MEASUREMENTS AND MODELING POLLUTION FROM TRAFFIC IN A STREET CANYON
Assessing and Ranking the Influences

by

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More than half a century, the scientific community is trying to understand the mechanisms and conditions of pollution dispersion within urban areas. Thereat, special attention has been focused on specific areas, such as a street canyon, in which harmful concentrations higher than allowed are more likely registered. However, there is still a controversy about the conditions of occurrence and impact of the individual air pollution components due to fluctuations of key contributions. Given that OSPM is a well-known semi-empirical model specializing in the assessment of air quality within a street canyon. After its testing and validation, the results of subsequent simulations were used as a basis for planning a special experiment in order to implement 48 full factorial designs. Using the response surface methodology, as the final objective, an answer was precisely given on the impact and contribution of urban air pollution components. In addition to the main objective of this study, as a secondary, but not less important result defining emission factors for CO and NO_x *can be emphasized, which to date have not been determined for the fleet of Serbia.*

Key words: *vehicle emission, street canyon, COPERT, OSPM*

Introduction

Urban areas are not seen as a homogeneous entities, and the largest air pollution concentration occur in the streets canyons. A street canyon is generally a basic geometric unit of urban labyrinth of the city center at most, *i. e.* relatively narrow street lined on both sides with the buildings along the roadway [1]. Given that in such environments emission dispersion occurs in relatively isolated areas and in the vicinity of vehicles, modeling can explain the processes at the level of the street [2]. Also, it is necessary to better understand the influence of meteorology, city topography, background air pollution, and direct contribution from vehicles emissions. Further, the turbulence of traffic flow is an additional mechanism of emission dispersion, *i. e.* plays an important role in the fluctuations of harmful concentrations values.

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Although recent studies combine experimental work and mathematical modeling to date the rank of single and combined impact of the previously mentioned components of urban air pollution has not been determined and whether and how it fluctuates depending on changes in one or several components simultaneously.

One of the most commonly used methodologies for modeling vehicle emission in the European context is COPERT methodology [3]. Lots of laboratory data was statistically processed within COPERT project which has resulted that the emission, *i. e*. the emission factors can be expressed as a function of vehicle speed. On the other hand, the semi-empirical OSPM is precisely specialized in the assessment of air pollution within the canyon streets, where vehicle emissions are modeled using COPERT methodology. Therefore, if the OSPM model assessments were correct, using the deduction method it is possible to get realistic emission factors of certain harmful substances for the fleet of Serbia at a cheap and affordable way, for the definition of which it would otherwise be necessary to provide expensive equipment, considerable financial resources, conduct complicated measurement methodology, and it would take a lot of time.

Velickovic *et al*. [4] has used COPERT method to the case of the city Novi Sad, Serbia, using available literature data, but there have not been adequate measurements required for exactly application of this method (*e. g*. not determined emission factors).

Traffic modelling on a street network gives a possibility to simulate environmental indicators of noise and air pollution by network sections, generated by the use of passenger cars [5].

Aim of the paper is assessment and ranking of the influence of vehicle pollution in street canyons. Determination of emission factors for the fleet of Serbia for COPERT method and their experimental verification by measuring input parameters such as: average driving speed, traffic flow, and the air quality in Kraljevo city are also important aims of the paper.

Materials and methods of experimental research

In order to test and validate the OSPM, it is necessary to select the harmful substances for analysis. The first is CO, *i. e*. an inert compound for which the chemical transformations within a street canyon are irrelevant. This is particularly important because vehicles with spark-ignition engine are the main source of CO in a street canyon [6], and due to a very short distance between the source and the receptor, only very rapid chemical reactions have a significant impact on measured concentrations [7]. On the other hand, if the CO is an inert gas, such characteristics do not characterize NO_x, *i. e*. mostly the mixture of NO_2, which quickly breaks down due to photochemical reactions, and NO, which rapidly reacts with ozone (creating a secondary NO_2) [8]. The NO_2 can also be transmitted directly from the exhaust system (primary NO_2), with the largest emissions associated with Diesel engines [9]. That is why the different characteristics of origin and time of existence pointed out CO and NO_x as the most suitable for analysis.

Measuring the concentrations of CO and NO_x was conducted by the City Institute of Public Health, Belgrade, which is part of the Center for Hygiene and Human Ecology and the National Laboratory for Human Ecology and Ecotoxicology of the Republic of Serbia. Methods of testing or sampling concentrations in the air are consistent with the following national-standards: (1) EN 14211 (standard method for measuring the concentration of NO_2, NO, and NO_x), (2) EN 14625 (standard method for measuring the concentration of ozone), (3) EN 14626 (standard method for measuring the concentration of CO), and (4) EN 14662-1 (standard method for determining the concentration of benzene).

Sample concentration in the air is harmonized with European directives on air quality (EC Air Quality Directives): (1) EU Directive 1999/30/EC (sampling of SO_2 and NO_x), (2) EU Directive 2000/69/EC (sampling of CO and benzene), and (3) EU Directive 2002/3/EC (sampling of ground-level of ozone).

Equipment used for registering the concentrations of CO and NO_x belong to first class of world-renowned apparatus for measuring air quality of an ambient environment. The data are read in real time, automatically on a digital display, whereat they are stored in the database for archiving and processing results. The necessary equipment consisted of the following apparatus: (1) automatic analyzer for CO, model APMA – 360 HORIBA, (2) automatic analyzer for NO_x, model APHA – 360 HORIBA, (3) automatic analyzer for ground-level of ozone, model APOA – 360 HORIBA, (4) eight channel device for air sampling AT 801H PROEKOS, and (5) gas chromatograph AGILENT 7890 with thermal desorption GERSTEL TDS 3.

For the street to be accepted in order to implement the experiment the following criteria had to be met: (1) sufficient length of the street to develop and maintain the maximum allowable speed of the vehicle, (2) traffic flow has to be unobstructed, except in the intersection area, (3) the high prevalence of passenger cars in the structure of traffic flow, (4) the street must be of two-way traffic regime, and (5) from one side and the other side of the street there have to be high buildings forming the shape of the canyon with their dimensions.

All of the above criteria are fulfilled by Dimitrija Tucovića street (DT) (state road second order *i. e.* a part of European Corridor E-761 and highway M5) in Kraljevo city with the measured length of the section of 305 m. Each of the traffic directions is composed of two lanes, with directions separated by traffic island. Also, the proximity to the bus station has further influenced the choice of the street, as alleged share of public transport vehicles can significantly contribute to increased concentrations of harmful substances to be assessed by the OSPM. Measuring of CO and NO_x concentration was carried out for a period of seven days, continuously from 06:00 a. m. to 05:00 p. m.

If the measurement position is considered, some researchers, such as Vardoulakis *et al.* [10] specify that the measurement height should be between 1.5 m (the height at which people breathe) and 4 m, not less than 25 m from the main intersections, and 4 m from the middle of the nearest traffic lane. For NO_x and CO, the place of measurement should be less than 5 m from the sidewalk curb. In the case of our experiment, height measurement was 3.5 m, while the distance from the nearest intersection was 30 m. As for the measurement and the distance from the curb, the mentioned distance is less than 5 m and at the limit of 4 m from the middle of the nearest traffic lane.

Figure 1 show DT street, the position of specialized vehicle for air quality sampling, position of automatic station for monitoring air quality and meteorological parameters and measuring equipment for recording air quality and speed of vehicles in the traffic stream. Given that OSPM is a semi-empirical model, meteorological data, and air pollution data from the background environment are essential for its operation where the most reliable information can be provided by automatic stations. The Government of Serbia in 2009 granted a license for a project of the Ministry of Environment and Spatial Planning and the Agency for Environmental Protection on automatic monitoring of air quality. Twenty-eight stations of such organized networks were deployed in 23 towns of Serbia and one of these is Kraljevo city (the program: EuropeAid/124395/D/SUP/YU Supply of Equipment for Air Monitoring). The measurement results in this automatic station were used as input data necessary for OSPM in order to define the necessary input parameters.

Figure 1. (a) DT street, (b) the specialized vehicle for measuring air quality, (c) and (f) the speed measuring equipment, (d) location of automatic measuring stations (drop with a dot and junction 1 (1) and junction 2 (2)), (e) part of air quality measuring equipment within specialized vehicle

The average driving speed is one of the most important inputs in the COPERT model where there is no standard procedure for its registration that is associated with the measurement of ambient air quality. In the case of our experiment measuring the speed of vehicles was realized by first class device, *i. e.* ProLaser III, which was until recently used by traffic police of the Republic of Serbia. The position of the operator during the measurement procedure was less than 8°, while the measurement distance was 25 m in DT street (fig. 1 c and fig. 1 f). In that case, according to the specification of the measuring device the error of registered results could be 1% and 0.5% respectably.

During the measurement of traffic flow a total of 81,184 vehicles were registered. The technique of manual continuous monitoring was applied during the period from 6:00 a. m. to 05:00 p. m. (in order to review 3 peak traffic periods, *i. e.* from 06:30 a. m.to 08:00 a. m., 11:00 a. m. to 01:00 p. m. and 02:30 p. m. to 04:00 p. m.). Each registered vehicle is classified into one of five categories, namely: (1) passenger vehicle (PV); (2) light truck vehicle (LTV); (3) heavy duty vehicle 1 (HDV1) (<32 t), (4) heavy duty vehicle 2 (HDV2), (>32 t) and (5) bus.

Theoretical study material and methods

In the experimental study of the process for its mathematical modeling, it is necessary to adopt a number of measured variables (k). Thereat it is always better to take a variable more, since their importance (significance) is easily revealed in the process of research.

The omission of important variables could affect the accuracy and reliability of the results. In order to evaluate and rank the impacts of individual independent variables (predictors) on the value of CO and NO_x concentration a full factorial experiment of type $N = 2^k$ was applied. Boundary conditions of variables x_i are defined by the previous testing of their distribution laws for adopted in advance probability $P = 95\%$ *i. e.* for the risk of 5%.

Full factorial design experiment type $N = 2^k$ for a certain series of experiments was realized with simultaneous variation of factors that contribute to CO air concentration [$mg \cdot m^{-3}$]

and NO_x air concentration [$\mu g m^{-3}$]. The estimated number of factors should be minimized, but with the activity of which, to a large extent, the precise concentration value can be determined. That is why four factors were singled out: the first factor for traffic flow variable – x_1 [$veh \cdot h^{-1}$], the second factor for background wind speed variable – x_2 [$m \cdot s^{-1}$], the third factor for background wind direction variable – x_3 [°] , and the fourth factor for the background environment CO [$mg \cdot m^{-3}$], or NO_x [$\mu g \cdot m^{-3}$], the concentrations variables – x_4 . It is necessary to emphasize that the goal is not to find the optimum operation of the process, but to determine the influence of linear factors x_1, x_2, x_3, and x_4 and their interactions on the dependent variables CO and NO_x.

To analyze the impact of factors x_1, x_2, x_3, and x_4 on the dependent variables CO and NO_x the Response Surface Methodology (RSM) was used [11]. The evaluation and ranking of the percentage impact of each factor were performed by the methodology for Selection of Multi-factor Linear Regression Model based on the Total Effect (SMLRM-TE) [12].

Within RSM for the Design of Experiment (DoE) the Full Factorial Design (FFD) was used. A complete computer data processing was realized by means of a computer program for Choice of Regression Equations of Multifactor Experiment Design with and without repeating (CoREMED) [13].

Discussion and analysis of experimental results

During the experiment of measuring the vehicles speed a total of 1044 samples was registered. The speeds are measured separately by category of vehicle and the direction of movement, and for the purposes of valid input values of COPERT methodology the mean value were adopted. Presented by vehicle categories, the adopted medium speeds are: PV (38 kmh^{-1}), LTV (36 kmh^{-1}), HDV1 (32 kmh^{-1}), HDV2 (30 kmh^{-1}) and Bus (34 kmh^{-1}). Meteorological data on the speed and winds flow direction from the back, ground environment were collected daily during the experiment.

Comparative analysis of measured and modeled values of CO and NOx concentration was conducted using eight statistical indicators [14] and the results are presented in tab 1. The ideal model would have (MG, VG, FAC2, R, IA) = 1, and (FB, NMSE, NRMSE) = 0. However, the acceptable limits of FB are ±30%, and then at least 50% of the modeled values have to be less than twice the measured values (FAC2). However, linear indicators FB and NMSE behave quite unstable on the occurrence of large fluctuations so that the logarithmic statistical parameters MG and VG are then much more stable. On the other hand, MG and VG are sensitive to small values which are generally the case at atmospheric conditions. It should also be emphasized that the FAC2 is the most robust indicator considering that it is not affected by markedly extreme values.

Table 1. Statistical indicators and agreement between measured and modeled concentration

Pollutant	Statistical indicators (acceptable agreement)							
	Fractional bias ($\vert FB\vert <0.3$)	Geometric mean bias ($0.7<MG<1.3$)	Normalized MS error ($NMSE<4$)	Normalized root MS error ($NRMSE<3$)	Geometric variance ($VG<1.6$)	Fraction of two ($FAC2>0.5$)	Index of agreem. IA	Pearson's corr.coeff R
CO	0.034	1.034	0.095	0.308	1.101	1.035	0.825	0.783
NO_x	0.334	1.24	0.215	0.463	1.427	0.714	0.825	0.833

Figure 2 shows the agreement of mean modeled and measured values, while the bars represent the standard deviation of 5% for statistical error within the population. The fig. 2

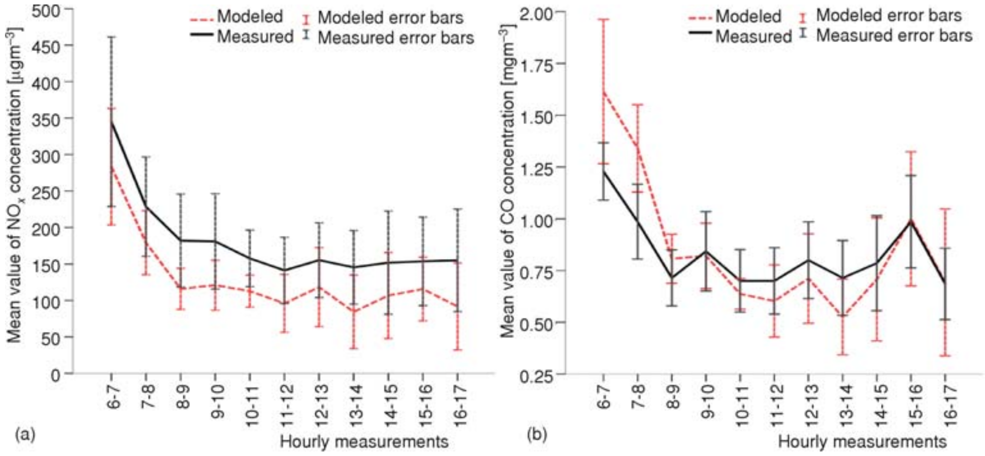

Figure 2. Comparative analysis between measured and modeled CO and NO$_x$ air concentration

shows clearly apparent trends of monitoring modeled and measured values of NO$_x$ and CO air concentration. Analyzing them separately, it is noticeable that the OSPM constantly monitors and underestimates the measured values of NO$_x$ air concentration fig. 2(a).

Analysis and interpretation of comparative results of CO air concentration is much more complex fig. 2(b), so it is necessary to adopt a parameter that includes all possible values of the traffic flow, and that doing so it does not depend on the percentage of cold starts engines which again strongly affects the CO emission. Therefore, it is better to present modeled and measured CO air concentrations according to real and theoretical maximum capacity of the street segment.

The theoretical maximum capacity of a movement at traffic signals [15] can be calculated:

$$K_i = \frac{S_i z_i}{C} \tag{1}$$

where S_i is the adjusted saturation flow *i* signal groups; z_i – the effective green length *i* signal groups, and C – the cycle length of intersection with traffic lights.

In the case of experimental section of DT street, the theoretical maximum capacity ($K_{\max}$) depends on the outgoing traffic flows between two streets intersections: (1) Vojvode Putnika (VP) and DT (junction 1) and (2) Hajduk Veljko (HV) and DT (junction 2). Using the method of the critical flow [16] operating cycles of junction 1 (85 s) and the junction 2 (100 s) a green intervals were calculated. Finally, $K_{\max} = K_{\mathrm{I}} + K_{\mathrm{II}} = (K_{1.1} + K_{3.2}) + (K_{3.1} + K_{3.2} + K_{2.2} + K_{4.1}) = 1.795$ veh·h^{-1}, and its percentage utilization in the days of measurements is presented in fig. 3.

It is clear that during utilization $K_{\max} \geq 60\%$, the OSPM underestimates the CO air concentration, and in the case $K_{\max} < 60\%$, CO air concentration is overestimated.

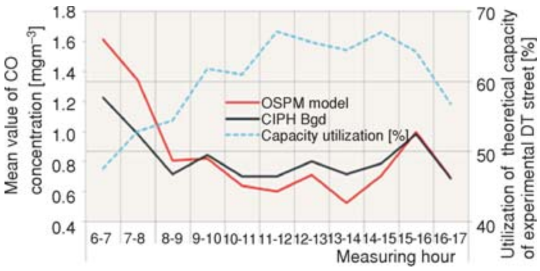

Figure 3. Relationships between measured (CIPH Bgd) and modeled (OSPM) values of CO concentration and utilization of $K_{\max}$ of DT street

To start the analysis with full factorial design, it is necessary to define the boundary conditions of variables. It is necessary to examine the laws of the hourly distribution of registered meteorological data and recorded traffic flow, *i. e.*: (1) background concentrations of CO and NO_x, (2) the speed of background winds, and (3) the traffic flow.

Checking the adequacy of the distribution law was performed using the Kolmogorov-Smirnov goodness of fit test [16]:

$$\max|\Delta F_i| = \max_{-\infty<x<\infty} |F_{i(x)} - F_{t(x)}| \leq \frac{\lambda_\alpha}{\sqrt{n}} \tag{2}$$

where $F_{i(x)}$ is the empirical distribution function, $F_{t(x)}$ – the cumulative distribution function, n – the number of samples, λ_α – the critical values of the Kolmogorov-Smirnov test (we arbitrarily chose $\alpha = 0.05$ for our significance level).

Table 2 presents the empirically determined distribution laws with proven adequacy for probability of $P = 0.95$. It is necessary to note that the direction limits of background wind flow are adopted for the prevailing directions, *i. e.* in the area between the west and north.

Table 2. Distribution laws with defined boundaries

Predictor	max $\|\Delta F_i\|$	$\lambda_\alpha/(n)^{1/2}$	Selected distribution	Boundaries	
				Bottom	Upper
Background NO_x, [μgm^{-3}]	0.048	0.155	~LN (2.314; 0.559)	3.41	46.296
Background CO, [mgm^{-3}]	0.039		~LN (–1.862; 0.165)	0.1076	0.2451
Background wind speed, u_b, [ms^{-1}]	0.085		~LN (–0.334; 0.295)	0.14	2.04
Traffic flow, q, [veh·h^{-1}]	0.046		~N (1072.34; 183.53)	638	1415
Background wind direction, Θ, [°]	–	–	–	270°	360° or 0°

The matrix of the process of full factorial design of experiment type $N = 2^k$ is used to denote two levels (+1, –1) (representing the experimental area shown in the last two column of tab. 2). It must be noted that the response functions are obtained in special experiments with new CO and NO_x concentration values determined by OSPM . The value of the free member β_0 in the regression equation is fictitious estimate of vector x_0 in the matrix of full factorial design process. The number of rows in the matrix is determined by the number of experiments N. Using the design of experiment type $N = 2^k$ in our case for $k = 4$ predictor (factor), the number of experiments is 16.

On the basis of the calculated regression factors $\beta_0, \beta_i, \beta_{ij}, \beta_{ijk}$, and β_{ijkl} and on the basis of the SMLRM-TE methodology calculated the percentage share of all the parameters of the regression was calculated $\beta_0, \beta_i, \beta_{ij}, \beta_{ijk}$, and β_{ijkl} (tabs. 3 and 4).

After reviewing the results in tabs. 3 and 4, the predictor (factor) background wind speed, at stable atmospheric conditions ($u_b \leq 2$ ms^{-1}), is a key factor influencing the value of the concentration of harmful substances in a street canyon. The second is the impact of the traffic flow.

To eliminate all dilemmas on the size of influence of selected factors and their aggregate effects, wind direction is divided into four sectors (West-North, North-East, East-South, and South-West), and the background wind speed was expanded by a step of 0.5 ms^{-1} to the value of 3 ms^{-1}. Additionally, every sector had varied wind speed, while other factors, according

Table 3. Ranking and selection factors of the CO concentration

No.	Regression factors β_0, β_i, β_{ij}, β_{ijk}, β_{ijkl}	Ranking factors	Sum of squares	F_{test}	Significant	R^2	TE factors	β_0, β_i, β_{ij}, β_{ijk}, β_{ijkl} [%]
1.	$\beta_0 = 0.90789659$	–	16.48552	70.72731	–	–	–	–
2.	$\beta_1 = 0.18873165$	2	0.56991	2.44508	Significant	0.78396	0.1794	17.94
3.	$\beta_2 = -0.38257055$	1	2.34176	10.04679	Significant	0.63051	0.2974	29.74
4.	$\beta_3 = -0.11094343$	4	0.19694	0.84490	Significant	0.89083	0.1528	15.28
5.	$\beta_4 = 0.06871501$	5	0.07555	0.32412	Significant	0.91117	0.0972	9.72
6.	$\beta_{12} = -0.06517960$	6	0.06797	0.29163	No signific.	0.92947	0.0486	4.86
7.	$\beta_{13} = -0.02991118$	8	0.01431	0.06141	No signific.	0.93724	0.0347	3.47
8.	$\beta_{14} = 0.00000001$	9	0.00000	0.00000	No signific	0.93724	0	0
9.	$\beta_{23} = -0.11180168$	3	0.19999	0.85803	Significant	0.83781	0.1529	15.29
10.	$\beta_{24} = 0.00000001$	9	0.00000	0.00000	No signific.	0.93724	0	0
11.	$\beta_{34} = -0.00000001$	9	0.00000	0.00000	No signific.	0.93724	0	0
12.	$\beta_{123} = -0.03014843$	7	0.01454	0.06239	No signific.	0.93339	0.0348	3.48
13.	$\beta_{124} = 0.00000001$	9	0.00000	0.00000	No signific.	0.93724	0	0
14.	$\beta_{234} = -0.00000001$	9	0.00000	0.00000	No signific.	0.93724	0	0
15.	$\beta_{1234} = -0.00000001$	9	0.00000	0.00000	No signific.	0.93724	0	0
16.	Error (residual vari.)	–	0.23309	–	–	–	0.0021	0.21

Table 4. Ranking and selection factors of the NOx concentration

No.	Regression factors β_0, β_i, β_{ij}, β_{ijk}, β_{ijkl}	Ranking factors	Sum of squares	F_{test}	Significant	R^2	TE factors	β_0, β_i, β_{ij}, β_{ijk}, β_{ijkl} [%]
1.	$\beta_0 = 128.52789050$	–	330,388.372	75.5362	–	–	–	–
2.	$\beta_1 = 26.33223750$	2	11,094.1877	2.53645	Significant	0.7290	0.1592	15.92
3.	$\beta_2 = -54.10760750$	1	46,842.1310	10.7094	Significant	0.5894	0.2701	27.01
4.	$\beta_3 = -15.68561250$	4	3,936.6150	0.90002	Significant	0.9214	0.1441	14.41
5.	$\beta_4 = 21.44299750$	3	7,356.8343	1.68198	Significant	0.8215	0.156	15.6
6.	$\beta_{12} = -9.04076250$	6	1,307.7662	0.29899	Significant	0.9378	0.0452	4.52
7.	$\beta_{13} = -4.17975750$	8	279.5260	0.06391	Significant	0.9449	0.0337	3.37
8.	$\beta_{14} = 0.00000250$	9	0.00000	0.00000	No signific	0.9449	0	0
9.	$\beta_{23} = -15.80701250$	5	3,997.7863	0.91401	Significant	0.8718	0.1341	13.41
10.	$\beta_{24} = -0.00000250$	9	0.00000	0.00000	No signific.	0.9449	0	0
11.	$\beta_{34} = 0.00000250$	9	0.00000	0.00000	No signific.	0.9449	0	0
12.	$\beta_{123} = -4.21290750$	7	283.9774	0.06493	Significant	0.9414	0.0339	3.39
13.	$\beta_{124} = 0.00000250$	9	0.00000	0.00000	No signific.	0.9449	0	0
14.	$\beta_{234} = 0.00000250$	9	0.00000	0.00000	No signific.	0.9449	0	0
15.	$\beta_{1234} = -0.00000250$	9	0.00000	0.00000	No signific.	0.9449	0	0
16.	Error (residual vari.)	–	4,373.9073	–	–	–	0.0237	2.37

to the experiment design, were taking the max or min values. In such a way, a total of 48 full four factorial design were completed. Thereat also conducted was multiple criteria evaluation of influential independent variables according to the criteria of changes in direction and background wind speed.

Overall results are presented in figs. 4 and 5, for the modeled concentrations of CO and NO_x respectively. Also it must be noted that there are presented only significant individual and joint factors influences with average impact values above 10%.

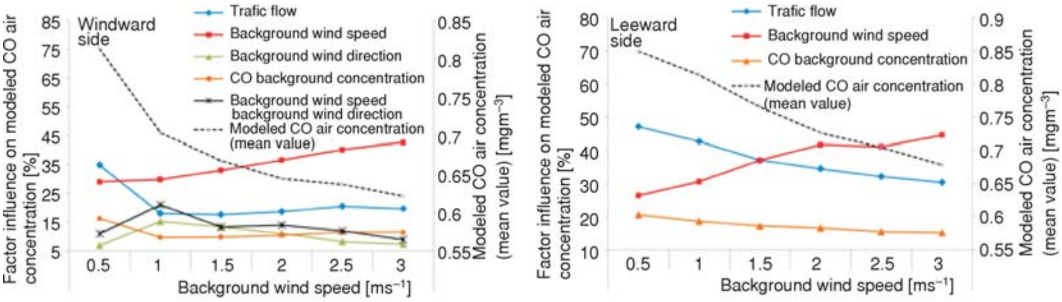

Figure 4. Factors influence on modeled CO air concentration in a street canyon

Analyzing the results presented in fig. 4 and fig. 5, the conclusion is that the traffic flow has the greatest impact on the value of the concentration of CO and NO_x in the windward side of a street canyon where u_b is up to 0.6 ms^{-1}. The traffic flow, also, has the greatest impact on value of CO and NO_x concentration on the leeward side of a street canyon where u_b is up to 1.5 ms^{-1}. From the above values onwards, the impact of u_b becomes dominant factor obviously creating conditions for a vortex formation (recirculation contribution). This confirms the theory of some scientists, such as Berkowitcz *et al.* [7], Hertel and Berkowicz [17], Murena *et al.* [18] or DePaul and Sheih [19] that the contribution of the third component of a street canyon concentrations, or re-circulation contribution (C_r), should appear at u_b ~1.5-2 ms^{-1}, except that now, by multi-criteria analysis, precisely defined stricter limits of 1.5 ms^{-1} and at the same time the percentage impact of single and combined factors (independent variables) was ranked.

However, one should not forget that OSPM validation studies did not exceed the value of R^2 = 0.89 (a street canyon without sides gap and geometrical ratio H/W = 1.1) [7], which

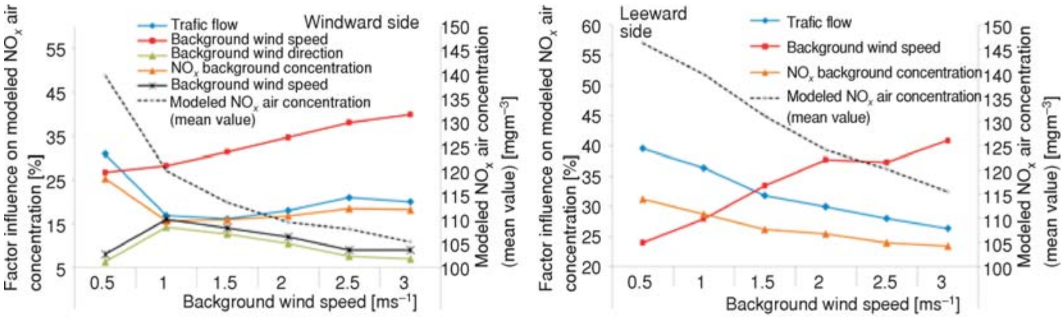

Figure 5. Factors influence on modeled NO_x air concentration in a street canyon

means that 11% variations in the modeled concentration is still unknown and is not covered by theoretical concepts and/or relationships in the model.

Given that the assessments of OSPM were correct (tab. 1), it is possible to get a realistic emission factors for CO and NO_x of the Republic of Serbia fleet using deduction method. In all studies to date, the values of these quantities are adopted as recommended by the IGB (2009) [20] for the Western Balkans countries. Table 5 presents the values obtained.

Table 5. The old IGB (2009) – Tier 2 method and new COPERT – Tier 3 method values of emission factors for air concentration CO and NO_x of the Republic of Serbia fleet

		Emission factor [gkm^{-1}]				
		PV	LTV	HDV1	HDV2	Bus
CO	IGB (2009) (Tier 2 method)	4.407	3.081	1.554	1.554	3.98
	COPERT (Tier 3 method)	7.145	2.364	3.338	2.816	3.266
NO_x	IGB (2009) (Tier 2 method)	0.802	1.181	7.292	7.292	13.059
	COPERT (Tier 3 method)	1.552	1.327	7.164	13.957	10.938

Note: IGB – Inventory guide book (EMEP/EEA 2009) [20]

Conclusions

It is obvious that OSPM has certain shortcomings in the accuracy of the estimated CO and NO_x concentration, and the following suggestions are being imposed in order to adapt the model of the adopted air quality assessment: (1) the adopted speed of traffic flow must be measured as accurately as possible and separately for each hour, (2) it is necessary to estimate as accurately as possible the number of vehicles without catalytic converter or the ones with the older technology of reducing harmful emissions, (3) in the hours when the theoretical capacity utilization is greater than 60%, it is necessary to increase the percentage of cold started engines, so that the air concentration CO estimate would be more correct.

The newly established EF are obtained by the method of deduction, *i. e.* knowing the final value of modeled CO and NO_x concentration, COPERT methodology has enabled us to define a real EF on the sample of Serbia fleet. By interpolating EF, according to technology of harmful emissions reduction with the number of vehicles of each technology, the integrated EF were obtained, where as the basis for unifying the recommended EF were used from the air pollutant emission inventory guidebook by Tier 2 method. It is important to emphasize that (unlike Tier 3 method used by COPERT program) the correction terms do not apply to them due to emission degradation (due to the total mileage of vehicles), the emission correction due to hot and cold emission relationship and there is no defined impact of reformulated fuels.

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Nomenclature

$F_{i(x)}$ – empirical distribution function, [–]
$F_{t(x)}$ – cumulative distribution function, [–]
C_r – third component of a street canyon pollution conc. (re-circulation contribution), [–]
k – number of measured variables, [–]
K_i – theoretical maximum capacity of a movement at traffic signals, [$veh \cdot h^{-1}$]
K_I – maximum capacity of a movement at traffic signals for junction 1, [$veh \cdot h^{-1}$]

K_{II} – maximum capacity of a movement at traffic signals for junction 2, [veh·h^{-1}]
$K_{\max}$ – theoretical maximum capacity between junction 1 and junction 2, [veh·h^{-1}]
$\sim LN$ – lognormal distribution, [–]
N – number of experiments, [–]
$\sim N$ – normal distribution, [–]
n – number of samples, [–]
q – traffic flow, [veh·h^{-1}]
u_{b} – background wind speed, [ms^{-1}]
x_1 – the first factor for traffic flow variable, [veh·h^{-1}]
x_2 – the second factor for background wind speed variable, [ms^{-1}]
x_3 – the third factor for background wind – direction, [°]
x_4 – the fourth factor for the background environment CO [mgm^{-3}] or NO$_x$ [μgm^{-3}] concentrations variables

Acronyms and Abbreviations

COPERT – computer programme to calculate emissions from road transport
DoE – design of experiment
DT – Dimitrija Tucovića street
EF – emission factor
FAC2 – fraction of two
FB – fractional bias
FFD – full factorial design
HV – Hajduk Veljko street
HDV1 – heavy duty vehicle 1, weight < 32 t
HDV2 – heavy duty vehicle 1, weight > 32 t
IA – index of agreement
IGB – inventory guide book
LTV – light truck vehicle
MG – geometric mean bias
MS – mean square
NRMSE – normalized root MS error
NMSE – normalized MS error
OSPM – operational street pollution model
PV – passenger vehicle
R – Pearson's corr. coefficient
RSM – response surface methodology
SMLRM-TE – selection of multi-factor linear regression model – total effect
TE – total effect
Tier – standards methods for calculating emissions of road vehicles
VG – geometric variance
VP – Vojvode Putnika streat
veh – vehicle

Greek symbols

β_0 – free member of polynomial
β_i – coefficients of linear effects of factors β_i, (i = 1,2,3,4)
β_{ij} – bi-factored interaction coefficients of factors β_{ij}, (i = 1, 2, 3, 4; j = 1, 2, 3, 4)
β_{ijk} – triple-factored interaction coefficients of factors β_{ijk}, (i = 1, 2; j = 2,3; k = 3, 4)
β_{ijkl} – four-factored interaction coefficients of factors β_{ijkl} (i = 1; j = 2; k = 3; l = 4)
λ_α – critical values of the Kolmogorov-Smirnov test
θ – background wind direction, [°]

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