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SIMULATION MODEL OF TRANSPORT SYSTEM OF POLAND AS A TOOL FOR DEVELOPING SUSTAINABLE TRANSPORT

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Abstract: *Paper presents features of simulation model of proecological transport system on the example of Poland. Model allows computational experimentation and inference on transport modal split and emission of pollution in national transport system. Particular elements of the model are characterized: transport networks for different modes, stock of vehicles, demand model for passenger and freight transport, and mechanism of material and passenger flows distribution into a network. Characteristics describing infrastructure, vehicles, and harmful compounds of exhaust gases are given. Model is implemented in PTV VISUM. Road and rail vehicles for passenger and freight transport are characterized and divided into groups according to types. The demand for transport services and emission of exhaust gases components are reflected in model of proecological transport system of Poland. The last part of paper presents exemplary results of research on estimating emission from transport activities.*

Key words: *EMITRANSYS, proecological transport system, simulation, Visum*

1. Introduction

The idea of promoting sustainable development was adopted in 1987, when World Commission on Environment and Development at the United Nations published a report [19] in which it noted that maintenance of an adequate state of the economy is determined by keeping a high level of welfare of society at that time. Achieving this state of economy is possible through introduction of management principles of sustainable development that meets basic needs of the present generation without compromising the ability of future generations to meet their own needs [19].

The concept of sustainable development in the following years was modified several times by United Nations [16], [17]. One of modifications was presented in the report of the International Union for Conservation of Nature (IUCN): "sustainable development is to maximize the net benefits of economic development while protecting and ensuring recreation of usefulness and quality of natural resources in the long term. Economic development means not only increase in per capita income, but also improves other elements of social welfare. It must also include the necessary structural changes in the economy and society as a whole."

The consequence of the ideas promoted by World Commission on Environment and Development was the recognition of sustainable development as one of the main objectives of the policy pursued by European Union. The reasons to carry out this type of policy were [5]:

- excessive dependence on fossil fuels threating economic security, negatively impacts on the environment and on society,
- growing demand for natural resources increases the pressure on the environment,
- accelerating climate change due to carbon dioxide emission and destructive to the economy natural disasters,
- slowly evolving competitiveness which can be increased through the use of ecological solutions such as innovative energy sources.

Transportation, as one of the branches of national economy with destructive impact on the natural environment, stays in the main area of interest of sustainable development. Consequently, this led to the idea of sustainable transport. According to the experts of the European Commission's, transport

system that meets assumptions of sustainable development (sustainable transport) is one that:
- ensures realization of communication objectives in a safe manner, without jeopardizing the health of people and the environment in a manner equal to the present and future generations;
- can function effectively, offers a choice of means of transport and sustains the economy and regional development;
- limits emissions and wastes to make them absorbable through the land, uses renewable resources in the amounts possible to restore, consumes non-renewable resources in amounts possible to replace by renewable substitutes, while minimizing land take and noise" [18].

Despite many negative impacts of transport on the environment (air pollution, climate change, noise, congestion, accidents, etc.) it is also one of the main factors of economic development. Therefore, the effective use of resources of transport system (superstructure and infrastructure) must be sought, while meeting the needs of public transport and minimizing the negative impact of transport on the environment. Sustainable transport must then reflect evenly diverse economic, social and environmental goals.

Unfortunately, Poland has not yet reached a balance in the development of the transport system. This is evidenced by tasks determined in current transport policy documents. The main problems of Polish transport, which should be resolved by 2025, are [13]:
- congestion, especially on national roads and in large urban areas,
- growing negative impact on the environment and civilization,
- high threat to life and limb from transport activity, especially from road mode,
- poor condition of technical infrastructure, especially roads,
- low productivity and low competitiveness of railway transport,
- risks arising from market opening.

The negative impact of transport on the environment and civilization is expressed by [13]:
- greenhouse gases emissions contributing to climate change,
- local air pollution affecting the health of local people and the natural environment,
- taking over valuable nature areas and cutting their continuity (fragmentation) by newly-built strings of technical infrastructure, contributing to loss of biodiversity,
- noise emission threatening human health.

In addition to neutralization of negative impact of transport on the environment and civilization, there is a need to overcome the challenges and external constraints related to ecology including [14]:
- EU environmental policy, in particular climate policy and emission limitations (including greenhouse gas emissions),
- intensifying struggle for access to increasingly limited resources of fossil fuels (oil, gas) resulting in a rapid increase in fuel prices, thus worsening the economic efficiency of transport and competitiveness of whole economy,
- climate change that negatively affects both infrastructure and transport services,
- need to preserve biodiversity and free migration of species.

In many countries, including Poland, a lot of efforts is taken to solve above issues and reduce negative impact of transport on the environment. In this article the particular attention is paid to the problem of modelling transport systems in terms of sustainable transport, especially due to the emission and the impact on air pollution and climate change. Paper introduces and characterizes simulation model of the transport system of Poland and describes selected results of simulation studies.

2. Assumptions for the model of a sustainable transport system

The model is a tool for analysis and evaluation of operation of existing or projected systems. Model should map those system properties which are important from the point of view of research [8]. According to the nature and tasks performed by transport systems it is necessary to include into a model elements and features like: [11]
- databases of types of vehicles used for realization of transport tasks,
- structure of transport links between transport nodes representing existing connections,
- database of technical and economic characteristics of means of transport and infrastructure representing their real and actual properties (derived from existing databases)

- tasks realized by national transport system reflecting transport needs for passengers and cargo movement,
- organization conceived as a way to distribute traffic on the network according to the level of emissions, stock of means of transport, and technical condition of infrastructure.

The scope of research on sustainable transport with disposed model requires including characteristics of transport system important for mapping the impact of transport on the environment. In addition, these parameters will occur in both; model constrains and criteria for assessing the transport system.

In order to study the emissivity of road transport and thereby use of internal combustion engines, the model of environmentally friendly transport system has been developed. Assuming that the database of vehicles is marked as **BST**, the structure of national transportation system is marked as **GE**, databases of characteristics of means of transport and structural elements are marked as **BFE**, the array of tasks performed by the system as **QE**, the organization of traffic on the network as **OE**, the model of environmentally friendly transport system (**MEST**) is noted as structured five:

$$\mathbf{MEST} = \langle \mathbf{BST}, \mathbf{GE}, \mathbf{BFE}, \mathbf{QE}, \mathbf{OE} \rangle$$

Particular elements of the model are described in details in [6], [9], [11] and [15].

The basic element of transport system having a direct impact on the environment is a stock of means of transport. Air pollution emitted by vehicles depends on many factors like: fuel composition, type and basic characteristics of the vehicle, deployment of transport infrastructure, velocity, places of congestion emergence and others. On the other hand measures of air pollution are: emissions and concentrations of primary pollutants (nitro oxides NO_x, carbon monoxide CO, or particulate matters PM_{10} and $PM_{2.5}$ as well as dust and soot). These pollutants have a negative impact on materials and buildings, crops and forests, and most importantly are harmful to the health and life of humans [2].

The fundamental quantity characterizing ecological properties of vehicle is road emission of pollutants, which is a derivative of the mass of pollutants to the route travelled. Emission of pollution is a function of vehicle speed, as well as current acceleration and time elapsed since the start of the engine.

It is assumed that total emission from motor vehicles in the area is a sum of emissions from [4]:

- engines heated to normal operating temperature,
- engines heating to normal operating temperature,
- evaporation of fuel from fuel system of vehicle.

For the purposes of the study it was assumed that investigated transport system hosts vehicles of different types, like cars, trucks, buses or coal cars. The determinants of separating types of vehicles are mode of transport, purpose, and loading capacity. Comprehensive recognition of types of vehicles is necessary for proper distribution of traffic on transport network elements. It was assumed that a set $\boldsymbol{ST} = \{1, ..., st, ..., ST\}$ of numbers of vehicle types is known. In addition, for each defined vehicle type, a set of numbers of individual vehicles $\boldsymbol{N}(st) = \{1, ..., n(st), ..., N(st)\}$ is given.

Particular vehicles, in addition to the mode, purpose and capacity, differ in type of engine and fuel (gasoline, diesel, liquid propane-butane LPG, compressed natural gas CNG or a hybrid engine) and emission standards that vehicle meet. These latter characteristics, for obvious reasons, are relevant to the model adopted for construction of environmentally friendly transport system. The following sets are then defined:

- set $\boldsymbol{RSP} = \{1, 2, .., rsp, ..., RSP\}$ of numbers of engine types,
- set $\boldsymbol{NEU} = \{0, 1, 2, ..., neu, ..., NEU\}$.of numbers of EURO emission standards.

The relations between types of means of transport, types of engines and qualifications of the emission standards are formalized as follows:

$$\boldsymbol{RSP}(st) = \{rsp \in \boldsymbol{RSP} : rs(rsp, st) = 1\}$$

$$\boldsymbol{NEU}(st) = \{neu \in \boldsymbol{NEU} : ne(neu, st) = 1\}$$

Database of vehicles **BST** has been constructed as a three elements vector: $\mathbf{BST} = [\boldsymbol{S}, \boldsymbol{ST}, \mathbf{v}(\mathbf{st})]$. $\boldsymbol{S}$ is a set of types of harmful compounds of exhaust gases. Each st-th type of vehicle is characterized by a vector of technical, technological, environmental and economic parameters:

$$\mathbf{v(st)=[}rsp(st), neu(st), q(st), m(st), c(st), em(s,st)$$

where:

rsp(*st*) – type of engine of *st*-th type of vehicle,
neu(*st*) – EURO standard of *st*-th type of vehicle,
q(*st*) – loading/cubic capacity of *st*-th type of vehicle,
m(*st*) – mode of transport (passenger/freight, railway/road) of *st*-th type of vehicle,
c(*st*) – unit cost of transport by *st*-th type of vehicle.
em(*s*,*st*) – unit emission of *s*-th type harmful compound from *st*-th type of vehicle.

Elements of structure of proecological transport system (***GE***), that is objects like roads, railways, marine and aviation connections define relations between origin, intermediate and destination points of goods or passengers flows, so define also the structure of transport system [9]. Therefore, the following infrastructure is essential for realization transport tasks:

– linear: existing transport connections (rail/ road),
– nodal: spatially separated facilities for handling cargo or servicing passengers (eg. transhipment points, logistics centres, intermodal transport terminals, railway stations, airports), together with appropriate equipment,
– information: all means of communication, data exchange standards and safeguards,
– superstructure: including means of transport which usage is determined by technical parameters of transport infrastructure and economic parameters.

In a formal way structure of environmentally friendly transport system has been mapped using the ***GE*** graph of form:

$$\boldsymbol{GE} = \langle \boldsymbol{WE}, \boldsymbol{LE} \rangle$$

where:
WE – set of transport nodes representing sources and mouths of freight and passenger flows, as well as intermediate nodes, $\boldsymbol{WE} = \{1, \ldots, a, \ldots, b, \ldots, i, \ldots, i', \ldots, WE\}$.
LE – set of transport connections (of various modes) occurring between selected transport nodes.

Database of characteristics of means of transport and structural elements of transport system **BFE** has been constructed as a vector: **BFE** = [**FLE**, **FWE**, **FSP**], where **FLE** database is for connections, **FWE** database is for transport nodes, and **FSP** is a database of transport resources. For example, each transport connection was characterized by a vector of technical, technological and green parameters like flow capacity, length, speed limit, allowed EURO standard or maximum load capacity of the vehicle on the connection.

Linear infrastructure of transport system has been divided by mode of transport (roads, railways, airports and inland water routes, etc.), a class of roads (national, provincial or municipal roads, railway lines of international importance AGC, AGTC or national and regional importance) and their characteristics, design parameters and traffic capacities.

The characteristics of transport network sections in the model include: assignment for modes of transport and for various types of vehicles, allowed emission standards, lengths, costs of using including tolls, speed limits, capacity depending on the number of tracks or the number of roads and number of lanes, directions, categories of railway line or road category and the technical grade of the road, restrictions for permissible gross weight of vehicle, axle load limits, horizontal and vertical gauges, types of areas where the section of road is located (eg. a protected area or an area with limited access for certain categories of vehicles), relevant for estimating the dispersion of exhaust gas: a longitudinal inclination of the road, road noise barriers or other, plantings, frequent wind directions, and the location of the section in the plan (direction).

The model of transport system requires specifying volumes/sizes of transport tasks to execute. Transport tasks are determined by the amount of cargo and number of passengers appearing at the points of origin or departure, and vanishing at the destination points. This is described by two-element vector ***QE*** defined as follows:

$$\boldsymbol{QE} = [\mathbf{X1}, \mathbf{X2}]$$

The first element, ***X1*** is the matrix of demand for freight transport, and the second element, ***X2*** is the matrix of demand for passenger transport.

To model distribution of cargo and passenger flows on the transport network elements, matrixes of demand for transport ***X1*** and ***X2*** must be decomposed to the segments of demand according to technical and economic determinants of transport needs (eg. transport of rock aggregates against the transport of furniture, or transport of passengers to and from work against the transport of passengers traveling on business) - Fig. 1 and Fig. 2. For more information on the methods and algorithms for estimating the demand for freight transport in the selected area of the national transport system and modeling assigning transport tasks in the passenger segment see [12] and [10].

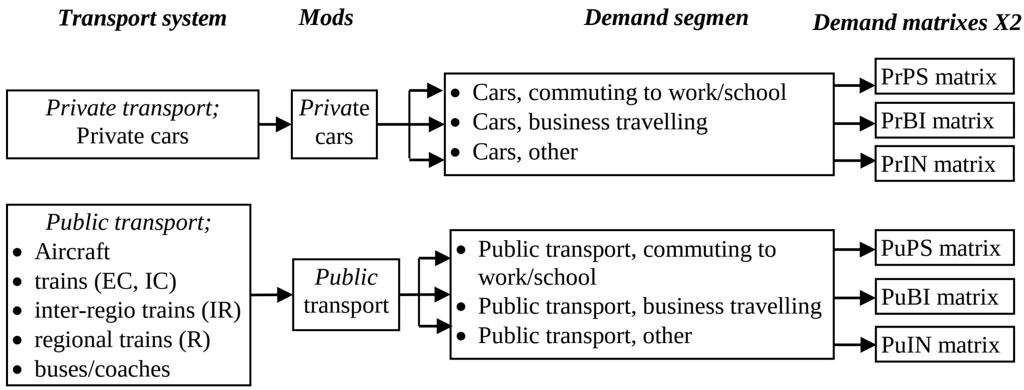

Fig. 1. Dependences between transport sub-systems and segments of demand in passenger transport in model of proecological transport system.

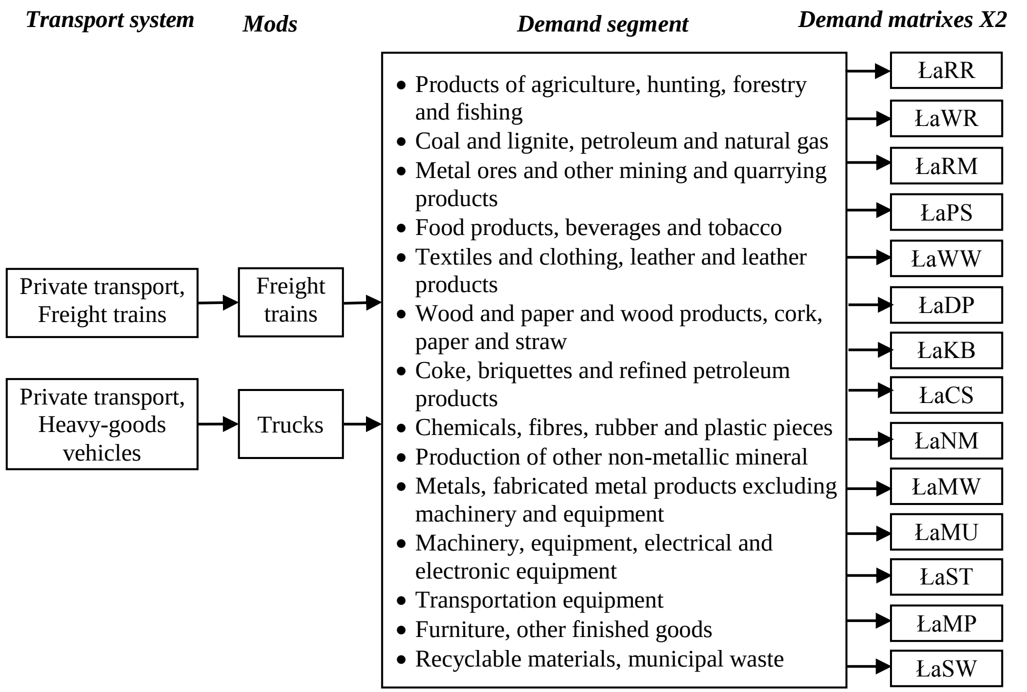

Fig. 2. Dependences between transport sub-systems and segments of demand in freight transport in model of proecological transport system.)

In principle, organization **OE** of traffic on the transport network is a way of matching capacity of the transport system, ie. its equipment to the tasks, to meet technical, economic and ecological constraints and bring established quality indicators to extreme values.
Organization determines the outcome of traffic distribution on the elements of multimodal transport network and on means of transport in the model of environmentally friendly transport system. Thus, organization determines desired way of performing transport due to selected evaluation criteria. In general, these can be written as follows: assuming that volume of harmful exhaust emissions related to engine type and EURO standard on p-th path in transport relation (a, b) is marked by $\psi(s, \mathbf{v}(\mathbf{st}), p\ (a, b))$, the problem is to determine the number $xt(p, st, (a, sb))$ of st-th type means of transport serving freight streams and number $xp(p, st, (a, b))$ of means of transport for the carriage of passengers moving within the transport network on p-th routes in the relations (a, b). At the same time solution quality assessment is done according to selected criterion like level of harmful exhaust emissions given as total amount or direct cost of transportation.
Concluding, one must find the work load on transport links from various types of means of transport as a consequence of identified demand for freight and passenger transport in different segments.

3. Criteria for assessing the distribution of traffic in terms of designing a sustainable transport system

Evaluation of the quality of transport system in terms of its sustainable development is not a simple task. This is mainly due to a number of factors to be taken into account and to be considered in terms of economy, social and environment. Thus, the sustainability of transport is the idea of transportation that meets all expectations of society, is economically beneficial, and minimizes harmful effects of on the environment.
Economic indicators for assessing sustainable transport system are directly related to the cost of moving. The costs consist of [7]: cost of vehicles movement, cost of nodal and linear infrastructure maintenance, costs of construction and modernization of transport infrastructure. Other economic indicators to assess sustainability of transport system relate to the structure of journeys carried out in the system and transport infrastructure.
Exemplary indicators to assess the structure of the movements are [8]:

– modal participation in transport work - defining the share of transport work of given mode according to transport work carried out by all modes of transport in general,
– modal participation of transport work in a particular area - defining the share of transport work of given mode according to total transport work for a fixed area.

Evaluation indicators of transport infrastructure include:

– share of roads of specified category in total linear infrastructure for different modes - the proportion of road length per category in the total road length for each mode of transport in Poland,
– spatial accessibility of various modes of transport - characterizing availability of different modes for the senders and receivers of freights,
– transport performance indicator - specifies the amount of work done per kilometre of transport linear infrastructure,
– vehicle utilization rate - specifies the average filling of vehicle of given class.

In terms of environment and social impact, assessment of sustainable transport system must be related to external costs of transport arising from [7]: pollution, noise, accidents, or congestion. These allow assess the impact of traffic on surroundings of transport infrastructure.
Indicators for assessment of transport system quality from the point of view of emissions are: total emission intensity in the area, the level of exceeding emission limits of particular harmful compounds and types of vehicles, length of roads and lines of different mode in protected areas, number of vehicles meeting given emissions standards.
Indicators for assessment of transport system quality from the point of view of noise are: human productivity loss due to lack of concentration, human productivity loss due to fatigue, lack of sleep and rest, increase in health care services.
Indicators for assessment of transport system quality from the point of view of accidents are:

total number of accidents in the area, number of fatal accidents in the area, the rate of accidents involving pedestrians, the rate of accidents involving cyclists.

Indicators for assessment of transport system quality from the point of view of congestion are: rate of traffic intensity in the area, the flow capacity of transport interconnections, the average speed profiles, etc.

The article presents a study in which emissivity is a main factor influencing sustainable transport system. Therefore, it was assumed that one of the criteria for assessing the distribution of traffic in model of proecological transport system is the size of total emission of particular harmful compounds emitted by vehicles performing tasks on a selected area of transport network. Optimal solution means minimization those criteria:

$$\forall_{s\in \boldsymbol{S}} \sum_{st\in \boldsymbol{ST}} \sum_{(i,i')\in \boldsymbol{LE}} \sum_{(a,b)\in \boldsymbol{E}} \sum_{p\in \boldsymbol{P}_{i,i'}^{ab}} \left[xt(p,a,b,st)+xp(p,a,b,st)\right]\cdot l(i,i')\cdot ema(s,st,i,i')\cdot \psi a(s,st,p,a,b) \longrightarrow \min$$

where individual emission rates $ema(s, st, i, i')$ and $\psi a(s, st, p, a, b)$ are determined according equations 1 and 2, and:

- $xt(p, a, b, st)$ number of st-th type freight vehicles moving on p-th path in relation (a, b),
- $xp(p, a, b, st)$ number of st-th type passenger vehicles moving on p-th path in relation (a, b),
- $l(i, i')$ length of route between i and i'-th nodal points,
- $lp^{max}(st, neu(st), rsp(st))$ number of available st-th type vehicles with $rsp(st)$-th type of engine and $neu(st)$-th EURO standard,
- $\psi(s, st, neu(st), rsp(st), p, a, b)$ the effect of length of transport route on the unit emissions of s-th harmful compound identified for st-th vehicle with engine type $rsp(st)$ meeting $neu(st)$-th emission standard and moving on p-th path in relation (a, b),
- $em(s, st, neu(st), rsp(st), i, i')$ level of unit emission of s-th type compound per kilometre for st-th vehicle with engine type $rsp(st)$ meeting $neu(st)$-th emission standard and moving on (i, i')-th section of transport network.

On the other hand economic criterion of distributing traffic on transport network is the direct cost of transportation. Taking into account previously formulated markings, this one is written by equations 3 where cost c(st, i, i‘) is a set described by formula 4.

$$\forall_{s\in \boldsymbol{S}}\ \forall_{st\in \boldsymbol{ST}}\ \forall_{(i,i')\in \boldsymbol{LE}^{PP}}\quad ema(s,st,i,i')=\frac{\sum\limits_{rsp(st)\in \boldsymbol{RSP}(st)}\ \sum\limits_{neu(st)\in \boldsymbol{NEU}(st)\cap \boldsymbol{NEU}(i,i')} em(s,st,neu(st),rsp(st),i,i')\cdot lp^{max}(st,neu(st),rsp(st))}{\sum\limits_{rsp(st)\in \boldsymbol{RSP}(st)}\ \sum\limits_{neu(st)\in \boldsymbol{NEU}(st)\cap \boldsymbol{NEU}(i,i')} lp^{max}(st,neu(st),rsp(st))} \tag{1}$$

$$\forall_{s\in \boldsymbol{S}}\ \forall_{st\in \boldsymbol{ST}}\ \forall_{(a,b)\in \boldsymbol{E}}\ \forall_{p\in \boldsymbol{P}^{ab}}\quad \psi a(s,st,p,a,b)=\frac{\sum\limits_{neu(st)\in \boldsymbol{NEU}(st)}\ \sum\limits_{rsp(st)\in \boldsymbol{RSP}(st)} \psi(s,st,neu(st),rsp(st),p,a,b)\cdot lp^{max}(st,neu(st),rsp(st))}{\sum\limits_{neu(st)\in \boldsymbol{NEU}(st)}\ \sum\limits_{rsp(st)\in \boldsymbol{RSP}(st)} lp^{max}(st,neu(st),rsp(st))} \tag{2}$$

$$\sum_{st\in \boldsymbol{ST}} \sum_{(i,i')\in \boldsymbol{LE}} \sum_{(a,b)\in \boldsymbol{E}} \sum_{p\in \boldsymbol{P}_{i,i'}^{ab}} \left[xt(p,a,b,st)+xp(p,a,b,st)\right]\cdot c(st,i,i') \longrightarrow \min \tag{3}$$

$$\forall_{st\in \boldsymbol{ST}}\ \forall_{(i,i')\in \boldsymbol{LE}^{PP}}\quad c(st,i,i')=k_l(st)\cdot l(i,i')+\frac{k_h(st)\cdot l(i,i')}{v(i,i',\mathbf{X}^*)}+k_d(i,i') \tag{4}$$

where:
- $k_l(st)$ the average operation cost determined for the unit of distance and dependent on the mileage of *st*-th vehicle,
- $k_h(st)$ the average operation cost determined for the unit of time and dependent on the work-time of *st*-th vehicle,
- $\boldsymbol{k_d(i, i')}$ the additional cost (eg. road fees)
- $v(i, i', \mathbf{X}^*)$ the average speed of the traffic stream on a particular section dependent on results of traffic flow distribution $\mathbf{X}^*$.

The fully formulated optimization task of distribution of traffic flow on the transport network (along with written constrains) for the modeling of proecological transport system are presented and detailed in [1], [2], [3], [9].

4. Simulation model of transport system of Poland

Striving for sustainable transport system is based on its proper designing and organization. This means achieving organization of material and passenger flows at particular resource allocation, reducing difficulties in access to the system for users, while reducing congestion and its excessive burden to the environment. The studies aimed to obtain these objectives are often implemented with tools allowing modeling of transport systems and conducting experiments on them.

In order to support sustainable development of transport systems a model of transport system of Poland was developed in PTV Visum. The computerized tool is intended to support planning and constructing transport system in terms of quantity of pollutants emitted into the environment (degree of environmental pollution) by users – that is traffic participants moving through transport network. The model of the transport system has been divided into two interrelated models:

- Network model – mapping nodal and linear infrastructure of transport system and describing availability of users to individual modes and means of transport. It consists of:
  - sections of roads, railways, waterways, air corridors, etc.,
  - nodes representing ends, beginnings or connecting elements,
  - nodes mapping relevant network elements (eg. places where technical characteristics of infrastructure change, places where freight and passenger flow disappear, appear or convert, places where modes of transport possibly can be changed),
  - communication areas, public transport stops,
  - sections and lines of public transport, together with timetables,
  - etc.
- Demand model – containing information about needs of freight and passenger transport in particular demand segments and with spatial allocation of that demand (communication areas).

Network model embraces national and provincial roads and railways as well as inland water routes and air corridors (actual mileage, other characteristics and parameters relevant to the research purpose). Transport networks of individual modes of transport were superimposed and connected in respective nodes, enabling users to change modes of transport when traveling or conveying.

In addition to the parameterization of transport infrastructure model embraces also railway and bus lines of public transport and appropriate timetables on regional and interregional level.

Constructing a model of sustainable development of transport system also required characterizing means of transport of various modes used to move passengers and cargo. According to that model takes into account a number of different types of vehicles: motorcycles, cars, buses, trucks and vans, electric multiple units, as well as the trains equipped with electric and diesel locomotives. Additionally, model is equipped with functions describing emission patterns of particular pollutants, which – combined with defined stock of vehicles allows to define level of harmful emissions from different transport modes. At the same time, taking into account anticipated changes in the structure of vehicles stock in a function of forecasted usage, it will be possible to identify expected impact of transport on the environment for different scenarios of transport system development.

The character of transport tasks performed by transport system of Poland is determined by types of transported objects (cargo or passenger), features of the cargo, requirements of passengers, transport relations, modes and types of used vehicles, etc. The size of transport tasks is a function of two primary factors: demand for transport reported in passenger and freight segment, and the transport ability arising from infrastructure capacity and availability of means of transport.

Demand for transport services in modelled system is given by OD matrixes (origin-destination) in a specific unit of measure. For the passenger movement it is a number of passengers, and for freight transport it is a number of tons handled per unit of time. Generating OD matrix requires determining points of origin and destination. It was assumed that for the model of large scale transport system of the country, these points will correspond to counties.

PTV Visum, when used to develop sustainable transport system, provides different procedures for distribution of traffic from individual and public transport. These procedures differ in the search algorithm and methods of demand distribution. The result of demand distribution is density of traffic on the elements of transport network (nodes, segments, connections, turning relations, lines, etc.). Functions describing emission of particular types of vehicles, measured in real conditions unit emissions of harmful substances as well as a tool provided by Visum – HBEFA module allow to carry out series of simulation studies related to the estimation of the level of harmful emissions from vehicles in each section of Polish logistics network.

5. Experiments with model implementation in PTV VISUM

To verify correctness of a model of environmentally friendly transport system implemented in PTV VISUM, a number of studies on the emission of harmful compounds by transport were carried out. The following discussion illustrates impact of a freight transport on the amount of pollutants emitted into the natural environment in Poland. Researchers analyzed pollution generated by trucks deployed on transport network according to criterion of minimal transport time, criterion of minimal total distance and criterion of minimal cost of transportation. Material streams are quantified in tons of cargo belonging to 14 material groups like: chemicals, wood, coke, machinery, furniture, metals, non-metallic products, agriculture products, ore, food, transport equipment, raw materials, coal and textiles. Demand for transport is expressed in tons per day in inter-county relations. Obtained results are shown graphically in Figure 3 and Figure 4.

For each analyzed variant the transport volume performed by different modes of transport was calculated (Figure 5), and expressed as percentage share (Figure 6).

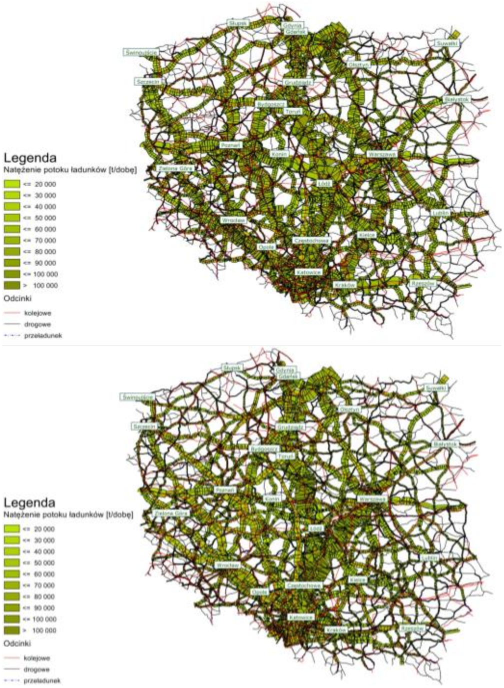

Fig. 3. Distribution of cargo flows on Polish transport network according to criteria of minimal transport time and total distance.

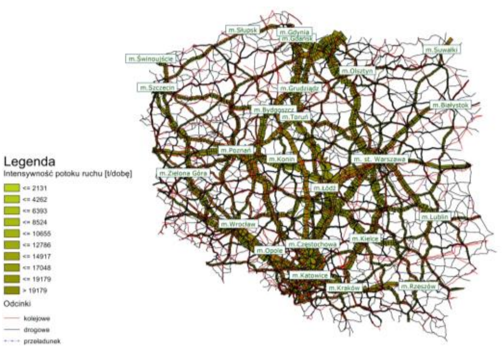

Fig. 4. Distribution of cargo flows on Polish transport network according to criterion of minimal transport cost.

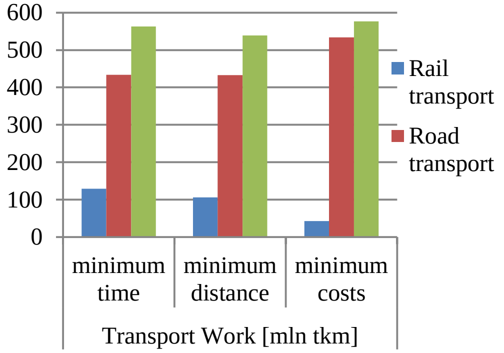

Fig. 5. Transport volume by mode of transport [million ton-km]

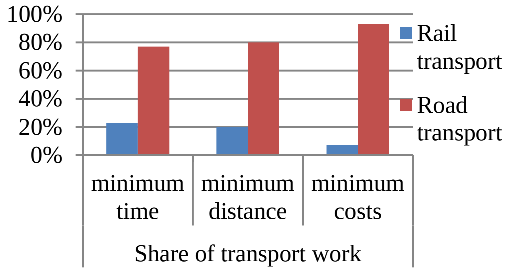

Fig. 6. Share of transport modes in total transport volume.

Due to the primary goal of research, the attention is paid to the road transport as a significantly predominant in transport volume and emission. It was assumed that freight transport will be performed mostly by three types of vehicles - vans, trucks without trailers and trucks with trailers. The results of traffic distribution expressed in a number of tons of cargo moving along particular sections of network were converted into a number of vehicles of each of above types. Calculations are based on data about number of vehicles of different types in segments of transport network resulting from National Traffic Measurements 2010 (an average daily traffic measurement), and their average capacity (determined on the base of data presented in Transportation Activity Results 2012). The share of particular types of vehicles and trucks for each variant is shown in Figure 7.
Number of various types of vehicles on sections of transport network, and their basic movement characteristics were used to estimate emissions of pollutants (CO_2, CO, HC, NO_x, PM) by road transport system as a result of transport of goods.

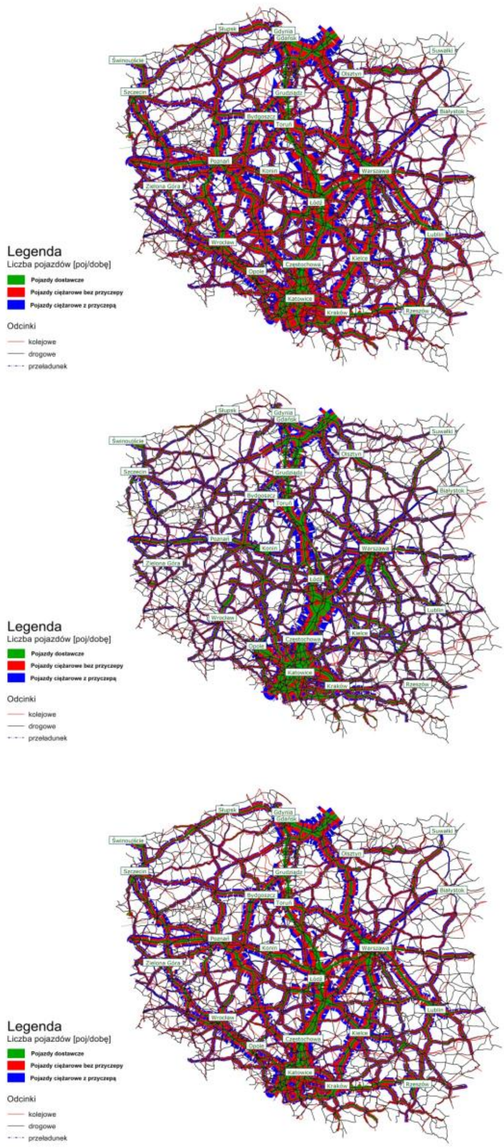

Fig. 7. Freight vehicles of different types burdening transport network of Poland in three variants according to criteria of minimal time of transport, distance and cost.

Calculations were done by HBEFA module provided by PTV VISUM. The emission of pollutants by transport system (expressed in tons) is shown in Figure 8.

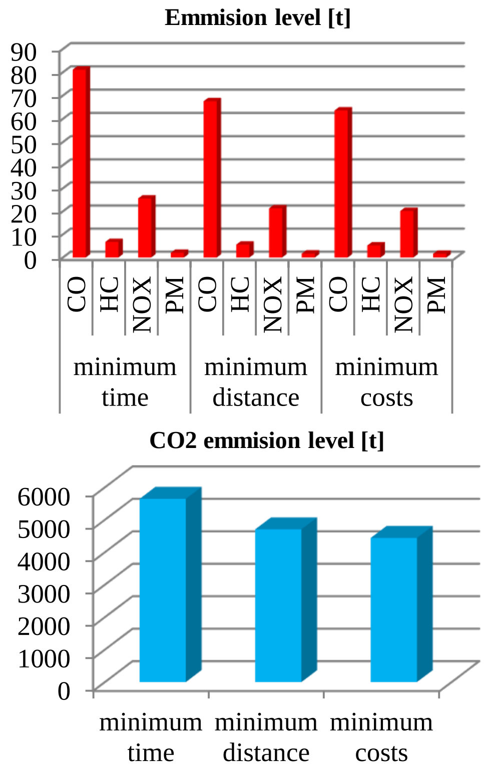

Fig. 8. The amount of pollutants emitted by road freight transport in three different variants of distribution traffic.

6. Conclusions

The idea of sustainable transport, due increasing negative impact on the environment, is an important challenge for twenty-first century society. Implemented for years technical, organizational and legislative solutions bring a significant effect in reducing impact that transport has on environment, but rapid growth in demand for transport (similar to the growth of GDP) and then growth of traffic compensates these achievements. In addition, by analyzing subsequent EURO standards, it can be seen that technical potential limiting emissivity of combustion engines is becoming more and more limited.

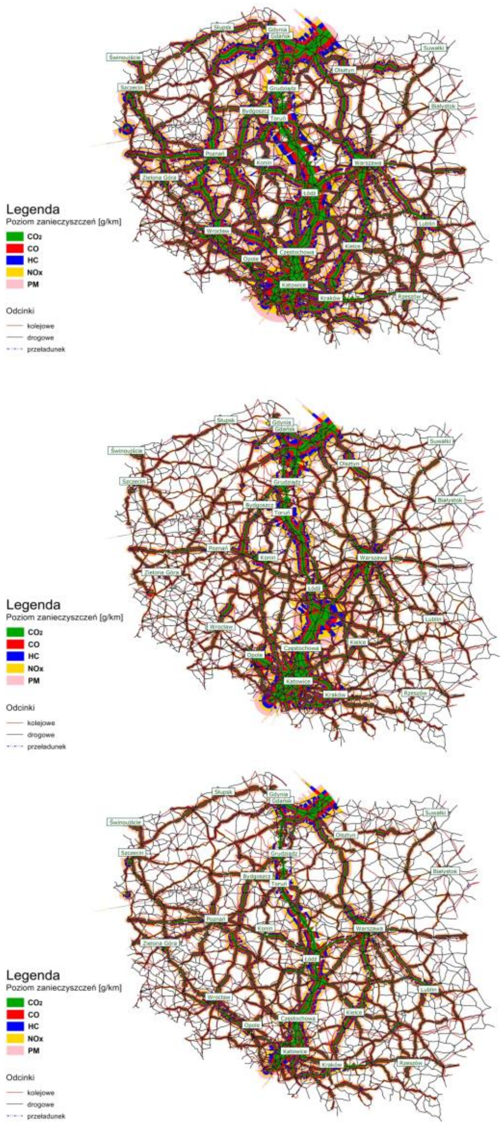

Fig. 9. Unit emissions of particular pollutants in three variants minimizing time of transport, distance and the cost.

With regard to presented evidences, the EMITRANSYS project's main objective is to develop simulation model of environmentally friendly transport system of Poland. Model takes into account emissivity of road transport, which is presently regarded as one of major burdens on the environment. What is worth of noting carried studies allowed identification of functional dependences representing emission of selected harmful compounds under real operating conditions of road vehicles. The resulting model allows obtaining answers about level of harmful exhaust emissions for different variants of traffic distribution on transport network.

As shown in the paper, the model can be used to determine actual level of emissions of harmful compounds of exhaust gases across the country for various criteria of spreading traffic. Simulation experiments revealed that apart from limiting the share of road transport in total volume, an important issue is the choice appropriate means of transport and routes of movement.

The model can be applied to determine scenarios of sustainable transport. It can map infrastructural and rolling stock investments, as well as any legislative solutions for development of environmentally friendly transport system. For example, it is possible to take into account reduction of movement of high-emission road means of transport, or solutions for the full internalization of external costs of transport.

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