THE ARCHIVES OF TRANSPORT *ISSN (print):* *0866-9546*
Volume 32, Issue 4, 2014 ***e-ISSN (online):*** *2300-8830*
DOI: *10.5604/08669546.1146993*

ANALYSIS OF THE TRAFFIC STREAM DISTRIBUTION IN TERMS OF IDENTIFICATION OF AREAS WITH THE HIGHEST EXHAUST POLLUTION

Tomasz Ambroziak[1], Roland Jachimowski[2], Dariusz Pyza[3], Emilian Szczepański[4]
Warsaw University of Technology, Warsaw, Poland
[1]e-mail: tam@wt.pw.edu.pl
[2]e-mail: rjach@wt.pw.edu.pl
[3]e-mail: dpz@wt.pw.edu.pl
[4]e-mail: eszczepanski@wt.pw.edu.pl

Abstract: *Transport is a sector that is said to be negatively affecting the environment. The continuous development of transport increases the negative impact on the environment and civilization. In the article authors present the parameters that were used to describe the size of harmful transport exhaust emissions, in particular by means of road transport and the factors affecting their size. The areas where the level of concentrations of air pollutants are exceeded in Poland were characterized and analysed. Also examples of the stream traffic distribution in the selected area of the transport network were presented.*

Key words: *transport, proecological transport system, PTV Visum, emission*

1. Introduction

Transport is one of the most negatively affecting the environment sectors, with the exception of certain types of heavy industry and agriculture[2]. The continuous development of transport increases the negative impact on the environment and civilization, which is expressed by [13]:

– greenhouse gas emissions that contribute to climate change,
– local emissions of air pollutants adversely affecting the health of local people and the natural environment,
– occupation of valuable natural areas and cutting their continuity (fragmentation) by the elements of a new technical infrastructure, contributing to loss of biodiversity,
– noise emission threatening human health

Because of the serious effects of transport on the environment should be searched for methods that contribute to limit these effects. Therefore, both on the national and international level, there are many assumptions that are being developed, which aim is to develop environmentally friendly transport system. The European Union has developed a number of documents which oblige European Union Countries to implement actions to reduce the negative impact of transport on the environment. In one of the White Papers of the European Commission [11] it was assumed that till 2050 the carbon dioxide emissions will be reduced by 60%. Ensuring the transformation of the transport system of the European Union in a sustainable environmentally friendly transport system, will be done by creation of multimodal logistic chains, increasing transport efficiency, improvement of vehicles powertrain. The European Commission proposed the following measures, which contribute to achieve goals such as:

– promotion of alternative sources of transportation,
– the introduction of speed limits on the roads in order to reduce energy consumption and emissions of harmful gases
– marking vehicles in terms of fuel consumption and CO2 emissions

On the other hand, one of the Green Papers has been devoted to urban mobility [12], where the problems of environmental degradation in urban areas were identified. Assumptions set out in the Green Paper contribute to an increase in the availability of transportation, economic development and improving the quality of life of the society and the quality of environment. Except the documents produced by the European Commission there can be also mentioned the actions such as increased awareness of society, the protection of the Earth's most important ecosystems, and the develop of the concept of sustainable development.

According to the European Commission documents, there is a need for development of ecological transport systems, which in its assumption should be environmentally and humans friendly. To achieve that, these documents should:
– ensure the availability of communication objectives in a safe manner, without jeopardizing human health and the environment, and in a manner equal to the current and subsequent generations,
– allow to function effectively,
– offer a choice of means of transport,
– sustain the economy and regional development,
– limit emissions and waste to the amount possible for their preoccupation with the environment,
– consume renewable resources in the amounts possible to restore them,
– consume non-renewable resources in the amounts possible to replace them by renewable substitutes
– minimize noise and occupancy of the land.

Minimizing the negative impact of transport on the environment and meeting the growing demands of transport are the opposite criteria. So it is necessary to search for a solution using multi-criteria evaluation taking into account these criteria.

The easiest way to reduce emissions is to reduce the number of vehicles. This can be done through more efficient use of vehicles for example by achieving a higher factor of an average vehicles load factors, reducing the mileage of vehicles, etc.

The issue of the negative impact of transport on the environment and human life and health is the subject of the research project entitled: "Development of environmentally friendly transport system". One of the elements of the project is to develop a mathematical model of the development of environmentally friendly transport system which takes into account the minimization of the negative impact of transport on the environment and minimization of the transportation costs. In this model, one of the conditions is to reduce emissions of harmful exhaust gases produced by means of transport

Therefore, in the article authors present the parameters that were used to describe the size of harmful transport exhaust emissions, in particular by means of road transport and the factors affecting their size. The areas where the level of concentrations of air pollutants are exceeded in Poland were characterized and analyzed. Also examples of the stream traffic distribution in the selected areas of the transport network were presented.

2. Exhaust emissions of harmful compounds

2.1. Factors affecting the level of emissions of harmful compounds

Air pollution coming from the sphere of transport depends on many factors. These include:
– the composition of the fuel,
– the characteristics of the engine and the standard of maintenance
– the nature and the basic characteristics of the vehicle,
– terrain,
– vehicle speed,
– congestion,
– other.

On the other hand, the measure of air pollution emissions is said to be a concentrations of individual primary pollutants in the exhaust gasflue gas (exhaust gas harmful compounds generated during the ride). The harmful compounds generated during the ride are:
– NO_x,
– CO,
– particles PM_{10} i $PM_{2,5}$,

The levels of specific primary pollutants emitted by means of transport can be described as a function $F(1, 2,\dots, x, \dots X, 1, 2,\dots, s, \dots, S)$ characterizing the impact of the features and characteristics of the vehicle (fuel composition, engine characteristics etc.) on emissions of various harmful exhaust compounds. According to this x is a number of a factor affecting the air pollution which is part of a set $\boldsymbol{X} = \{x = 1, \dots, X\}$, where the X is a number of factors affecting the pollution. On the other hand, s is the number of primary pollutants (harmful exhaust connection formed during the drive means of transport), belonging to the set $\boldsymbol{S} = \{s = 1,\dots, S\}$.

A schematic summary of the factors that cause changes in the volume of each harmful exhaust compounds is shown in Figure 1.

The contaminants mentioned earlier may adversely affect the materials and buildings, crops and forests, and may be harmful to plant life and health of animals and humans. The share of individual air pollutants produced by means of road transport in the total contamination of the substance is shown in fig. 2.

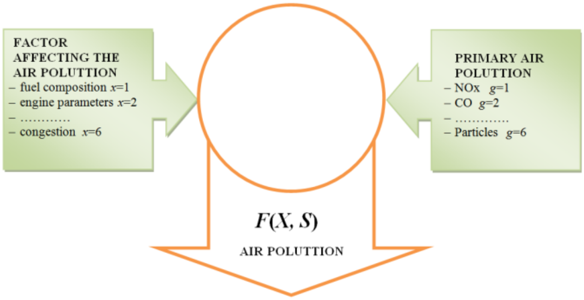


Fig. 1. Exhaust air pollution compounds

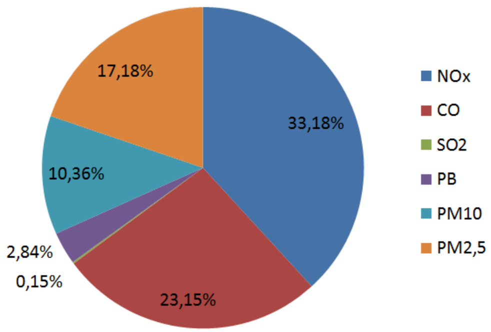


Fig. 2. The share of road transport in air pollution [3]

The impact of some factors causing such and not another emissions of harmful exhaust compounds is successfully limited. While reducing congestion, driving speed, or changing terrain are challenging projects, the change in fuel composition or characteristics of the vehicle's emission are current projects and consistently implemented. Changing the fuel composition was followed even by eliminating lead and its desulfurization. The vehicle emission reduction is possible by introducing EURO emission standards. The exhaust emission standards Euro (applicable in the European Union) consistently exacerbate limits of emissions of harmful exhaust compounds starting from the year 1988. The main task of the Euro is to reduce emissions of several major harmful compounds - nitrogen oxides (NOx), hydrocarbons (HC), oxides of carbon (CO) and particules (PM).

Despite the work on introducing more and more modern vehicles, pollution caused by transport activities is not reduced. This is mainly due to the growing development of the automotive industry. Therefore, it is necessary to conduct research not only in the technical area, but also in the area of organization of transport operations.

It should be noted that air pollution with harmful compounds do not only come from the area of transport. The other sources of emissions (resulting from the combustion of fuels) are [4]:

– combustion processes in the production and transformation of energy (eg. fuel combustion in power plants, heating plants),
– combustion processes in the municipal housing
– combustion processes in industry,
– production processes,
– area of extraction and distribution of fossil fuels,
– waste management,
– area of agriculture (waste droppings).

2.2. Identification and analysis of areas with the highest air pollution

Identification of areas with the highest air pollution require to characterize and parameterize the elements of transport infrastructure and superstructure. Therefore, each of the transport connections (i, i') characterized by the vector of the compounds of harmful exhaust gases which are emmited by individual means of transport, ie. $<\alpha(1, 1, i, i'), ..., \alpha(s, st, i, i'), ..., \alpha(S, ST, i, i')>$, where s is the number of harmful exhaust compound, and st denotes the number of type of transport.

In order to identify the areas of greatest environmental pollution caused by the effects of transport activity, authors defined as a set of $\boldsymbol{CS}, \boldsymbol{CS}=\{cs : cs=1, \ldots, CS\}$ - number of factors relating to the size of pollution. Polish transport network was divided into areas. *Ob* index indicates a single area. The set of all areas took the form as follows: $\boldsymbol{OB} = \{ob : ob = 1, \ldots, OB\}$. So the overall impact of the various factors affecting individual exhaust harmful compounds generated during driving, which cause the air pollution can be characterized by a function $F(\boldsymbol{CS}, \boldsymbol{S}, \boldsymbol{OB})$ [1].

The analysis of the areas due to the concentration of the individual compounds harmful exhaust emissions was based on a report assessing air quality in the zones of Poland which provides an annual Chief Inspector of Environmental Protection on the basis of data from the provinces [3]. The last such document includes an analysis conducted for the year 2013. The evaluation report was based on two criteria:

– for the protection of human health,
– for the protection of plants.

The Assessment due to the first criterion is subjected to: sulfur dioxide, **nitrogen dioxide**, **carbon monoxide**, benzene, ozone, **PM_{10}**, lead, arsenic, cadmium, nickel and benzo (a) pyrene in PM_{10}, **$PM_{2.5}$**. Due to the second criterion the evaluation is made to: sulfur dioxide, nitrogen oxides and ozone. Bold substances are emitted by means of transport in the form of harmful compounds. That is why they are so important for the development of environmentally friendly transport system.

Measurements are carried out with respect to the zone such as:

– agglomerations with a population of over 250 thousand. (not assessed in terms of plant protection),
– cities with a population of over 100 thousand. (not assessed in terms of plant protection),
– rest of the province, not belonging to the agglomeration and cities with over 100 thousand of residents.

Each zone for each air pollution is classified in one of the classes depending on its level of concentration:

– **A**- not exceeding the permissible level,
– **B**- above the permissible level, but not exceeding the permissible level plus the margin of tolerance,
– **C** - above the permissible level plus the margin of tolerance,
– **D1** - not exceeding level for long-term,
– **D2** - above the level of the long-term.
–

The first analyzed substances that cause air pollution and are derived, from transport are nitrogen oxides (NO_x). The map with areas of Polish classification zones for the protection of human health criterion is shown in Figure. 3. For plant protection criterion the levels of nitrogen oxides are not exceeded.

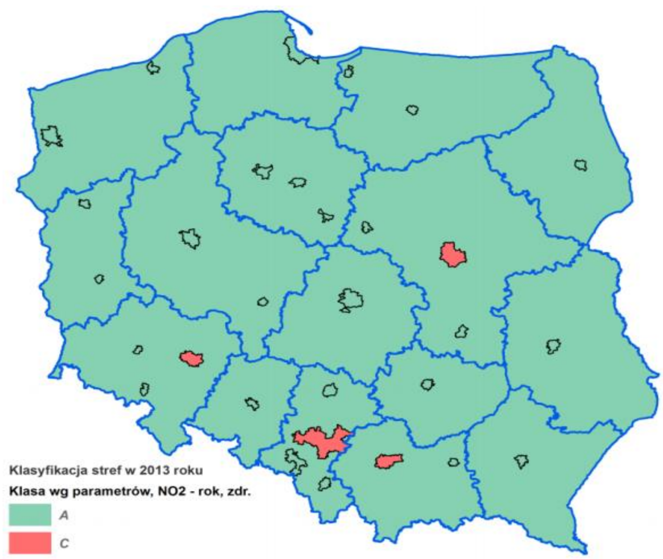


Fig. 3. Classification of zones in Poland for NO_2 for 2013 (the protection of human health)

Analysis of this map shows that in terms of human health protection nitrogen dioxide levels above acceptable levels (40ug / m3) was recorded in four areas: the agglomeration of Warsaw, Cracow and Silesia conurbation and Wroclaw.
Another analyzed the substance that cause air pollution derived from transport are carbon monoxide (CO). All analyzed areas for carbon monoxide pollutant were assigned with Class A, which are the areas where emission limits are not exceeded (Fig. 4).
Another analyzed parameter influencing the level of dust pollution are classified to a group of PM_{10}. Fig. 5 shows the classification of zones from the point of view of protection of human health criterion.
From the point of view of the protection of human health criterion, the level of PM_{10} did not exceed the permissible level (40ug / m3) only in three zones These zones are the following province: zachodniopomorskie, warmińsko-mazurskie and podlaskie. In all the other provinces emission limit has been exceeded.
The last analyzed parameter influencing the level of dust pollution are classified to a group of PM2.5. Fig. 6 presents the classification of zones from the point of view of protection of human health criterion.
Among the areas of Poland, the pollution does not exceed the acceptable levels (25ug / m3) of air pollution with PM2.5 in the following provinces: zachodniopomorskie, warmińsko-mazurskie, kujawsko-pomorskie, lubelskie and lubuskie. Permissible emission levels of $PM_{2.5}$ were also exceeded in Kalisz, Legnica and Wroclaw.
Analysis of these figures (3-6) indicates that only for nitrogen oxides and particulate matter PM_{10} and $PM_{2.5}$ pollution levels were exceeded at least in some places or areas. From the point of view of plant protection criterion, none of the above emission limits of exhaust of harmful compounds exceed acceptable levels.
For the selected zone analyzed above in the previous section of the article, the mathematical model of the traffic flow distribution and a calculation example will be presented.

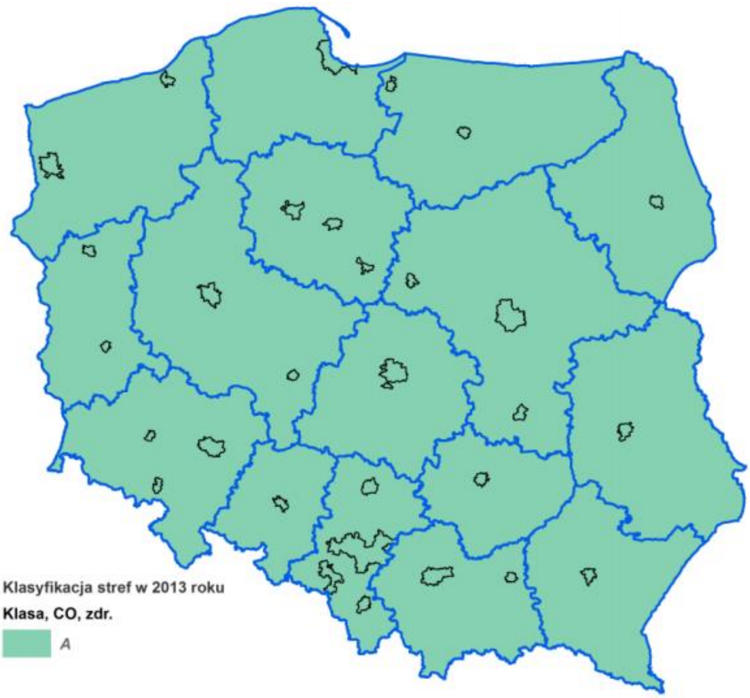


Fig. 4. Classification of zones in Poland for CO for 2013 (the protection of human health)

Fig. 5. Classification of zones in Poland for PM10 for 2013 (the protection of human health)

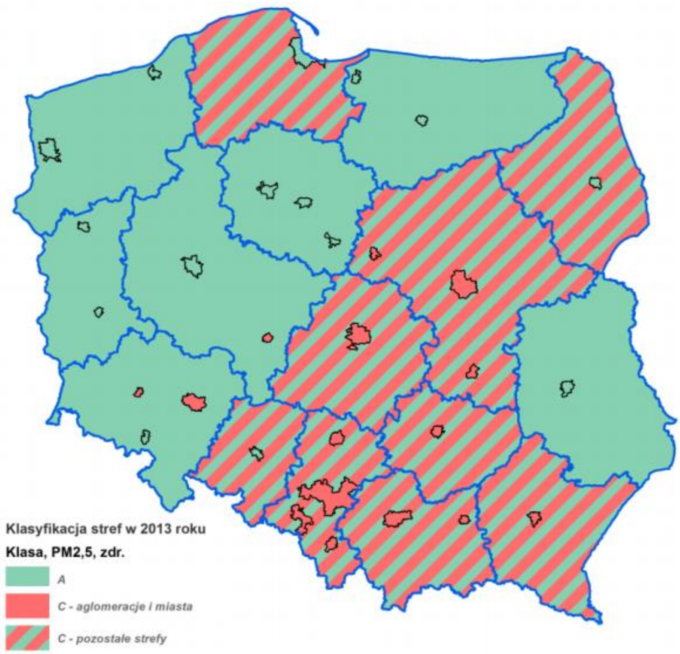


Fig. 6. Classification of zones in Poland for $PM_{2,5}$ for 2013 (the protection of human health)

3. Mathematical model for traffic stream distribution

3.1. Introduction

The movement of goods and people in the transport system is implemented using a variety of means of transport. This means that an increase in the efficiency of the transport system while minimizing harmful emissions can be achieved primarily through the rational use of transport infrastructure. At the same time the parameters of transport infrastructure as well as its distribution, saturation in the geographical areas, the level of technical design and condition affect the ability to maintain, cost, quality and time of transport [6], [8].

The tool for the analysis and evaluation of the operation of existing or projected systems is the model that should be mapped to the system properties that are important from the point of view of the research [5]. Given the nature and the tasks performed by the transport system, it is necessary that the model is mapping properties such as:

- ESTs representing the actual structure of transport links between elements of the system;
- Characteristic elements of the structure of EST mapping the real properties of the elements;
- Transport task EST determining the size of the flows of goods and people in relation origin-source;
- Organization EST shows how to adapt the infrastructure and equipment for the tasks.

For the purpose of research the model of transportation system in ecological terms (**MEST**) was defined as a structured five ***MEST*** = ⟨***ST***, ***GE***, ***FE***, ***QE***, ***OE***⟩ [7].

Construction of the model was determined by the need to define a set of ***ST*** numbers of types of transport means, a set of ***FE*** characteristics of the vehicles and infrastructure elements. The size of the transportation system tasks was determined as ***OE***.

The structure of the model of environmentally friendly transport system defining the relationship between the elements, as well as with the environment was indicated by the graph ***GE***=<***WE***, ***LE***>, where the ***WE*** is a set of elements of punctual infrastructure of the system (nodes), and by ***LE*** determines the set of transport links existing between the elements of the punctual structure.

Relationship between all the elements are determined by existing transport links. Any transportation link is characterized by many parameters such as: the number of lanes, the area in which it is located (city, protected area), capacity and other.

Elements of linear infrastructure (roads, railways) depending on the traffic stream loading them have a different speed of traffic stream, which, as mentioned above determines the amount of harmful emissions.

Variables

Due to the ecological aspect of the transport system, the numbers that are being searched refer to the number of vehicles moving through the transport network. Thus, the decision variable denoted as $x(st,rsp,neu,i,i',k)$ in the formulated optimization task will be understood as a decision variable of a vehicles flow distribution (number of vehicles of that type) on the transport network MEST.

Criteria function(*)

The criteria function has the interpretation of the criterion of minimizing exhaust emissions of harmful compounds.

The search for values of decision variables to minimize the objective function required the development of database containing parameters of the model elements. The data required for the model referred to: types $rsp \in \boldsymbol{RSP}$ of engines powering vehicles $ob \in \boldsymbol{OB}$ areas of a structure of a model, means of transport *k*, the length of transport connections (*i, i'*) between the highlighted elements of the system, the volume of emission (λmax (*s*, *ob*)) of compound *s* generated by *st*-th type of vehicle with an engine of this type *rsp* with the emission standard *neu* while driving at a speed *v*. The model also required the data referring to the maximum level of harmful compounds emission *s* in the area *ob*.

(*) $\forall s \in \boldsymbol{S}$

$$\sum_{st \in \boldsymbol{ST}} \sum_{neu \in \boldsymbol{NEU}} \sum_{(i,i') \in \boldsymbol{LE}} \sum_{k \in \boldsymbol{K}} \sum_{rsp \in \boldsymbol{RSP}} x(st,rsp,neu,i,i',k) l_{i,i'} em(s,st,neu,rsp,v) \longrightarrow \min$$

Constraints

The constraints imposed on the values of decision variables are based on the constraints of the typical traffic stream distribution task [9][10]. These constraints refer to:

– reduction of the implementation of the demand for transport,
– not exceeding the capacity of the transportation connections
– conditions imposed on the stream of traffic, such as traffic stream non-negativity, traffic stream additivity, saving of the traffic stream.
– type of decision variable

4. Case study

4.1. Computation data

For the purpose of research, the traffic stream has been spread on the road and rail network. Analysis of figures 3-6, which represent the areas with the highest degree of pollution fumes indicates that the main factor exceeding the permissible levels of harmful compounds are exhaust partices of $PM_{2.5}$ and PM_{10} particulates.

Computational experiment has been implemented for road and rail networks of Wrocław Agglomeration. The choice was dictated because the annual allowable emissions of harmful exhaust compounds in this agglomeration was exceeded. The distribution of the traffic flow was made using PTV Visum. PTV VISUM provides variety of procedures distributing material and passenger flows into a transport network differing of searching algorithms and demand management. The distribution allows obtaining traffic intensities on elements of transport infrastructure.

The distribution of traffic stream (the stream of passengers) was carried out in two variants. In the first variant the traffic streem was distributed on the road network. In the second variant the traffic flow was distributed on road and rail network. The road and rail network of the Wrocław Agglomeration, is shown in Fig. 7 (black line – road network, red line- rail network)

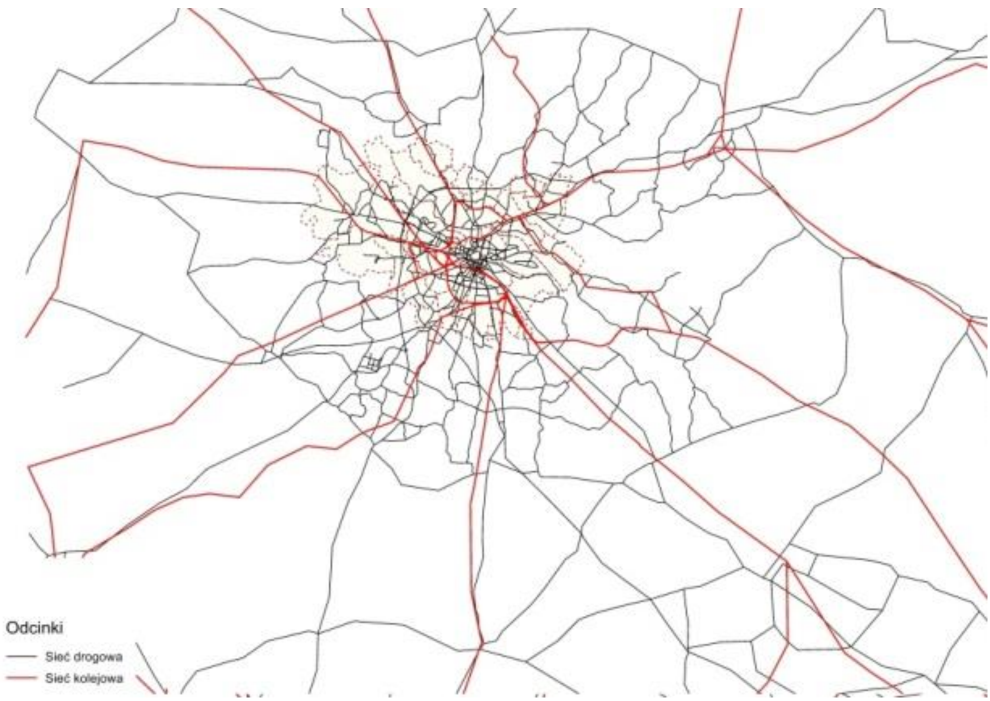


Fig. 7. The structure of a road and rail network of the Wroclaw Agglomeration

4.2. Results

The aim of the variants of traffic stream distribution was to show how the load of road streem will decrease when there is a possibility to travel also by train. Therefore, in the first variant the passangers streem entering and leaving the Wroclaw Agglomeration was distributerd only on road network The results of the distribution for variant 1 are shown in Fig. 8.

The results of the traffic stream distribution in the second variant, where passengers had access to road and rail transport are shown in Fig. 9.

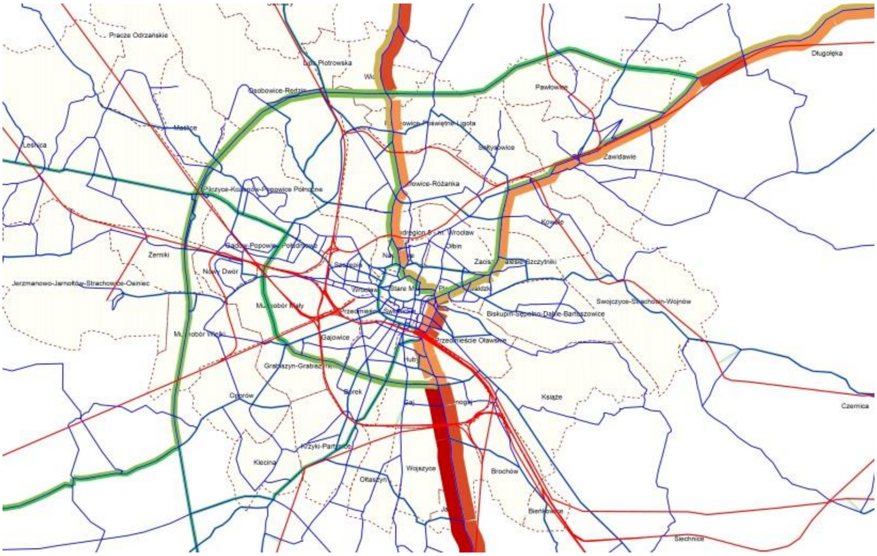
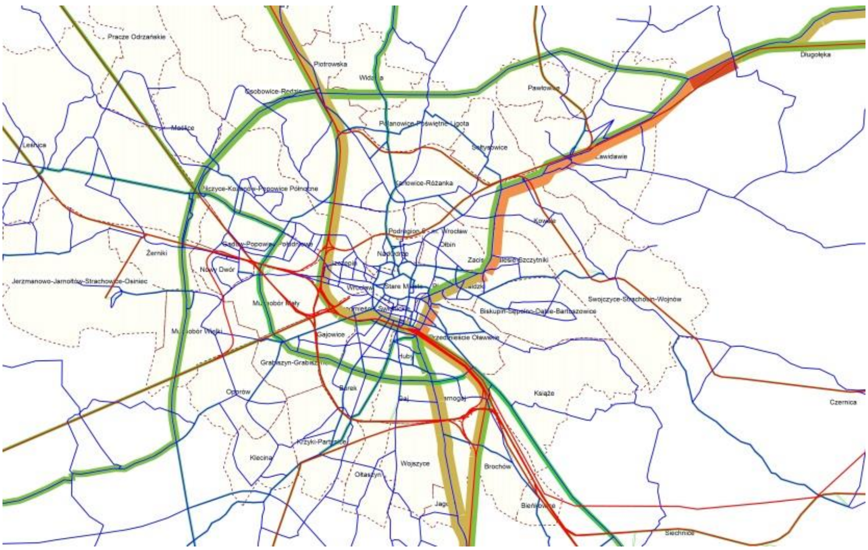


Fig. 8. Traffic stream distriburion the road network of the Wroclaw Agglomeration



Rys. 9. Traffic stream distriburion the rail and road network of the Wroclaw Agglomeration

5. Summary and conclusions

Analysis of figures 8 and 9 shows that the transfer of the traffic stream on the rail network resulted in the decrease in the share of road transport in the realization of the total demand for transport. Half of the road traffic coming from south was moved on rail. Consequently a smaller share of road transport on main roads on Wrocław Agglomeration results in less intensity of pollution from transport powered by a combustion engine. Besacuse of that it is important to move traffic flow from the conventional road transport into rail transport.

From the point of view of maximum allowed emission levels in different zones of Poland, the use of rail transport can be one of the key ways to reduce the total emission in these zones.

Acknowledgments

This work has been carried out under the research project „Designing the proecological transport system" (EMITRANSYS) funded by the National Centre for Research and Development.

References

[1] Ambroziak, T., Gołębiowski, P., Pyza, D., Jacyna-Gołda, I., Merkisz-Guranowska, A.: Identification and Analysis of Parameters for the Areas of the Highest Harmful Exhaust Emissions in the Model EMITRANSYS. Journal of KONES Powertrain and Transport, 2013, cz. 20, nr 3, str. 9-20.

[2] Colovile, R.N., et. al., The transport sector as a source of air pollution, Atmospheric Environment, Vol. 35, Is. 9, pp. 1537–1565, Elsevier 2001.

[3] Inspekcja Ochrony Środowiska: Ocena jakości powietrza w strefach w Polsce za rok 2013, Warszawa 2012, WWW: http://www.gios.gov.pl

[4] Inspekcja Ochrony Środowiska: Zanieczyszczenie powietrza w Polsce w 2009 roku na tle wielolecia, Warszawa 2011, www: powietrze.gios.gov.pl

[5] Jacyna M. (red.): System logistyczny Polski. Uwarunkowania techniczno-technologiczne komodalności transportu, Wydawnictwo Oficyny Wydawniczej Politechniki Warszawskiej, Warszawa 2012

[6] Jacyna M., Wasiak M., Jacyna-Gołda I., Pyza D., Merkisz-Guranowska A., Merkisz J., Lewczuk, K. Żak J., Pielecha J., A holistic approach to modelling of the ecological domestic transport system, Materiały konferencyjne XVIII Congreso Panamericano de Ingeniería de Tránsito, Transporte y Logística (PANAM 2014), Santander, 06-2014.

[7] Jacyna M., Żak J., Jacyna-Gołda I., Merkisz J., Merkisz-Guranowska A., Pielecha J.: Selected aspects of the model of proecological transport system. Journal of KONES, 2013, cz. 20, nr 4, str. 193-202.

[8] Jacyna M., Żak J., Jacyna-Gołda I., Merkisz J., Merkisz-Guranowska A., Pielecha J.: Selected Aspects of the Model of Proecological Transport System, Journal of Kones, Powertain and Transport, Instiitute of Aviation, ISSN 1231-4005

[9] Jacyna M.: Modelowanie i ocena systemów transportowych. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 2009.

[10] Jacyna M.: Some aspects of multicriteria evaluation of traffic flow distribution in a multimodal transport corridor. Archives of Transport 1999, cz.10 nr1-2, str. 37-52.

[11] Komisja Europejska: Biała Księga. Plan utworzenia jednolitego europejskiego obszaru transportu – dążenie do osiągnięcia konkurencyjnego i zasobooszczędnego systemu transportu [on-line].

[12] Komisja Wspólnot Europejskich: Zielona Księga. W kierunku nowej kultury mobilności w mieście [on-line].

[13] Leszczyński J. Modelowanie systemów i procesów transportowych, Oficyna wydawnicza Politechniki Warszawskiej, 1999.