, the street network sections were classified as typical profile types (e.g., type 201 – U profile, with the building height/profile width ratio = 1/3, and up to 20% gaps).

Data obtained at the automatic monitoring station M1 (Fig. 1) used for measuring the air quality in Novi Sad was used as input (flow) for the simulation of the impact of traffic on $NO_2$ emissions. Monitoring Station 1 is located in a residential area of the city and away from the busy city streets. It was assumed that the measured pollutant concentrations at the sampling points where traffic is not the primary contributor represent the effect of other sources of pollution in the city (heating, industry, etc.).

Measured annual average $NO_2$ value, which served as a benchmark for assessing the concentration increases as a result of traffic, is 19.9 μg/m$^3$ [26]. For the 98 percentile value, 55 μg/m$^3$ was adopted, which exempted the measurements in which extremely high values were recorded. Since the M1 monitoring station does not take $PM_{10}$ measurements, for this pollutant an average annual value of 20 μg/m$^3$ was adopted as a basis for assessing the impact of traffic.

This value is proposed on the basis of the field data obtained at other automated stations in Serbia located in urban areas and away from the city's main streets. Data from monitoring station M2 (Fig. 1), located in the vicinity of the main city centre street characterized by extremely high traffic volumes, was used to compare the simulation and calibration outputs.

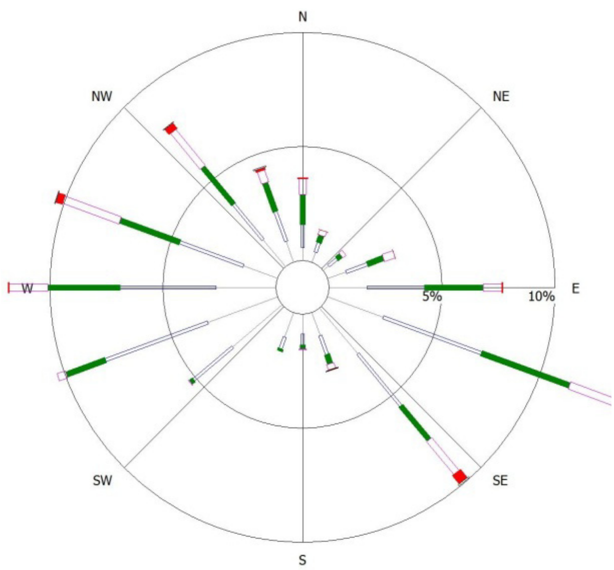


Fig. 2. Annual wind distribution for Novi Sad, Serbia (%).

Table 1. Traffic volumes and pollutant levels for all cross sections used in modeling.

| | AADT (vehicle per day) | GV+BUS (%) | $PM_{10}$ μg/m³ | $NO_2$ μg/m³ | $NO_2$– 98 percentil μg/m³ |
|---|---|---|---|---|---|
| P1 | 29,858 | 15.37 | 37.0 | 56.8 | 123.5 |
| P2 | 29,829 | 25 | 36.9 | 64.4 | 136.2 |
| P3 | 30,470 | 20.62 | 36.0 | 63.1 | 136.0 |
| P4 | 36,928 | 10.18 | 29.1 | 47.5 | 99.8 |
| P5 | 39,810 | 7.76 | 29.6 | 48.3 | 100.7 |
| P6 | 44,254 | 7.66 | 29.6 | 48.3 | 100.8 |
| P7 | 47,343 | 6.34 | 31.0 | 51.3 | 104.1 |
| M2 | | | 45 | 61.7 | |
| P8 | 43,175 | 5.16 | 28.6 | 45.8 | 96.3 |
| P9 | 40,528 | 5.7 | 28.2 | 44.9 | 95.3 |
| P10 | 40,216 | 5.53 | 28.1 | 45.1 | 94.7 |
| P11 | 37,460 | 6.05 | 27.9 | 44.6 | 95.5 |
| P12 | 33,396 | 6.3 | 29.6 | 42.6 | 93.9 |
| P13 | 31,079 | 10 | 20.3 | 47.4 | 99.0 |
| P14 | 27,398 | 9 | 29.6 | 51.0 | 107.4 |
| P15 | 28,255 | 6.92 | 31.1 | 51.3 | 107.3 |

AADT – annual average daily traffic, GV – goods vehicles, BUS – buses

Meteorological conditions were demonstrated through the weathervane, based on data provided by the Republic of Serbia Hydrometeorological Service for 2009. Meteorological condition data are provided for 365 days at hourly intervals and include wind speed and direction, temperature, relative humidity, and cloud cover (Fig. 2).

## Results

The greatest traffic volume (AADT) during the day is recorded on the cross-sections of P6 and P7 (Bulevar Oslobodjenja). On the same section, the greatest number of heavy vehicles (buses) is noted in relation to the rest of the Boulevard (Table 1).

The cross-sections P1, P2, and P3 (Kornelija Stankovica and Partizanska streets) are characterized by lower traffic volumes and a significantly higher share of freight vehicles in comparison to the rest of the network. These conditions are explained by the fact that part of the street network comprising the selected sections belongs to the transit roadway on which freight vehicle traffic is permitted.

According to the data recorded at the automated stations for air quality control in Serbia [26], the greatest annual average $NO_2$ concentration was recorded at the M2 station in Novi Sad. Hence, data from this location was used for calibration of the modeled values, whose comparison yielded the difference of approximately 17% (the modeled 51. 3 μg/m³ $NO_2$ was compared to the recorded 61.7 g/ μg/m³ $NO_2$). Calculated (simulated) annual mean concentration values for each section are shown in Table 1.

In all sections included in the pollutant modeling in Novi Sad, the average annual $NO_2$ value exceed the 40 μg/m³ threshold, imposed by the Republic of Serbia Directive on Air Quality Monitoring Conditions and Requirements [28]. The highest modeled value of this pollutant has been recorded along Partisan street (sections P2 and P3), characterized by a high share of freight vehicles (about 25%) in the traffic flow composition.

On the same transit road, the highest values of the modeled annual mean $PM_{10}$ concentrations were also recorded. In contrast to the output of the simulation results pertaining to the $NO_2$ concentrations, the simulated $PM_{10}$ values revealed that the limit of 40 μg/m³ was not exceeded in any of the observed sections [28]. Comparison of the model results and the values recorded at the monitoring station M2 (i.e., 31 μg/m³ vs. 45 μg/m³ $PM_{10}$) indicates a greater variation in the results obtained for $NO_2$. The values recorded at the M2 monitoring station indicate breaches of the limit and tolerance values of $PM_{10}$ [26].

Fig. 3 shows a portion of the simulation results on the part of the street network characterized by a high participation of freight vehicles in the traffic flow composition (section P1). Reduction in the pollutant concentrations in the studied section is anticipated to occur with the completion of the ring road around Novi Sad and the relocation of the transit traffic of freight vehicles outside the area intended for housing.


Fig. 3. Visual presentation of modeling results.

## Conclusions

The methodology applied in this work indicates that, based on the data from only two automatic stations for air quality control, the impact of traffic on the pollutant emissions throughout the street network can be estimated as a function of land use indicators (street profile width, building height, and distance between objects) and meteorological conditions.

A simple evaluation of the base case shows that the simulated annual mean $NO_2$ concentrations are in good agreement with the values reported from the official measurement locations and the model is able to predict urban-scale annual average air pollution. The achieved model error for $NO_2$ annual mean concentrations was 17%, which complies very well with the required accuracy standards (30%) given by the European Directive and the Republic of Serbia Directive on Air Quality Monitoring Conditions and Requirements. The obtained results are also in good agreement with the values reported by other authors [21-23], indicating that, with more accurate initial values, better simulation of $PM_{10}$ and other pollutant emissions can be obtained. According to the same directives, the maximum feasible model error of $PM_{10}$ annual averages (50%) [1] is met by the model with a value of 31%. Greater deviation can be justified by the unreliable (assumed) initial values, i.e. input data used in $PM_{10}$ simulation. More reliable results of modeling the traffic impact on the level of $NO_2$ emissions indicate that, even in $PM_{10}$ modeling, lesser variations can be achieved by the inclusion of additional calibrations and more accurate input parameters.

The importance of the research presented in this paper lies in the potential application of the obtained results in several different directions, from air quality monitoring and analysis in urban areas, where traffic is one of the dominant pollutant sources, to the development of air quality plans and testing the transport policy effects. Along Bulevar Oslobodjenja (sections from P4 to P11), as the city's busiest street, the established transport regime prohibits heavy vehicle traffic. Thus, potential solutions to the air pollution problem should be based on the implementation of other transport policy instruments.

In addition to renewing the fleet and increasing the share of "clean" vehicles, the focus should primarily be on measures that would reduce the use of cars and the redistribution of travel to other forms of environmentally friendly transport (public transport, cycling, walking). Quality databases and the availability of modern software technologies enable testing the effects of different transport policy instruments at the pollutant emission level and defining the strategy of sustainable urban transport and the overall system.

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