Models of the Impact of Road Transport in Air Quality Management System

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The paper presents categorization of models used in environmental monitoring taking into account the factors of emissions into the air, and the impact of road transport emissions. The information collected was related to the share of road transport in the creation of the emission in the Lodz region, analyzed as a case study. Types of substances were classified according to their harmfulness and intensity derived from traffic sources. Particular attention has been given to the issue of dispersion models used in environmental monitoring, the practice of their use and suitability for road transport.
Keywords: environmental monitoring, air quality, pollutant dispersion models, road transportation.

1. OUTLINE

Nowadays it can be observed that globalization has contributed to an increase in the amount of transported goods and raw materials. This is due to the intensification of the frequency of transportation including road transport. The result appears to be an increased amount of harmful emissions into the atmosphere. Toxic gases and dust are emitted to atmospheric air, and this problem is particularly noticeable in the large cities, to which the city of Lodz is classified.

With the development of environmental awareness in society through the pressure exerted on government authorities and businesses, the number of actions taken to protect the environment increases. So far, direct and indirect instruments have been developed to raise awareness of society, as well as of operators, on issues related to ecology.

It should be noted that the collection of such relevant information requires the development of an appropriate course of action and development of adequate tools to carry out such measurements and that will bring the desired results. In the region of Lodz measurement stations measure the level of pollution emitted from sources of different origin. Using appropriate mathematical models and combining them with the findings in the measurement data, the annual evaluation of environmental quality is developed. Because of the subject area addressed in this paper, the way of collecting data to create a report for the annual assessment of air quality in this region is the most important aspect. Particular interest in this regard is the emission of selected gases and dust coming from the line source (road transport).

The presented considerations may become very important for the entire logistics industry in the context of the expected steady increase of overall road transport emissions in the atmosphere.

2. AIR QUALITY EVALUATION SYSTEMS

One of the main thematic areas that are a part of State Environmental Monitoring is the quality of the air, which has a direct impact on the quality of life of people.[1] Analyzed problems are inextricably linked to the functioning of the Atmospheric Air Monitoring (AAM). The term should be understood as "a system of measurements, analyses, assessments and forecasts of air pollution, taking into account all the circumstances and factors contributing to this state and to its

[1] W. Andrzejczak (et al.), *Raport o stanie środowiska w województwie łódzkim w 2011 roku, Wojewódzki Inspektorat Ochrony Środowiska w Łodzi*, Biblioteka Monitoringu Środowiska, Łódź 2012, p. 95

changes[2]." The underlying purpose of the AAM include collection of information on pollutants that are introduced into the atmosphere, as well as data on concentration levels of individual air pollutants. This also applies to information about moving and concentration of these pollutants. The main purpose of the AAM is "air quality management through effective planning of objectified remedial actions, protection and prevention[3]." The main objectives of the AAM must also be reduction of emissions of air pollutants and the development of risk assessments for society and ecosystems. There is a national network of AAM, which consists of a primary station and general surveillance stations and regional networks. They operate under the Environmental Protection Inspectorate and are focused on the impact of economic entities on the natural environment in the region[4].

Air quality assessment systems are based on a number of regulations. It is mainly Environmental Protection Act of 27 April 2001 (consolidated text in Journal of Laws of 2008 no. 25, item. 150.), and subsequent decision of the Minister of the Environment. During the work on the assessment of air quality any recommendations of GIOŚ[5] are also taken into account. Important is the fact that in 2012, the Act of 13 April 2012 amended the Act - the Environmental Protection Act and some other laws. These changes are intended to "adjust Polish legislation to the requirements of Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (Journal of Laws, of the EU L 152 of 11 06.2008) - CAFE[6]". In the wake of these changes further processes commenced that are also relevant for air quality assessment for dust PM 2.5.[7].

The previously described considerations that air quality assessment is performed on the basis of regional air quality assessment systems. The supervision of these activities is exercised by Voivodship Inspectorates for Environmental Protection WIOŚ[8]. The main task of WIOŚ in the air quality monitoring is to make the initial, five-year and annual assessments of air quality in the voivodship. Results of five years assessment affect the way of the air quality assessment system and the need for its possible modification. The annual air quality assessments are conducted in order to determine the state of air pollution in the areas of evaluation and identify any violation of air quality standards. They are also used to determine the need for air protection programs in the recovery plans implemented by the voivodship board. This is obviously a response to poor air quality[9].

Considering the issues related to the development of remedial programs it should be emphasized that they must comprise information on the expected changes in emissions that are a consequence of implementation of international agreements, economic and technological changes. Therefore, the development of these programs will require accordingly diverse sets of models. For this reason, the practice of modelling propagation of air pollution which is currently used in Poland must immediately be subject to radical changes. In addition, a few requirements can be mentioned, which imply not only the need for new models but, consequently, new methods. The most important requirements for the area of interest covered in this paper include first of all the need to take account of all pollution sources existing in the given area, in particular caused by road transport, as well as to determine the contribution of individual sources of pollution in state of contamination of the zone[10].

Previous considerations are best summarized by the words that emphasize the fact that "the functions of the quality management system includes a number of tasks that requires modelling which is implemented in a whole new perspective[11]."

3. TOXIC EMISSIONS INTO THE AIR CAUSED BY ROAD TRANSPORT

Road transport is a significant contributor to the amount of pollutants entering the air. This is particularly noticeable in urban areas where traffic is intensified, for the harmful substances mainly include gases and dust, and among them[12] carbon dioxide, nitrogen oxides, sulphur dioxide, carbon

[2] J. Skrzypski, W. Kamiński, E. Jach-Szakiel, *Zarządzanie jakością powietrza i bezpieczeństwem ekologicznym jako element zrównoważonego rozwoju dużych miast,* op. cit*., p.* 54
[3] Ibid.
[4] Ibid., p. 55
[5] W. Andrzejczak (et al.), *Raport o stanie środowiska w województwie łódzkim w 2011 roku*, op. cit., p. 95
[6] Ibid.
[7] Ibid.
[8] Ibid.

[9] Ibid., p. 96
[10] G. Mitosek, Ocena jakości powietrza w strefach w Polsce za rok 2011, Inspekcja Ochrony Środowiska, Warszawa 2012, p. 8
[11] G. Mitosek, Ocena jakości powietrza w strefach w Polsce za rok 2011, Inspekcja Ochrony Środowiska, Warszawa 2012, p. 8
[12] B. Suchecki, *Zanieczyszczenia powietrza emitowane prze transport drogowy*, 05.04.2006, http://lanckoronska.zm.org.pl/?a=koalicja.broszuras_03#Gazy_i_pyly

monoxide, polycyclic aromatic hydrocarbons, benzene, and lead, platinum, ozone and dioxin.

Measurements within the framework of the State Environmental Monitoring on air pollution in the context of the analysis include only sulphur dioxide, carbon monoxide, carbon dioxide, nitrogen and particulate matter PM 10.

Sulphur dioxide is an odourless gas characterized by suffocating properties and is poisonous to living organisms. As a result of oxidation sulphur trioxide is produced in the air. Thus, it is included in acid rain, which degrade water tanks and acidify the soil.[13] It should be noted that the emissions of sulphur dioxide in the Lodz region derived from line sources is only nearly 1.4% of its total emissions[14]. Another pollution entering the atmosphere is carbon monoxide, which is a highly toxic, colourless and odourless gas, which is commonly called the fumes. It arises as a result of incomplete combustion of flammable materials, shortage of oxygen. Carbon monoxide has a negative effect on human health and life.[15] According to data from the report of Voivodship Inspectorates for Environmental Protection (WIOŚ) in Lodz in 2011, by far the largest share 54.9% of the total emissions of carbon monoxide was road traffic.[16]

The most dangerous of the ingredients which contaminate the atmosphere are nitrogen oxides. Nitrogen dioxide is a toxic gas which has a sharp suffocating odour and reddish colour. As a result of numerous studies the negative impact of the gas being analyzed on the human respiratory system was confirmed, which in higher concentrations leads to damage to lungs. It is also a component of acid rains and smog. An important source of nitrogen dioxide is road traffic. In 2011, the total share of emissions in the voivodship was 17.4%[17].

Road traffic contributes to emissions of PM 10 and produces 20.3% of the total emissions in the Lodz region[18]. The term dust contamination should be understood in a variety of ways. The degree of its harmfulness mainly affects the chemical and mineralogical composition, as well as the grain size[19]. In simple terms it can be assumed that the dust should be defined as "a mixture of small solid particles suspended in the air (dispersed phase of the two-phase solid-gas[20])."

Due to the particle size division of particles is used which according to the literature on the subject can be expressed as follows[21]:

- TSP Total Suspended Particulates - is the total dust content in the air,
- Fine particulate PM 10 (Particulate Matter) - is the fraction of particulate matter, the particles which have a diameter less than 10 microns,
- Very fine particulate PM 2.5 - a fraction of particulate matter, reduction and colloidal, wherein the particles have diameters smaller than 2.5 microns.

Initially, only the term TSP has been used. Over the time, research has shown that dust particles of diameter less than 10 microns are far less harmful to human health than the particles with a smaller diameter. Thus there appeared to mark PM 10 in the air. Today, the greatest harm is attributed to particles whose diameters are smaller than 2.5 microns. As a result, there is indication of PM 2.5 in the air. Additionally, some countries only specify standards for acceptable levels indicated just by two particles. It is associated with the introduction of appropriate methods for measuring these particles.

Natural sources of origin of the dust are settling materials, sea sprays, plants and animals, volcanic eruptions and forest fires . The anthropogenic sources of dust in the air shall cover all production processes and fuel combustion processes, with particular emphasis on solid fuels.

According to research damaging dust influences primarily human health, as well as plants, soil, water and materials and also reduces visibility. "The dust gets into the human body primarily through the respiratory system, or indirectly through the digestive system when contaminated food is consumed."[22] It was also found that "the particles having diameters greater than 10 microns stop in upper parts of the respiratory tract, where they are discharged[23]:

[13] J. Chodkowski (red.), *Mały słownik chemiczny*, Wiedza Powszechna, Warszawa 1974, p. 142
[14] W. Andrzejczak (et al.), *Raport o stanie środowiska w województwie łódzkim w 2011 roku, op. cit.*, p.107
[15] J. Chodkowski (red.), *Mały słownik chemiczny*, op. cit., p. 533
[16] W. Andrzejczak (et al.), *Raport o stanie środowiska w województwie łódzkim w 2011 roku*, op. cit., p. 110
[17] Ibid., p. 109
[18] Ibid., p. 111
[19] K. Juda-Rezler, *Oddziaływanie zanieczyszczeń powietrza na środowiska*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2006, p. 66
[20] Ibid.
[21] K. Juda-Rezler, *Oddziaływanie zanieczyszczeń powietrza na środowiska*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2006, p. 66
[22] Ibid., p. 68
[23] Ibid., p. 68-69

- PM 10 (with the exception of PM 2.5) penetrate into the lungs, but they do not accumulate there, they can accumulate in the upper part of the respiratory tract;
- PM 2.5 penetrate to the deepest lung parts, where they are accumulated.

The studies indicate that especially particulates PM 2.5 cause very serious health effects such as premature death, aggravation of asthma, acute respiratory reactions, chronic bronchitis, decreased lung function. In addition, together with sulphur dioxide and other compounds, particulate matter contributes to the incidence of black smoke and also has impact on the greenhouse effect[24].

There is no doubt that the road transport clearly affects the quality of the air. For the purposes of reporting to the European Commission a list of potential violation of criterion concentrations of pollutants in 2011 was set up. 20 reasons are listed, 5 of which are directly related to the road transport. It should be mentioned[25]:

- the impact of emissions associated with the movement of vehicles in the city centre with intense traffic,
- the impact of emissions associated with the movement of vehicles on main roads lying near the measurement station,
- the impact of the local petrol stations,
- the impact of a nearby parking lot,
- secondary emission of dust from the exposed surface such as roads, sidewalks, etc.

4. TYPES OF AIR POLLUTION AND THEIR MEASUREMENT

The air is a natural asset, which is a renewable resource, however, possible to be depleted in such cases as smog in big cities. Due to the emission source and the method of air emissions the source is divided into emissions from[26]:

- point sources - structured emission, which is produced during power generation and industrial processes. It has high emitters from a few to several hundred meters,
- line sources - emissions from road transport, routes, rail or river transport, in which an emission source is close to the surface of the earth,
- surface sources - emissions of individual heating systems, large outdoor tanks, large-scale fires
- agricultural sources - emissions from crop and farming

The largest source of line emissions in the Lodz region is road transport. Substances emitted from motor vehicles affect the purity of the air, causing an increase in the concentration of pollutants, especially in the immediate vicinity of roads and their impact diminishes with distance. It should be noted that the number of vehicles each year is growing steadily. According to data from the Statistical Office in Lodz in 2011, the number of passenger cars increased by 5.3% trucks 4.4% buses by 4.6%, tractors 3.6% motorcycles by 7.7% [27]

According to research conducted by WIOŚ in Lodz in 2011, compared to the previous year there was an increase of emissions in line sources and in point sources[28]. This is due to the increasing number of vehicles and expansion of roads. It should be noted that the data for estimating emissions from line sources are not complete[29].

Over the past several years as a result of efforts to protect the environment in the region of Łódź a significant improvement in air quality has been noted. This situation is mainly due to elimination of some of the sources of air pollutant emissions. Unfortunately it is not possible to completely eliminate transportation-related emissions. For this reason, despite the evident air quality improvement overall improvement is not satisfactory[30].

Research and analysis of the concentrations of air pollutants from various sources (point, line, surface, and others) are made possible by the appropriate emission measurements. They are the main method used to determine the state of air quality. In the Lodz Region there are 3 measurement network that include[31]:

[24] K. Juda-Rezler, *Oddziaływanie zanieczyszczeń powietrza na środowiska*, op. cit. 68-69

[25] G. Kłos (et al.), Roczna ocena jakości powietrza w województwie łódzkim w 2011r., Wojewódzki Inspektorat Ochrony Środowi, Łódź 2012, p. 8

[26] W. Andrzejczak (et al.), *Raport o stanie środowiska w województwie łódzkim w 2011 roku*, op.cit., p. 100

[27] Główny Urząd Statystyczny w Łodzi, http://www.stat.gov.pl/lodz/51_PLK_HTML.htm

[28] W. Andrzejczak (et al.), *Raport o stanie środowiska w województwie łódzkim w 2011 roku*, op. cit., p. 100

[29] Świątczak B. (i inni), *Wstępna ocena jakości powietrza w województwie łódzkim dla As, Ni, Cd, B(a)P, w pyle Pm 10 w latach 2001-2005*, Wojewódzki Inspektorat Ochrony Środowiska, Łódź 2006, p. 23

[30] J. Skrzypski (red), *Programowanie zrównoważonego rozwoju regionów*, Polska Akademia Nauk Oddział w Łodzi, Łódź 2004, p. 35

[31] W. Andrzejczak (et al.), *Raport o stanie środowiska w województwie łódzkim w 2011 roku*, op. cit. , p. 95

• automatic measurement network (continuous),
• manual measurement network (daily),
• passive network measurements (monthly).

In the Lodz Region 9 stations are automatic, 15 manual measurements stations (measurements are carried 24 hours a day) and 118 passive measurement stations (these are monthly measurements of passive collection). The results of measurements with the support of mathematical modelling of air quality help to established annual and five-year assessments of air quality, which has already been discussed in previous paragraphs.

It should be noted that the dynamics of air pollutants is possible to be measured only through automatic and manual stations. Only those stations can provide data to verify the mathematical models and to try to link the source of contamination of the measured values.

5. AIR POLLUTION DISPERSION MODELS

There are four basic types of air pollution dispersion models which were developed:[32]

Box model - this is the simplest type of model. It assumes the existence of a limited air layer in the geographical area. It also assumes that air pollution inside the box is evenly distributed and that assumption is used to estimate the pollution. Although useful, this model is very limited in its ability to accurately predict the dispersion of air pollutants because the assumption of uniform distribution of pollutants is too simple. It does not require to run climate data or meteorological data.

Gaussian plume model is one of the oldest models (circa 1936) and is the most common type of model in the study of air pollution. It assumes that the dispersion has a Gaussian distribution of pollutants, which means that the distribution of pollution has a normal distribution probability at the time propagation. Gaussian models are most often used to predict the dispersion from point sources. Data required to use this model are climate data including average size of wind direction and wind strength. For this model streaks of clouds were taken into account.

Lagrangian model is based on a mathematical model of the movement of molecules. In this type of model, the spread of contamination is described by simulating the movement of a large number of pseudoparticles representing certain amount of impurities. Their movement is made up of moving average (wind) and a random component, related to the characteristics of turbulence. Lagrangian model uses a moving reference point as the transition from their original position. It is said that in the Lagrangian model observer moves with the plume. This model is important in modelling pollutant resulting from episodic events such as volcanic eruptions or the failure of a nuclear power plant. It is less suitable for modelling the line emission.

Eulerian model - dispersion model comparable to the Lagrangian one, because it tracks the number of packets of pollutant emissions moved from their initial position. The main difference between the two models is that the model uses a fixed three-dimensional Cartesian grid as a reference rather than moving reference system. It is said that the observer is embedded in a grid of points and does not move along the plume.

All basic models have been enriched during a time and lead to a new type of modelling. Here are the basic directions of development of models associated with a variety of input data, which may include:[33]

- Meteorological conditions such as wind velocity and direction, ambient temperature, humidity, precipitation, cloudiness and solar radiation, the type and intensity of atmospheric turbulence in all layers of the atmosphere (which is referred to as the Pasquill atmospheric stability classes);
- The concept of the source and intensity of the emission intensity from the source (concentration or amount of harmful substances in the line emission or in terms of accidental emissions) source location and height, the type of source and output speed, output temperature;
- Terrain elevation in the emission source location and at the location of measuring stations, such as the surrounding buildings and structures, position, height and width of any obstructions (such as buildings or other structures) in the path of the emitted gas plume, surface roughness, or the use of more general parameters the ground category "rural" and "urban".

[32] Turner, D.B. (1994). *Workbook of atmospheric dispersion estimates: an introduction to dispersion modeling (2nd Edition ed.).* CRC Press.

[33] L. Łobocki *Wskazówki metodyczne dotyczące modelowania matematycznego w systemie zarządzania jakością powietrza,* Ministerstwo Środowiska GIOŚ, Warszawa 2003

Table 1. Impact of meteorological data on models on different levels

ID	Parameter	Influence	Measurement	Level A	Level B	Level C
1.	Wind	High	the height 10 meters in the fields of meteorology, the grid every 5 km, averaging at 1 h	further averaging and map with the average annual wind	to evaluate the prevalence of atmospheric calms	deficiency a measurement system in the grid at every 5 km
2.	Pasquill atmospheric stability classes	High	parameter calculated for use in level B and C	No importance	Local important parameter	the most important parameter of observation and simulation of dispersion of emissions
3.	Temperature	Low	averaging from the meteorological station	parameter included in the scale of large areas	considered negligible	considered negligible
4.	Precipitation	Low	averaging from the meteorological station	parameter included in the scale of large areas	considered negligible	considered negligible
5.	Humidity	Low	averaging from the meteorological station	parameter included in the scale of large areas	considered negligible	considered negligible

Source: own elaboration

For the purposes of clear categorization, models adopted three levels of use.

Level A is the level of the annual averaging all input parameters. Such models can take into account the climate data calculated from the acquisition of meteorological data and averaged on an annual basis in the passive stations. Such a division is suitable for determining the mean values on large areas. These models allow to conclude from the tiniest of observed climate change over long periods confronted to estimates of emissions overall. These models do not include the source of emission.

Level B is the level which targets specific local areas, where critical meteorological parameters are such as a high prevalence of silent weather or areas with unfavourable atmospheric equilibrium. These areas require detailed meteorological monitoring on an ongoing basis and confirmation of data on emissions. Modelling is aimed at validation of the empirical influence of unfavourable weather events on the measured dispersions. The model is improving in relation to any extreme events observed.

Level C is a level that assumes continuous measurements even in dense measurement grid without separation of episodic phenomena. It is a constant level of integrated monitoring of large areas. Such a system should be considered as an ideal state of integration of meteorological stations and pollution measuring stations. This level is not yet economically feasible in the current scale in the region of Lodz.

The above table presents the impact of the meteorological data collected and models of different levels. It can be observed that in all the levels, the most important matter is the strength and direction of the wind measured at the surface of the earth. Additional parameters such as temperature, humidity, precipitation are negligible. The level in models B and class balance of atmospheric parameters have been developed for the model level B and level C.

6. MODELLING OF AIR EMISSIONS FROM ROADS

The basic concept of air emissions from roads concerns calculation of the levels of air pollutants near highways or roads by treating them as line sources. The model considers features such as traffic flow, vehicle speed, the proportions of other vehicles (mix truck). Also terrain around the road and local meteorology may be taken roadway geometry into account. As a benchmark the extreme weather conditions of the site are taken into account.

The calculations are so complex that a computer model is necessary to achieve reliable results. Validation of the model may be needed in relation to the data collected from the station in a local environment, this step is not justified in every case because the best models have been extensively validated in a wide range of input data.

The result of the calculation is usually a set of isometric lines in plan or section view. Typically, these lines can be given as carbon monoxide, total reactive hydrocarbons, nitrogen oxides, particulates PM10 and benzene. One can run the model and study techniques to reduce the negative concentrations of pollutants in the air (for example, through the reconstruction of roadways geometry, changes in the speed control or restrict certain types of vehicles). The model is often used in the design of major new roads. Existing models of air emissions from roads correspond to the level B used in dispersion models.

7. CONCLUSION

The ideas contained in this paper show that the air pollution comprises many factors, among which should be mentioned those that arise as a result of the operation of road transport. Nowadays, one can observe a significant increase in the number of vehicles, which in turn increase the percentage of air pollutants originating from the line source. This is particularly evident in comparison with decreasing the percentage of the emission of air pollutants from point sources of industry and households.

It is also noticeable that the state institutions that deal with environmental monitoring include in their measurements the analysis of ambient air quality. In addition, it is increasingly important to precisely define and measure different types of air pollutant emissions. Undoubtedly, the correct identification of these sources with the help of modelling techniques is the foundation for the creation and implementation of recovery plans. Unfortunately, the current measurement system is not adapted to modern challenges. This also applies to basic methods of collecting data on the selected theme which were used, that do not produce results. Basic models which were used are not sufficient to specify the share of pollution from specific sources.

Models presented in the paper can be used at different levels. So, advanced models make it possible to determine the association of emissions, which are measured by a single source. However, it is possible only for a small area, in the situation of a map of areas with locally occurring adverse weather conditions. For a small area, one can be tempted to increase the air emissions from sources of line sources - road transport. The use of the level C models covering larger areas is not appropriate in areas with favourable weather conditions, as it is the case in the region. This applies in particular to economic reasons. It should be emphasized that no doubt there will be an obstacle to the detailed modelling of sources of pollution coming from road transport. However, the collection of data for level A analysis is adequate because of the indicated level of data used and the average per year. Therefore, the data for this model are simplified and do not contain many parameters, and can even take into account the parameters of limited importance. The system of measurement has to improve considerably in the region of Lodz to make use of advanced models possible.

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