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MODELS OF TRAFFIC FLOW DISTRIBUTION FOR VARIOUS SCENARIOS OF THE DEVELOPMENT OF PROECOLOGICAL TRANSPORT SYSTEM

Ilona Jacyna-Gołda[1], Żak Jolanta[2], Piotr Gołębiowski[3]
[1]Warsaw University of Technology, Faculty of Production Engineering, Warsaw, Poland
e-mail: jacyna.golda@gmail.com
[2,3]Warsaw University of Technology, Faculty of Transport, Warsaw, Poland
[2]e-mail: j.zak@wt.pw.edu.pl
[3]e-mail: pgolebiowski@wt.pw.edu.pl

Abstract: *The paper is a result of a research work concerning the development of an environmentally friendly transport system - Project EMITRANSYS. The publication contains the issues of shaping the transport system, where important factor due to the aspect of sustainable development is including the external costs in transport activity. This paper presents a mathematical model of the distribution of the traffic flow in the transport network. The paper presents selected aspects of the problem of multi-variant distribution of the traffic stream on the network transport for defined scenarios for the transport system development. Traffic distribution on the network has been made due to the criterion function – external cost connected with air pollution. The paper presents modal split of traffic ecological flow for chosen scenarios of the development domestic transport system.*

Key words: *distribution of traffic on the network, the external costs of transport, development of transport system*

1. Introduction

The division of tasks between the different transport modes, especially in conditions of market economy, is primarily determined by the results of economic calculations maintained by the transport users. The European Union transport policy increasing emphasis on the efficient development of different modes. Creation of a smooth and coherent transport network is a still current problem, since there are no proposals for a system approach to this issue. There were not the desired effects in promoting the role of intermodal transport in order to reduce the negative environmental effects of road transport.

The main tasks connected with modernising and improving the transport network in Poland are:

infrastructure flow capacity improvement,

1) development of an integrated transport network compatible with European Community standards,
2) improvement of traffic safety and environment-friendliness of investments.

From the analysis of the problem [1], [2], [6], [7], [14], [18] it follows that in modal split between different modes of transport, namely about the structure of the transport system, especially under market economy conditions, primarily decide economic calculation results conducted by transport users. Participants of transport process in a natural way are looking for optimal solutions regarding to meet the traffic needs , where the price of the transport service is essential, but not one decision criterion. The more so because more often dominant factor in assessing of the usefulness of the various modes of transport in the context of their participation in the transport is the concept of comprehensive logistics services, including not only the transport of passengers and cargo, but the whole process, which is the transport chain, from the source which generates a traffic flow to its estuary [8], [9], [10].

In the overall approach to the modelling of transport systems especially in proecological terms, it is important to increase the level of emissions of harmful gases emitted by means of transport.

As is known, the various modes of transport are integral elements of the transport system and development of each of them has certain effects in other branches. Contemporary transport policy of each country draws especially attention to the issue of the relationship between the functioning road transport and other modes of transport, including in particular the rail transport. Because road and rail transport satisfy the basic needs of the buyers of transport services, it is appropriate to analyse the adaptation of rail and road transport infrastructure for performed transport tasks.

Conducted transport policy not only in Poland pay particular attention to reduce road transport because it is noticeable its continuous development, which from the point of view of environmental protection is not beneficial. As is known road transport entails not only the irreversible effects of environmental destruction, but also a greater threat to human life. Therefore, it should be look at ways to support making the right decisions regarding to development of the transport system taking into account the limitation of environmental degradation caused by transport activities [5], [8], [9], [11].

2. Scenarios for the development of transport system - research methodology

To quote the [13], [15] programming development of transport system is to determine the relationship between the forecast for tasks for the transport system, its equipment and the cost of fulfillment of tasks by this system. Models mapping such relations are called models for allocating resources which are necessary to carrying out the tasks.

In this regard, we can talk first about models, which aim is to show the link between size of the tasks performed by the transport system, its equipment and cost of implementation and, of course, ecological problems.

Conducting research regarding to the development of transport infrastructure it is essential to resolve many problems corresponding to the subsequent stages of the investment in infrastructure and changing its parameters. In this approach, the distribution of funds is closely related to distribution of freight flows, and hence with the organization moving traffic flow in the transport network.

Study on the impact of different strategies by managing authority such as transport policy, the behaviour of the transport service providers shaping transport network infrastructure is conditioned by the disposal by these authority relevant tools required to conduct the research. Especially if shaping transport system, taking into account environmental aspects is made. This requires a generalization of the model of traffic flow distribution on the national transport system network in such a way that it was possible and sufficient to assessment of the characteristics of the infrastructure to adapt this system to transport tasks while minimizing exhaust emissions emitted by means of transport.

Hence the study of the development of the national transport system in terms of ecological require solution of many problems corresponding to the subsequent stages of the investment changing the structure and characteristics of the elements of this structure and the total for all stages analysis of results. In carrying out such research becomes justified to define many scenarios for infrastructure development of the transport system, including the development of low emission modes of transport (fig. 1).

For the defined scenarios it should be made the distribution of traffic flow due to the defined quality solution assessment indicators, allowing for measurement of the cost of the level of harmful exhaust emissions for different decision-making situations.

Analysis of many variants of the distribution of traffic flow will allow for modification of characteristics of the infrastructure both point and linear infrastructure elements of the transport system. Modifying transport connections we modify the structure of the transport network.

The analysis of the transport system infrastructure development needs solving many issues, corresponding to successive stages of the investment. We assume that the distribution of financial resources is closely connected with the distribution of cargo i.e. with organization of cargo flows in transport networks. If we modify the characteristics of logistics facilities and transport connections we also modify the structure of the transport network.

In the case of the transport system development should be defined relations between the estimated size of tasks, system equipment and the cost of implementing these tasks. It must be remembered, that the modernization and extension can’t consist only on the creation of an integrated transport network and increase its throughput (although it is very important), but it must impact on the improvement of safety and environmental protection.

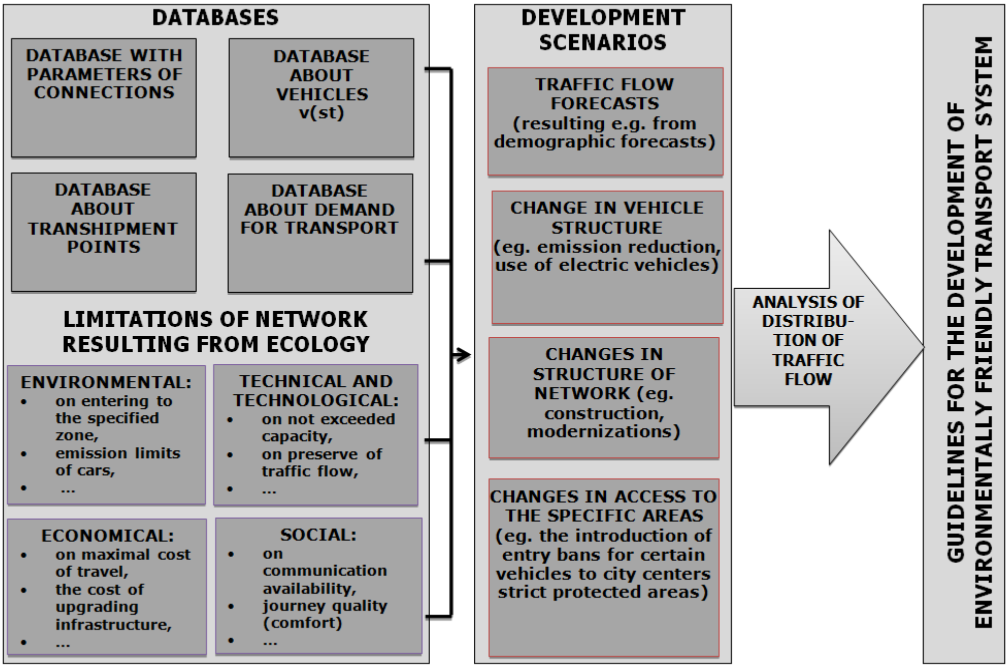

Fig. 1. Scenarios of the transport system development
Source: own work

Degradation impact of transport on the environment pulls together significant costs, both indirect (appear in the design, manufacture, use and destruction of means of transport and infrastructure) and direct (accidents, noise, vibration). Although the effects of this impact is difficult to quantify, it is more and more such studies are conducted (such as Poland) [10].
In the case of the external costs of this heterogeneity is also clearly noticeable. In table 1 is presented a list of external costs for each mode of transport.
In summary the criterion of external costs, allows the prediction of the behaviour of all participants of transport services. The results obtained allow you to select such instruments of preferences – restrictions aimed at providers of transport services, which will result in desirable from the point of view of transport policy, distribution of demand between technology and road transport, and indirectly between transport service providers operating in the system.

Table 1. The size of external costs for each mode of transport

Mode of transport	The sum of external costs	
	min	max
road – in the city	2,1 [eurocents/vehiclekm]	1,92 [euro/vehiclekm]
road – outside the city	1,0 [eurocents/ vehiclekm]	1,09 [euro/vehiclekm]
rail – in the city	48,3 [eurocents/trainkm]	10,77 [euro/trainkm]
rail – outside the city	26,7 [eurocents/ trainkm]	9,2 [euro/trainkm]
air	1605 [euro/flight]	
inland waterways	105 [eurocents/shipkm]	14,82 [euro/shipkm]

Source: own work based on [17].

3. Transport system development models taking into account environmentally aspect

3.1. General assumptions

According to research carried out within the project EMITRANSYS [1], [8], [9], [10], [11], [12] model of the transport system includes a representation of these elements and these properties of the system which are important for point of view the aim of research [13]. This will allow for the ability to analyse and assess the functioning of the existing or projected transport systems.

The model of environmentally friendly transport system (***MEST***) is described as follows:

$$\boldsymbol{MEST} = \langle \boldsymbol{ST}, \boldsymbol{GE}, \boldsymbol{FE}, \boldsymbol{QE}, \boldsymbol{OE} \rangle \quad (1)$$

where:

ST – set of various types means of transport, $st \in \boldsymbol{ST}$,

GE – graph of system structure**,** ***GE***= <***WE***, ***LE***>, where ***WE***={1, ..., *a*,…, *i* , *i'*…, *b*, ..., WE} is a set of elements of the structure and ***LE*** is the set of transport connections,

FE – set of characteristics of elements of the structure,

QE – matrix of transport tasks,

OE – organization of system.

The individual elements of the model are described in detail in the articles [8], [9].

In the model ***MEST*** we defined the following sets:

– ***E*** – transport relations,
– $\boldsymbol{P}^{ab}$ – transport paths for transport relation (*a*,*b*), single path numbered by index *p*,
– ***RSP*** - numbers of engine types, $rsp \in \boldsymbol{RSP}$,
– ***NEU*** – numbers of EURO emission standards, $neu \in \boldsymbol{NEU}$,
– ***S*** – types of harmful exhaust emissions compounds, $s \in \boldsymbol{S}$,
– ***SPT*** - segments of the demand for transport of goods, $spt \in \boldsymbol{SPT}$,
– ***SPP*** - segments of the demand for transport of passengers, $spp \in \boldsymbol{SPP}$.

More information about the structure of ***MEST*** can be found in [8], [9] and [11].

MEST model takes into account the volume of freight and number of passengers appearing in points of origin and the disappearing in points of receipt of goods and passengers, written using a two-element vector ***QE*** = [**X1**, **X2**]. Because the volume of demand is not constant but is subject to constant changes it has been described by distribution of the random variable, respectively:

– for carriage of goods **X1** = [{*X*1(*a*, *b*, *spt*), p(*X*1(*a*, *b*, *spt*))}],
– for carriage of passengers **X2** = [{*X*2(*a*, *b*, *spp*), *p*(*X*2(*a*, *b*, *spp*))}].

Furthermore, in the model included the following parameters:

– {*EM*(*s*,*st*,*neu*,*rsp*,*v*)); p(*EM*(*s*,*st*,*neu*,*rsp*, *v*))} – distribution of the random variable of emission of harmful exhaust gases during the driving with a speed at distance unit,
– connected with vehicles ie. *rsp*(*st*) – type of motor, *neu*(*st*) – a kind of Euro standard, *q*(*st*) – capacity, *c*(*st*) – the unit cost of transport by vehicle type *st*, *q1*(*st*,*spt*) / *q2*(*st*,*spp*) - average capacity utilization / vehicle capacity expressed in weight or number of passengers,
– length *l*(*i*, *i'*) and capacity *d*(*i*, *i'*),
– speed on connection *v*(*i*, *i'*) and speed limit $v^{max}(i, i')$,
– maximal emission of harmful compound of type *s* in connection (*i, i'*), $\lambda max(s,(i, i'))$,
– numer of vehicles type *st* with Euro standard *neu* use for transport *h*(*st*, *neu*),
– derating factor of driving speed depends on the volume of the traffic flow $\Psi(x(i, i'))$,
– external cost factor, $\eta(ob,k)$,
– and others.

Organization of the traffic flow in the ***MEST*** model is the result of the distribution the traffic flow on the elements of the transport network and on means of transport different types. Because of the subject and scope of the research scenarios of the traffic flow distribution are defining by matrices:

– **XT, XT** = [*xt*(*p*, *a*, *b*, *st neu*, *rsp*)] matrix of variables with interpretation of carry goods,
– **XP, XP** = [*xp*(*p*, *a*, *b*, *st*, *neu*, *rsp*)] matrix of variables with interpretation of carry passengers.

If in the model is included the modernization of existing or building new infrastructure additionally are sought values of the amount of financial outlays spent on the modernization of existing or building new infrastructure - *f*(*i*,*i'*), **F**=[*f*(*i*,*i'*)].

3.2. Limiting conditions and indicators of quality solution assessment

Among the restrictions can be distinguished environmental, technical, technological, economic and social constraints. In the group of environmental constraints should be highlighted limitations that affect on reduction of emission by means of transport:

1) on emissions for the transport connection:

$\forall s \in \boldsymbol{S} \;\; \forall (i,i) \in LE$

$$\sum_{rsp \in \boldsymbol{RSP}} \sum_{neu \in \boldsymbol{NEU}} \sum_{st \in \boldsymbol{ST}} \left[\left(xp\begin{pmatrix} i,i',st, \\ neu,rsp \end{pmatrix} + xt\begin{pmatrix} i,i',st, \\ neu,rsp \end{pmatrix} \right) \cdot E\left(EM\begin{pmatrix} s,st,neu, \\ rsp,v \end{pmatrix}\right) \right] \le EM\left(i,i',s\right) \quad (2)$$

2) on the limitation of access to the area because of admissible Euro standard:

$$\forall neu \in \text{NEU} \quad \forall rsp \in \text{RSP}$$
$$\forall st \in \text{ST} \quad \forall (i,i') \in \boldsymbol{L}\text{E} \quad (3)$$
$$\operatorname{sgn} xt\left(st,i,i',rsp,neu\right) neu\left(st\right) \le neu(i,i')$$

$$\forall neu \in \text{NEU} \quad \forall rsp \in \text{RSP}$$
$$\forall st \in \text{ST} \quad \forall (i,i') \in \boldsymbol{L}\text{E} \quad (4)$$
$$\operatorname{sgn} xp\left(st,i,i',rsp,neu\right) neu\left(st\right) \le neu(i,i')$$

3) on the speed of journey:

$$\forall \left(i,i'\right) \in \text{LE} \quad v\left(i,i'\right) =$$
$$v^{max}\left(i,i'\right) \cdot \psi \left(\sum_{st \in \text{ST}} \sum_{neu \in \text{NEU}} \sum_{p \in \text{P}_{ii'}^{ab}} \sum_{rsp \in \text{RSP}} \left(xt\begin{pmatrix} p,a,b, \\ st,rsp, \\ neu \end{pmatrix} + xp\begin{pmatrix} p,a,b, \\ st,rsp, \\ neu \end{pmatrix} \right) \right) \quad (5)$$

It should also be taken into account constraints:

1) resulting from the preset capacity of connections (sections) of paths,
2) resulting from being at the disposal number of means of transport,
3) of decision variables type,
4) connected with traffic flow,
   and others.

Formal writing of mentioned restrictions were presented in the papers [8], [9], [11], [13], [15].

As the efficiency indicators for quality solution assessment of the proecological transport system we can highlights:

1) economic criteria: eg. the cost of transport:

$$\sum_{st \in \text{ST}} \sum_{neu \in \text{NEU}} \sum_{(i,i') \in \text{LE}} \sum_{rsp \in \text{RSP}} \sum_{(a,b) \in \boldsymbol{E}} \sum_{p \in \boldsymbol{P}_{i,i'}^{ab}} \left[xt\begin{pmatrix} p,a, \\ b,st, \\ \text{rsp,neu} \end{pmatrix} + xp\begin{pmatrix} p,a, \\ b,st, \\ \text{rsp,neu} \end{pmatrix} \right] \cdot l\left(i,i'\right) c\begin{pmatrix} i,i', \\ st,rsp \end{pmatrix} \longrightarrow \min \quad (6)$$

2) ecological criteria: e.g. emissions of harmful compounds, the number of vehicles with the least number of vehicles with the lowest numbers of Euro standard used to transport, the external cost or minimize emissions of harmful substances emitted for each of the compounds separately:

$$\forall s \in \boldsymbol{S}, \; \sum_{neu \in \text{NEU}} \sum_{st \in \text{ST}} \sum_{(i,i') \in \text{LE}} \sum_{(a,b) \in \boldsymbol{E}} \sum_{rsp \in \text{RSP}} \sum_{p \in \boldsymbol{P}_{i,i'}^{ab}} \left[xt\begin{pmatrix} p,a, \\ b,st, \\ \text{rsp,neu} \end{pmatrix} + xp\begin{pmatrix} p,a, \\ b,st, \\ \text{rsp,neu} \end{pmatrix} \right] \cdot l\left(i,i'\right) E\left(EM\begin{pmatrix} s,st, \\ neu,rsp, \\ v \end{pmatrix}\right) \longrightarrow min \quad (7)$$

3) social criteria: e.g. availability of transport, external cost of accidents:

$$Kz(\text{i,i'}) = \sum_{(\text{i,i'}) \in \boldsymbol{LE}^{ob}} \sum_{st \in \boldsymbol{ST}(i,i')} \left(\sum_{spp \in \boldsymbol{SPP}} xt\begin{pmatrix} i,i', \\ st,spp \end{pmatrix} \eta \begin{pmatrix} \text{i,i'}, \\ \text{st,spp} \end{pmatrix} + \sum_{spt \in \boldsymbol{SPT}} xp\begin{pmatrix} i,i', \\ st,spt \end{pmatrix} \eta \begin{pmatrix} \text{i,i'}, \\ \text{st,spt} \end{pmatrix} \right) \longrightarrow \min \quad (8)$$

Due to the proecological character of the model, main criteria are the environmental criteria like criterion of external costs and the criterion of the structure of the vehicles due to its emissivity. In this regard, we have proposed three models of solution proecological transportation system:

1) **MoDes_1**- with the minimization of external costs, taking into account existing infrastructure and maximum use of vehicles with high emission standard,
2) **MoDes_2**- with the minimization of external costs with upgrading of existing infrastructure,

3) **MoDes_3-** with the minimization of external costs with the possibility of upgrading or expanding of existing infrastructure and change the structure of vehicle.

The **model MoDes_1** allows on the analysis of the distribution of traffic flow under varying demand with regard to the minimization of external costs, taking into account existing infrastructure.

In the modelling of transport systems it is assumed that description of the structure of the transport system in line with the formalism proposed in sections 3.1 and 3.2 is known. Thus, both locations to the system - inputs and outputs and the transport network with characteristics are known.

In this model is looking for such a distribution of traffic flow in form of matrices:

– **XT, XT** = [*xt*(*p*, *a*, *b*, *st neu*, *rsp*)] – matrix of variables with interpretation of carry goods,
– **XP, XP** = [*xp*(*p*, *a*, *b*, *st*, *neu*, *rsp*)] – matrix of variables with interpretation of carry passengers,

taking into account limitations described by expressions (2) – (6) mentioned in this section and limitations:

1) resulting from the preset capacity of connections (sections) of paths,
2) resulting from being at the disposal number of means of transport,
3) of decision variables type,
4) connected with traffic flow,

so that the criterion functions:

$$Kz = \sum_{(i,i')\in \boldsymbol{LE}} \sum_{st\in \boldsymbol{ST}(i,i')} \begin{pmatrix} \sum_{spp\in \boldsymbol{SPP}} xt\begin{pmatrix} i,i', \\ st,spp \end{pmatrix} \eta \begin{pmatrix} \text{i,i',} \\ \text{st,spp} \end{pmatrix} + \\ \sum_{spt\in \boldsymbol{SPT}} xp\begin{pmatrix} i,i', \\ st,spt \end{pmatrix} \eta \begin{pmatrix} \text{i,i',} \\ \text{st,spt} \end{pmatrix}, \end{pmatrix} \longrightarrow \min \tag{9}$$

achieves the minimum values.

The **model MoDes_2** allows on the analysis of the distribution of traffic flow under varying demand with regard to the minimization of external costs, taking into account modernization or construction of new infrastructure.

In the modelling of transport systems it is assumed that description of the structure of the transport system in line with the formalism proposed in sections 3.1 and 3.2 is known. Thus, both locations to the system - inputs and outputs and the transport network with characteristics are known.

In this model is looking for such a distribution of traffic flow in form of matrices:

– **XT, XT** = [*xt*(*p*, *a*, *b*, *st neu*, *rsp*)] – matrix of variables with interpretation of carry goods,
– **XP, XP** = [*xp*(*p*, *a*, *b*, *st*, *neu*, *rsp*)] – matrix of variables with interpretation of carry passengers,

taking into account limitations described by expressions (2) – (6) mentioned in this section and limitations:

1) resulting from the preset capacity of connections (sections) of paths,
2) resulting from being at the disposal number of means of transport,
3) of decision variables type,
4) connected with traffic flow,

and $F = \sum_{(i,i')\in LE} f(i,i')$ where: F – total cost of the modernization or construction of infrastructure,

so that the criterion functions:

$$Kz = \sum_{(i,i')\in \boldsymbol{LE}} \sum_{st\in \boldsymbol{ST}(i,i')} \begin{pmatrix} \sum_{spp\in \boldsymbol{SPP}} xt\begin{pmatrix} i,i', \\ st,spp \end{pmatrix} \eta \begin{pmatrix} \text{i,i',} \\ \text{st,spp} \end{pmatrix} + \\ \sum_{spt\in \boldsymbol{SPT}} xp\begin{pmatrix} i,i', \\ st,spt \end{pmatrix} \eta \begin{pmatrix} \text{i,i',} \\ \text{st,spt} \end{pmatrix} + f(i,i') \end{pmatrix} \longrightarrow \min \tag{10}$$

achieves the minimum values.

The **model MoDes_3** allows on the analysis of the distribution of traffic flow under varying demand with regard to the minimization of external costs, taking into account modernization or construction of new infrastructure and changing structure of the vehicles.

In the modelling of transport systems, taking into account the principles of sustainable development it is assumed that structure description of the transport system is known and it is compatible with formalism proposed in the model **MoDes_2.**

In this model is looking for such a distribution of traffic flow in form of matrices:

– **XT, XT** = [*xt*(*p*, *a*, *b*, *st neu*, *rsp*)] – matrix of variables with interpretation of carry goods,
– **XP, XP** = [*xp*(*p*, *a*, *b*, *st*, *neu*, *rsp*)] – matrix of variables with interpretation of carry passengers,

taking into account limitations described by expressions (2) – (6) mentioned in this section and limitations:
1) resulting from the preset capacity of connections (sections) of paths,
2) resulting from being at the disposal number of means of transport,
3) of decision variables type,
4) connected with traffic flow,

so that the criterion functions:

$\forall neu' \in \mathrm{NEU}\, neu' \leq 3$

$$\lambda(neu') = \frac{\sum_{st \in \mathrm{ST}} h(st, neu')}{\sum_{neu \in \mathrm{NEU}} \sum_{st \in \mathrm{ST}} h(st, neu)} \cdot 100\% \longrightarrow \min \tag{11}$$

achieves the minimum values.

Presented models show only some of the issues concerning the development of the transport system in proecological terms. Under the project EMITRANSYS was developed [19] seven models considering the specificity of the problem.

4. Distribution of traffic flow in relation Warsaw - Łódź for selected scenarios for the development of transport system

4.1. General assumptions

In order to analyze the impact of decisions on the commitment of financial resources in the development of transport infrastructure and of rolling stock in exchange on lower emissions we made the distribution of traffic flow on the communication line Warsaw – Łódź. Wyróżniono w nim transport drogowy i kolejowy. Distinguished in It road and rail transport. To solve optimization tasks of distribution outlined in section 3.2. models we used hybrid algorithms implemented in the program What'sBest! 10.0. We analyzed a fragment of the transport network shown in fig. 2.

Data on the relationship of transport, characteristics and demand in the segment of interregional transport needs are presented in table 2.

Structure of the analyzed fragment is shown as a graph in fig. 3.

Table 2. Characteristics of the analyzed connections between Warsaw and Łódź

No.	Type of connection	Relation of connection	Length of connection [km]	Journey time [h]	The average price per ride [PLN]
Relation Warsaw – Żyrardów (8500 pass./day)					
1	railway	via Grodzisk Maz.	43	0:55	19,00
2	bus	via motorway A2	60	1:05	19,00
3	car	via motorway A2	61	0:45	26,11
Relation Warsaw – Skierniewice (5500 pass./day)					
1	railway	via Mszczonów	99	2:11	26,00
2	railway	via Żyrardów	66	2:32	23,00
3	railway	via Sochaczew	91	1:31	22,90
4	bus	via motorway A2	90	1:25	26,00
5	car	via motorway A2 and 719	84	1:10	37,00
6	car	via motorway A2	89	1:02	38,09
Relation Warsaw – Łódź (4000 pass./day)					
1	railway	via Mszczonów – Koluszki	174	3:16	44,00
2	railway	via Sochaczew – Zgierz	141	2:03	42,00
3	railway	via Żyrardów – Koluszki	141	2:32	42,00
4	railway	via Sochaczew – Skierniewice – Koluszki	163	2:35	44,00
5	railway	via Sochaczew – Koluszki	168	2:22	44,00
6	railway	direct connection	141	2:12	42,00
7	bus	via motorway A2	140	2:25	20,00
8	car	via motorway A2	129	1:30	64,00

For this study we defined, for the fragment transport network, three scenarios of infrastructure development taking into account the environmental aspect, i.e.:

- in scenario I SC_1 we assumed varying demand and taking into account existing infrastructure. We assumed that in the year 2020 volume of transported passengers will increase by 5% compared to 2014, in 2025 by 8%, and in 2030 by 11%. We used to solve the model **MoDes_1**;
- in scenario II SC_2 we assumed varying demand and taking into account modernization or construction of new infrastructure. Demand forecasts adopted as in scenario I. We used to solve the model **MoDes_2**;
- in scenario III SC_3 we assumed varying demand and taking into account modernization or construction of new infrastructure and changing structure of the vehicles. We used to solve the model **MoDes_3.**

Computational experiments were performed by examining distribution of the traffic flow using a hybrid algorithm implemented the package What'sBest! 10.0 developed by Lindo Systems.

Fig. 2. Scheme of fragment of the transport network (red line – rail connections, blue line – bus connections, violet line – car connections)
Source: own work based on [24]

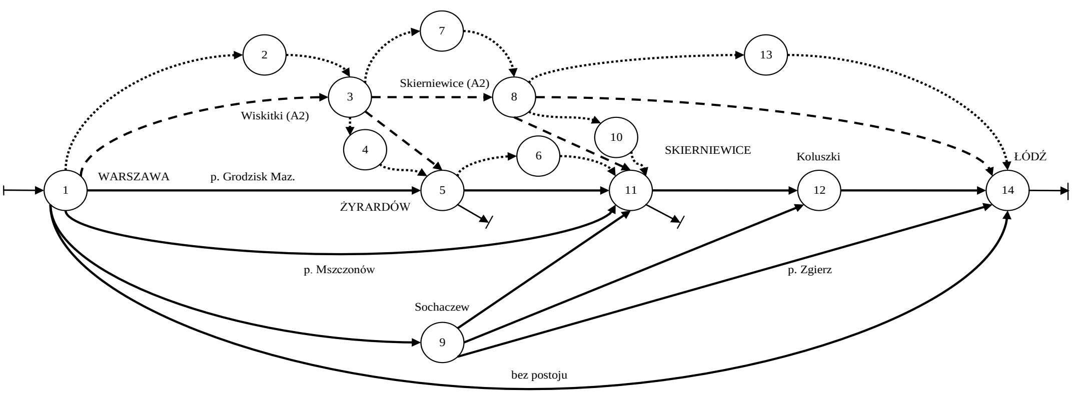

Fig. 3. The structure of connections between Warsaw and Łódź

4.2. Distribution of the traffic flow according to the first scenario

Received from the program What'sBest! results we have implemented in the PTV VISUM and presented in fig. 4.

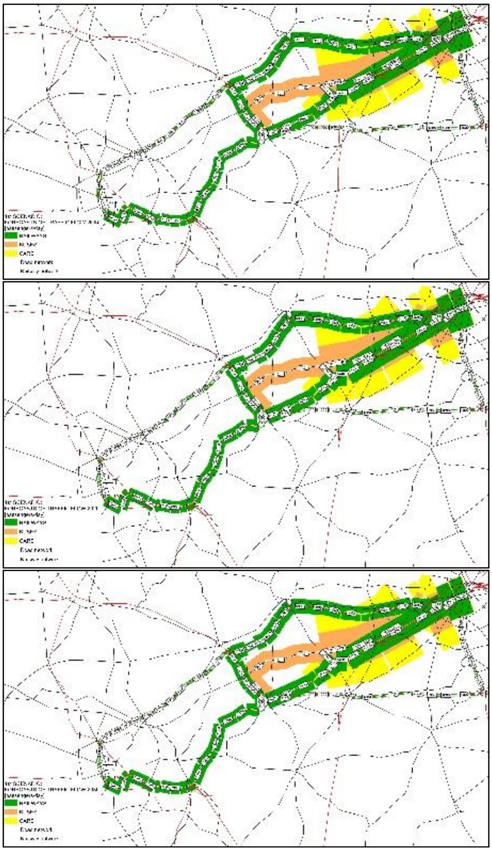

Fig. 4. Distribution of passengers flow for the first scenario in 2014 (a), 2020 (b) and 2030 (c)

Figure 4 shows that the:
- most of passengers were transported using rail transport,
- least of passengers was directed on bus connection,
- among rail connections which are the most loaded, it is modernized connection Warsaw – Żyrardów – Skierniewice, Warsaw – Sochaczew,
- in relation Warsaw – Żyrardów most of passengers drove by road – by individual car and buses,
- in relation Warsaw – Skierniewice not used the car connection,
- in relation Warsaw – Łódź passengers were transported only by rail – connections through Sochaczew and direct connection from Warsaw to Łódź.

The inclusion of forecasts resulted in an increase in the number of passengers, on the car connection in relation Warsaw – Żyrardów (from 6% to 8%) and on direct railway connection Warsaw - Łódź. Growth of the flow has also appeared on the rail connection Żyrardów – Skierniewice (from 3% to 4%).

4.3. Distribution of the traffic flow according to the second scenario

In the conducted experiments it was assumed that in 2015 due to the completion of the next stage of modernization on the line Warsaw – Łódź. In 2020, due to the termination of modernization works in december 2015, assumed that there will be decommissioned railway connections: Warsaw – Mszczonów – Skierniewice, Warsaw – Sochaczew – Skierniewice, Warsaw – Sochaczew – Koluszki and selected on the route Warsaw – Sochaczew – Zgierz – Łódź. Movement between Warsaw and Łódź will be conducted only through the route Warsaw – Żyrardów – Skierniewice – Koluszki – Łódź (due to the improvement of parameters it will increase capacity). Distribution of passengers flow for the years 2014, 2020 i 2030 are shown in fig. 5.

The figure 5b indicates that the liquidation of rail connections launched in connection to the modernization of railway line Warsaw – Łódź caused a complete transfer of passengers flow in relations Warsaw – Żyrardów and Warsaw – Skierniewice from bus connections on the rail connections Warsaw – Żyrardów – Skierniewice – Koluszki and Warsaw – Sochaczew – Zgierz – Łódź and decrease of the load on the road connection.

Increasing the number of passengers which should be transported by a modified in relation (fig. 5c) to the first scenario structure resulted renewed increase of the load on the car connection in relation Warsaw – Żyrardów and increase of the load on the bus connection between Warsaw and Łódź. There was also a slight increase in the load on the rail connection Żyrardów – Skierniewice.

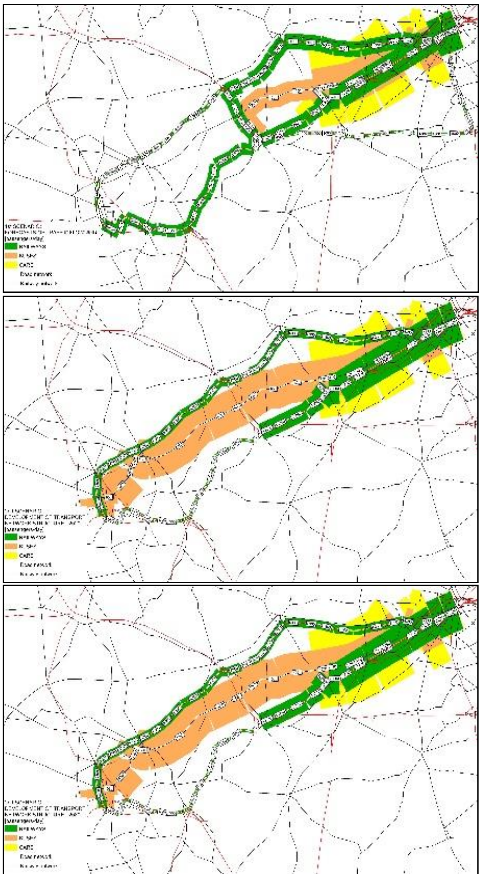

Fig. 5. Distribution of passengers flow for second scenario in 2014 (a), 2020 (b) and 2030 (c)

4.4. Distribution of the traffic flow according to the third scenario

In the third scenario, the development of the transport system is expressed by changing of the structure of vehicles moving along various connections in the analysed fragment of rail-road network. During preparation of the distribution takes into account the first scenario (increasing load), and the second scenario (modification of structure of the transport network). Distribution of passengers flow for the years 2014, 2020 and 2030 are shown in fig. 6.

In 2020, the share of cars that meet the lowest standard was lower as compared to the base year 2014 by 2% and taken into account in the calculation of cars with engines with Euro 6 standard cause a significant decrease load on the car connections (individual automotive) and a large increase on the railway connections. In subsequent years, there has been an increase in importance of road connections.

Presented analysis showed that the restrictions on the network and increasing size of passengers traffic flow to transport without modifying the structure of the transport network and the structure of the vehicle resulted increasing share of road transport in realization of tasks and the partial transfer of traffic flow from rail transport on passenger cars. From the table 3 follows that if they are not made any modernization work and they will not change the structure of the currently riding vehicles total external costs of air pollution will increase.

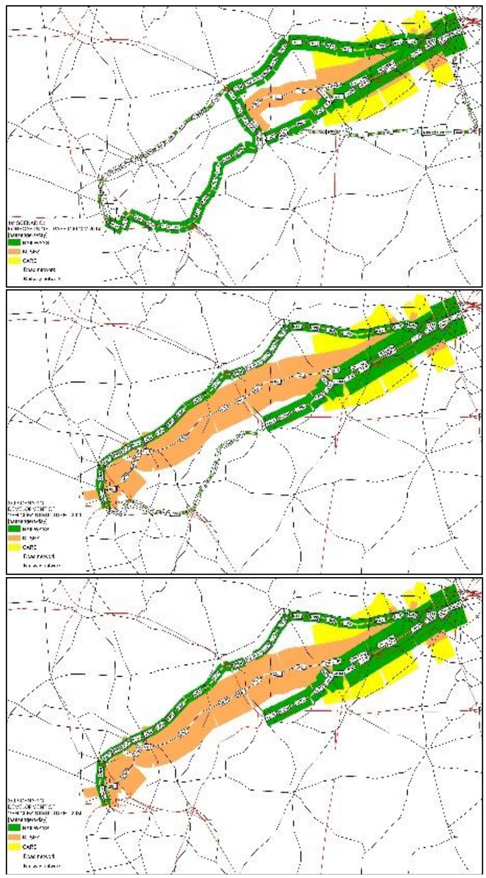

Fig. 6. Distribution of passengers flow for third scenario in 2014 (a), 2020 (b) and 2030 (c)

Table 3. Demand and total external cost for selected scenarios

	SCENARIO I			SCENARIO II		SCENARIO III	
	2014	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**
Demand – railways [pass./day]	12002	12202	12442	15900	15900	15900	15150
Demand – cars [pass./day]	4798	5498	6338	2700	3540	2700	3540
Demand – buses [pass./day]	1200	1200	1200	300	540	300	1290
Total external cost [PLN]	20527	22675	25253	15939	18540	15465	14927

5. Summary

Shaping of sustainable development of the transport system should integrate the social, environmental and economic objectives which are considered both from the point of view of transport policy various countries and the European Union.

Presented in paper approach to the development of the transport system shows that:

1) scenario analysis showed the validity of high-emission vehicles traffic restrictions;
2) actions of transport policy should be directed to the development of infrastructure, especially urban ring roads and areas particularly valuable natural;
3) by limiting access to certain areas of greater emission vehicles in favor of electric vehicles or rail transport;
4) multivariate analysis of transport systems development scenarios allows for the development of guidelines for:
   – the validity of the construction and modernization of infrastructure,
   – the appropriateness of removing infrastructure facilities.

Usage to carry out the distribution of traffic flow PTV VISUM tool allows for performing multivariate analyzes for both the selected area network (eg. communication line Warsaw – Łódź) or the whole of Poland.

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