Dissemination Modeling Of Air Pollution From Vehicles In Road Junctions

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Development of civilization takes place mainly in a natural way in industrial clusters. That agglomerative network consisting in tying urbanised areas can be transformed with time, through functional connections, into metropolitan centres [1], which should provide with the efficient transport infrastructure. At the stage of planning-urban concept from the scope of communicative solutions, assumptions are referred to combine aspects of functional, technical, economic, and environmental. The organised transport is an only perspective way of transferring in large urbanized areas. Currently the predominant form of transport people and goods in the country is an individual using circular transport vehicles.

Keywords: linear emission, model of pollution dispersion, road junction

1. INTRODUCTION

The natural development of civilization takes place mainly in industrial clusters. That agglomeration network consisting of connected urbanized areas, by means of time and through functional connections, can be transformed into metropolitan centers [1], which should be provided with efficient transport infrastructure. At the stage of town planning concept from the scope of transport service solutions, ideas are presented to combine functional, technical, economic, and environmental aspects. The public transport seems to be the only perspective for transportation in large urbanized areas.

Currently the predominant form of passenger and goods transportation in the country is individually used wheel transportation (especially vehicles).

Over the last ten years, the share of road goods transport has tripled. It is expected that by 2020, road transport will grow by 1.6 - 2.1% annually, and the demand for road transport by Polish foreign trade will increase by 150 - 190%. Work in transport will increase by 37 - 44% by 2012 compared to 2005 [2]. Therefore, the priority of investment by 2015 will be the construction of motorways and expressways as well as building a network of local roads, including the construction of 26 ring roads of the total length of 203 km by 2012. Ring roads will be built in the cities and metropolitan areas the most affected by high traffic nuisance [3]. Basing on the function demand analysis, new transport solutions will be implemented to connect the areas of numeral settlements by ring roads with the use of a collision-free traffic joining system.

The knowledge of the substance emission from motor vehicles and its distribution in the atmosphere becomes the fundamental environmental issue in the town planning process. Fuel combustion results in car engines results in exhaust gases formation, their composition, depending on pollutants present, can be divided into three groups [4]:

- products of the incomplete and partial burn: hydrocarbons (HC), carbon monooxide (CO), dust (PM),
- nitrogen-air oxidation products (NOx)
- additives and contaminants combustion products and the other compounds (Pb, S, PM).

The point-like character of the mobile emission sources causes the linear spread of outlet gasses and linear-volumetric mixing (dilution) in the atmosphere.

The need for limiting the negative influence of emission on the environment pushes for defining its mechanism and modeling a spread pattern for this phenomenon.

To define that mechanism of emission spread resulting from by the combustion process, the mathematical models of Euler, Langrange and Gausse were used.

2. METHODOLOGY

In accordance with the Disposition of the Minister for Environment of 5 December 2002, and subsequently of 26th January 2010 on reference values for certain substances present in the air, to determine the state of air pollution, the Gauss (Pasquilla formula) model is used. According to this regulation it is necessary to present on an analytic network distribution of the maximum substance concentration in the air, including its annual average, as well as taking into account the statistics for meteorological conditions. This document also sets the reference point for the average concentration of certain substances in the air.

Calculations for the emission spread in the environment have been conducted in accordance with the calculation methodology contained therein with the use of the CALINE 3 model, which was developed by P.E. Benson on behalf of the State of California Department of Transportation, U.S.A. CALINE 3 is widely used in the EU countries for the analysis of the substance concentrations in the air in the vicinity of roads. This model is preferred by the Ministry of the Environment and the Main Inspectorate for Environmental Protection. As a model recommended for use, it was mentioned in the “Methodological guidance on mathematical modeling of air quality management system”.

CALINE 3 is a micro scale model, based on the Gauss diffusion equation and it applies the concepts of a mixing zone. It takes into account a thermal and mechanical turbulence caused by motor vehicles. In this model, its roadway consists of straight sections, homogeneous in terms of height, width, emission volume etc. Program divides each of these sections into a number of elementary line sources, located perpendicularly to the wind direction. Length and orientation of the element is a function of the angle between the wind directions and the given road stretch.

CAINE 3 model takes the area directly above the road as a zone of uniform emission and turbulence. This area is so-called the mixing zone and is defined as the area above the roadway. Within the ground-level of the mixing zone mechanical turbulence occurs; it is caused by the movement of vehicles and thermal turbulence, caused by the ejection of hot gases.

The analytical model takes into account the parameters and the emitter location, as well as meteorological conditions, i.e. the atmospheric equilibrium, wind speed and direction, and the average temperature for the calculation period. The statistics for the a.n. meteorological parameters were developed by the state meteorological center and were used to develop models in both variations.

To compare the analytical method for the emission spread from motor vehicles, the junction of two roads with different traffic streams was used. There were four substances chosen for which annual average values were calculated, taking into account the limit values, specified in the Disposition of the Minister for Environment of 26 January 2010. The reference values for the individual substances are listed in Table 1.

Table 1. Acceptable concentration limits for individual air pollutants [6]:

No	Name of substances	Chemical Abstracts Service (CAS)	Reference values in μg/m^3 average per:	
			Hour	year
1	Nitrogen dioxide	10102-44-0	200	40
2	Sulfur dioxide	7446-09-5	350	20

3	Benzene	71-43-2	30	5
4	Suspended dust (PM10)	-	280	40

In accordance with the a.n. regulation, the reference value of a substance in the air or acceptable substance levels in the air is considered to be met only if the frequency of crossing the D_1 value by the average substance concentration over one hour is not greater than 0.274% time within a year for SO_2, and 0.2% time within a year for other substances.

The communication knot calculated into the coordinate grid (figure 1) has been processed – it involved finding the characteristic points and simplifying of the bends into a number of straight sections. Two modeling variations for the pollution spread patterns were performed: system including the collision-free connecting roads (slip roads) to join the main traffic (Option 1) and the simplified road-cross like version (Option 2). The arrangement of accepted variants is presented on the site plan for the modeling (figure 2).

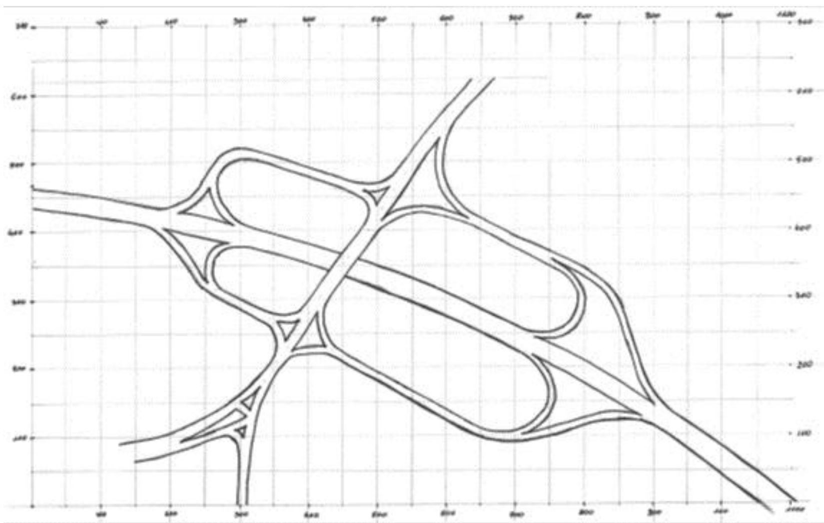
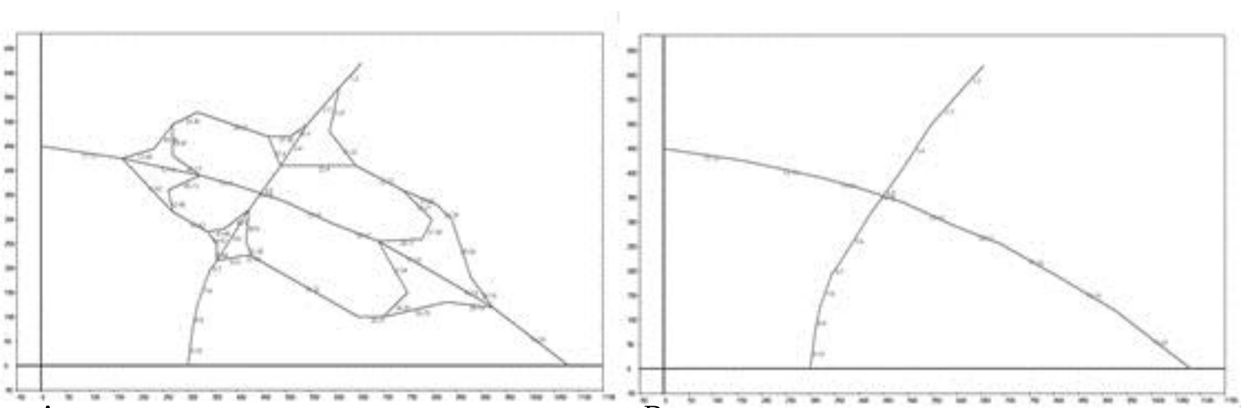


Fig.1. Analyzed road junctions on scaled mesh, source: own research.



A B

Fig. 2. The location plan presented as a straight line system. A - option with slip roads, B –simplified option; source: own research

To create a model of the spatial concentration distribution of selected four substances, the annual value of the aerodynamic coarseness of the area coefficient was assumed at the level of 0,035 (for winter 0.001 and for summer 0.07) [6]. The traffic stream (SDR) was based on data provided by General Directorate for National Roads and Motorways: for the north – south section on the level 13.944, and for the section east – west on the level 39.164 vehicles per day [7]. Emission factors for each class of motor vehicles were based on the figures 3 and 4.

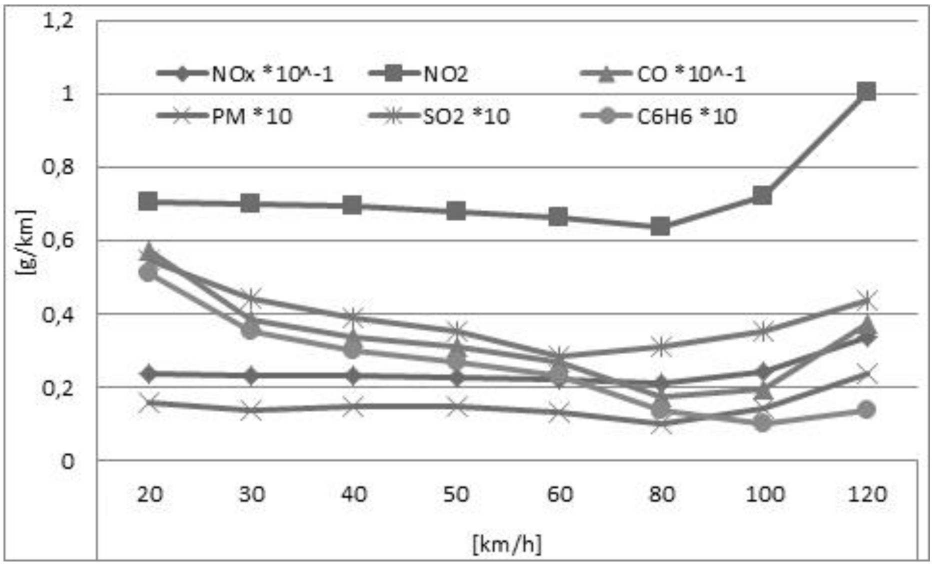


Fig. 3. Individual emission factors from internal combustion engine passenger vehicles (NO_2 emission was assumed as 30% of the NO_X emission) [8].

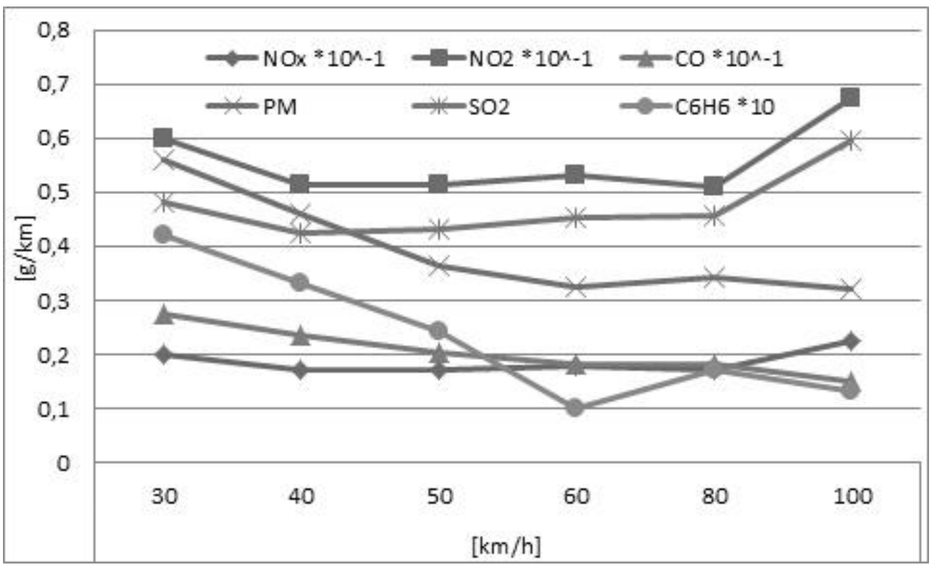


Fig. 4. Individual emission factors from internal combustion engine passenger vehicles (NO_2 emission was assumed as 30% of the NO_X emission) [8].

The percentage share of particular vehicle groups accepted for the modeling has been summarized in Table 2.

Table 2. Participation of particular vehicle groups [9].

No	Vehicle category	Share in total number of vehicles [%]
1.	Car	76,29
2.	Truck	7,70
3.	Lorry	13,70
4.	Bus	2,00
5.	Motorcycle	0,31

3. MODELING PROCESS RESULTS

As a result of conducted calculations, a spatial pattern of the annual average concentrations of tested substances was obtained. Graphical form of the results is shown in figures 5-12, showing the contour line of concentration.

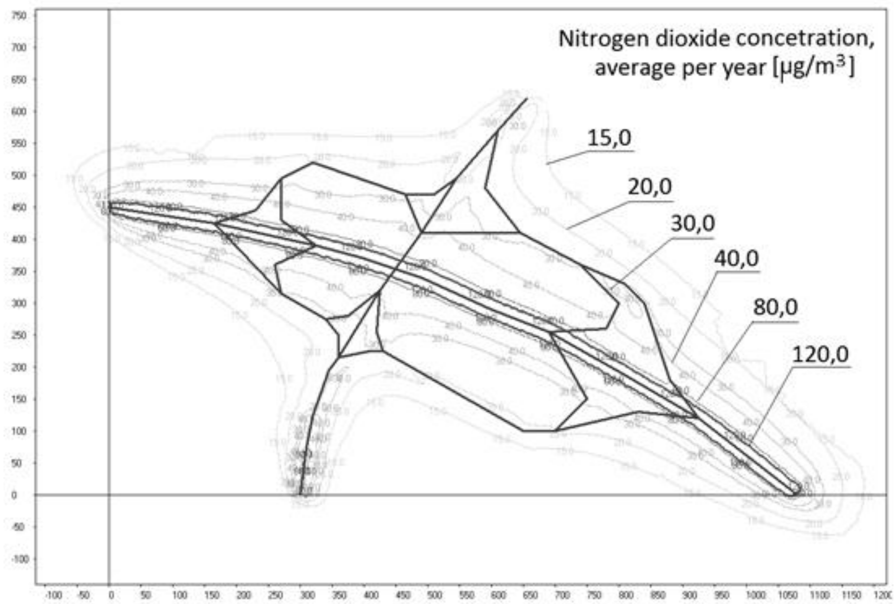


Fig. 5. NO_2 distribution for the slip road option (option 1).

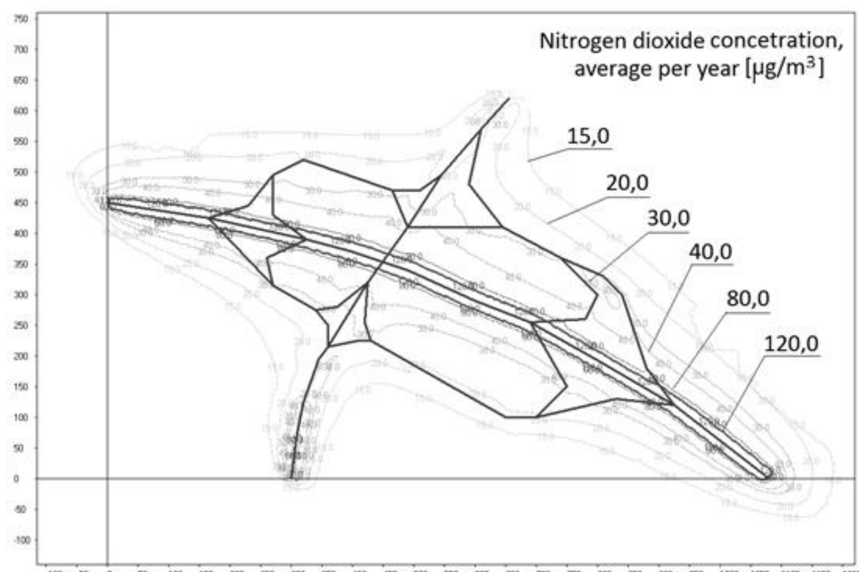


Fig. 6. NO_2 distribution for the simplified option (option 2).

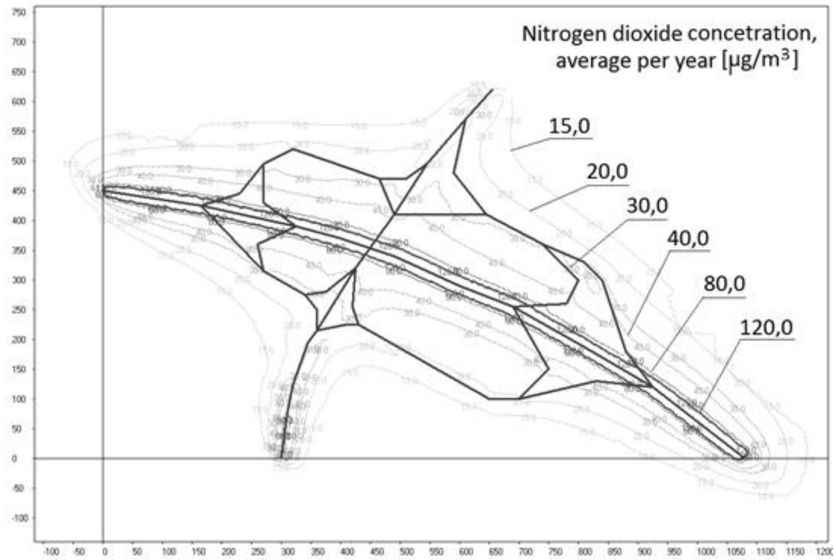


Fig. 7. SO_2 distribution for the slip road option (option 1).

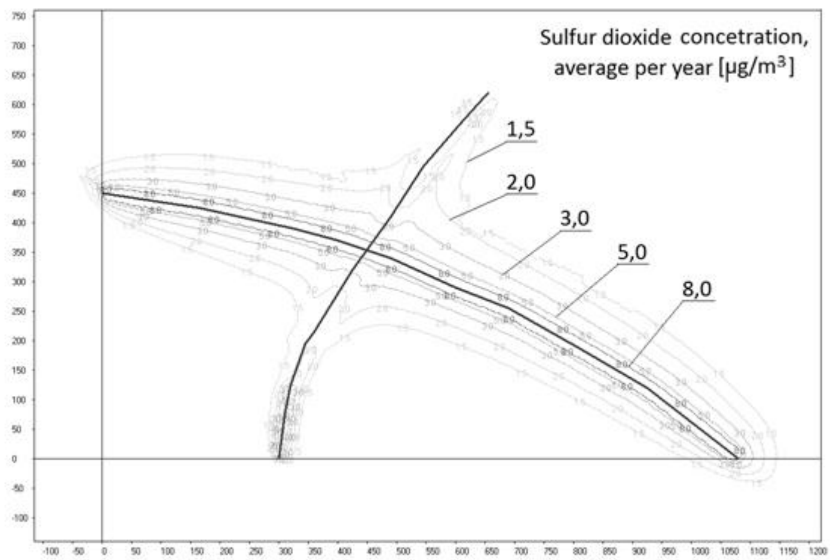


Fig. 8. SO_2 distribution for the simplified option (option 2).

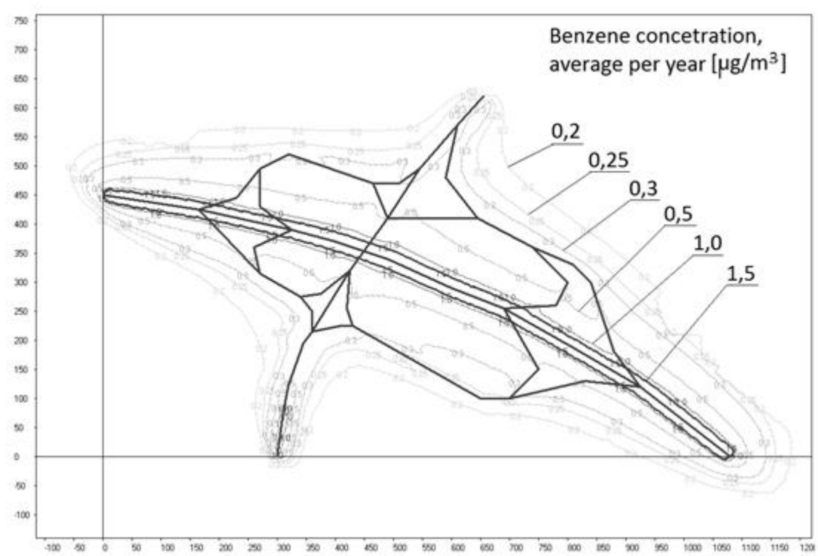


Fig. 9. Benzene distribution for the slip road option (option 1).

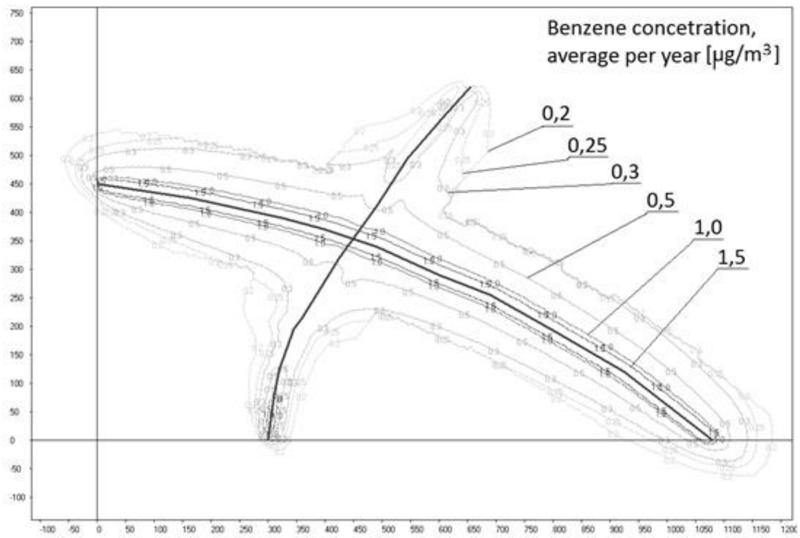


Fig. 10. Benzene distribution for the simplified option (option 2).

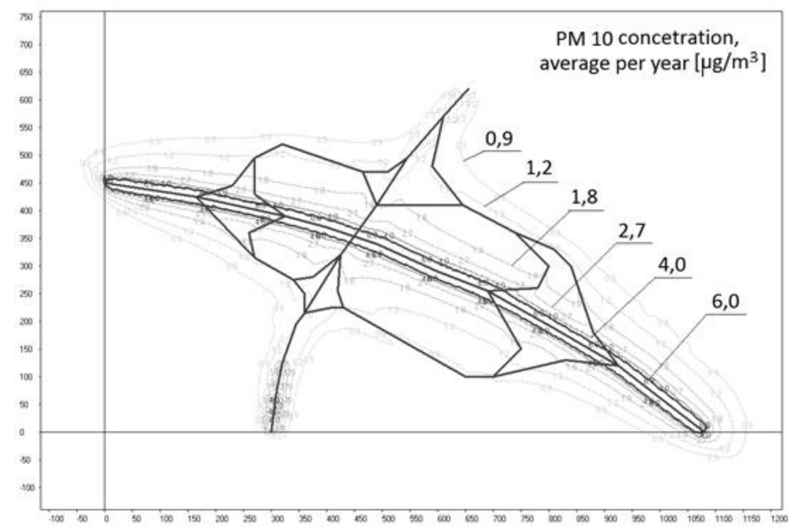


Fig. 11. PM10 distribution for the slip road option (option 1).

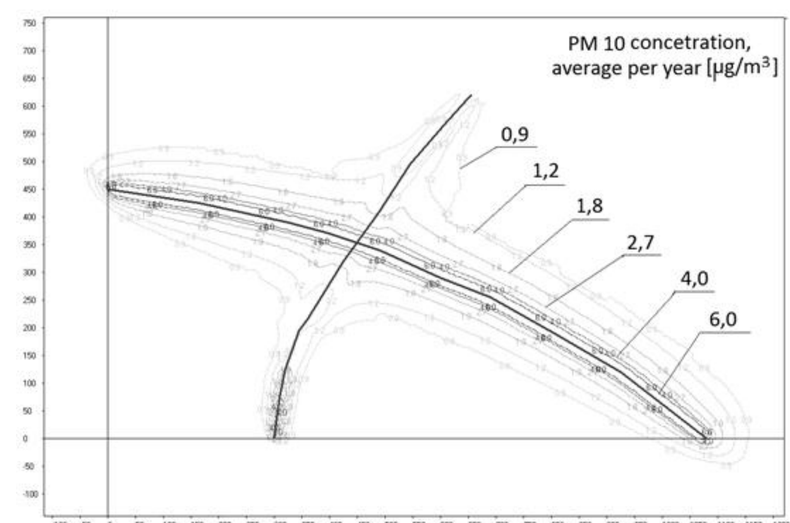


Fig. 12. PM10 distribution for the simplified option (option 2).

Basing on the calculations done for both of the variations, similar values of the maximum concentration for both the hourly average as well as the annual average values were observed for both models. Positioning of the elevated concentration results for tested substances, within the main east-west and north - south routes, shows similar values. The differences in the isoline scope determining increased concentration for both variations result from the presence of the connecting roads, which lead the road traffic away from the main routes. The highest average concentration values of discussed substances have been summarized in Table 3.

Table 3. The highest recorded annual average concentration values

Name of substances	Option with slip roads (option 1)		Option simplified (option 2)	
	Average concentrations [μg/m^3] – the highest value	% acceptable exposure limit	Average concentrations [μg/m^3] – the highest value	% acceptable exposure limit
Nitrogen dioxide	186,389	465,97	185,396	463,49
Sulfur dioxide	13,063	65,31	12,991	64,95
Benzene	2,489	49,78	2,499	49,98
Dust (PM10)	8,778	21,94	8,734	21,83

The frequency of exceeding the highest permissible concentrations hourly averaged has been presented in the table 4.

Table4. The highest detected hourly concentration and the exceeding frequency

Name of substances	Limit of exceeding frequency	The highest concentrations averaged up to one hour [μg/m^3]	
		option with slip roads / exceeding frequency	option simplified / exceeding frequency
Nitrogen dioxide	18 times / 0,2 %	709,901 / 37,697	727,719 / 37,27
Sulfur dioxide	24 times / 0,274 %	49,755 / 0,00	50,994 / 0,00
Benzene	18 times / 0,2 %	9,478 / 0,00	9,811 / 0,00
Dust (PM10)	18 times / 0,2 %	33,432 / 0,00	34,284 / 0,00

The quadruple exceeding of the allowable concentration level for the NO_2, occurring in the slipstream area, has been observed.

Based on the Air Quality Report [10] prepared by Voivodship Inspectorate for Environmental Protection (WIOŚ) for the region with the discussed communication knot, it was possible to establish the background concentration for the following substance: nitrogen dioxide –17.0 [μg/m^3], sulfur dioxide 7.0 [μg/m^3], hung dust (PM10) – 25.0 [μg/m^3] and benzene – 2.3 [μg/m^3].

Basing on the a.n. substance levels, some numerical calculations for the introduction of additional air pollution, resulting from motor vehicle traffic, have been performed. It needs to be mentioned, that the natural level of NO_2 in the analyzed area was at 42.5 % of the maximum level for that substance, as specified by a.n. Regulation [6]. In 2010, the allowance margin for the NO_2 reference value was completely reduced [5], therefore numerous limit exceedings for sites with increased average daily motor traffic with the higher background levels should be expected.

4. SUMMARY

Despite the fact, that for the both models the obtained peak concentration values were similar (for the slip road and the simplified option), it does not mean that both models are similar. Dispersion models are used to determine the increased concentration regions. The purpose of spread pattern modeling is determining the range of the higher substance concentration caused by linear emission onto a receptor located in the junction vicinity. Therefore the reference of the highest calculated concentration values to the highest values allowed by the Polish law. At the decision-making stage deciding on the location of a communication knot, a special attention should be paid to the receptors, which may be exposed to the direct impact of elevated concentration levels caused by road traffic. While determining the potential receptors, both the impact on health as well as environment protection should be taken into account. Therefore, it is arguable to perform detailed emission spread modeling for those communication knots, which show any signs of exposure of third parties to elevated substance concentration.

Based on comparative analysis of the results for the emission distribution concentration modeling for both variations, with and without the slip roads, it is concluded that the simplified replacement of the ramp curves with straight sections is appropriate, and increasing their number by dividing them into smaller sections will only impede the computational process, complicate the form of the analyzed results and, what is more, will have no significant impact on their value.

5. REFERENCES:

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