Rationalization of Cargo Flow Apportioning in the Context of Transport Infrastructure Development

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This paper is a result of work carried out under research grant for development the Model of Logistic System of Poland in terms of transport co-modality. The paper presents problems of rational apportioning cargo flows within transportation network. Regarding transport co-modality, the optimization task of apportioning material flow through transportation infrastructure elements was formulated. The assessment of adjusting transportation network to transportation tasks was provided with regard to transportation system development. Technical and ecological conditions of material movement process were given special consideration.
Key words: rationalization of cargo flows, transport co-modality, transportation system development

1. INTRODUCTION

The division of tasks between the various transport modes (the structure of tasks) is primarily determined by economic calculations carried out by transport users, especially in a market economy. Users are naturally looking for optimal solutions to meet the transportation needs, in which the price for transportation service is a basic, but not the only decision criterion.

Economic growth of the EU members leads to continuous increase of freight transport volume in Europe, resulting in negative occurrences such as congestion, accidents, environment pollution, increased energy consumption in transport (higher fuel consumption, loss of energy). The European Commission is still looking for new solutions in the area of constructing transport networks. More environmentally friendly intermodal transport seemed to be the answer to the rapid growth of road transport. Currently, the EU transport policy puts increasing emphasis on the efficient development of different modes of transport. The concept of comodality appears in this aspect [6]. This is primarily a preference for such forms of transport that will include co-modality defined as a harmonious functioning and cooperating of all transport sub-systems. Wherever possible, transport should be adjusted into a more environmentally friendly, safer and more efficient option.

Formation of transport system should meet both the forecasts of transport needs and EU standards and requirements in this field. This implies the need to consider different interests (objectives) of individual participants of transportation process, in which service quality and delivery time are perceived as measures for transport evaluation.

In this aspect, proper aligning of transportation infrastructure into ongoing tasks requires the following studies and researches:

- modelling rational apportioning of cargo flows in the transport network elements consisting of different modes of transport in aspect of co-modality,
- modelling of rationalization of cargo flows apportioning in terms of adapting transport system infrastructure to ongoing tasks with regard to complementarity and competitiveness of different transport modes,
- assessing the level of adaptation of transportation system infrastructure to the reported transport needs with regard to

usage various forms of transport and co-modality,
- developing a tool based on a system model allowing multi-variant analysis of cargo flow apportioning that covers different types of transport in terms of co-modality.

Therefore studies regarding the rationalization of cargo flows apportioning should take into account both the conditions of transport system within the country and conjunction with neighboring countries as external conditions. It should be noted that the role and importance of different modes of transport to the movement of cargo flows results from their specificity and ability to perform specific transport tasks in given transport relations. Multivariate analysis of cargo flows apportioning should include technical and technological as well as economic and ecological aspects of transport system. Also the organization of various types of logistics facilities such as transshipment terminals, logistic centers, intermodal terminals – including recycling plants – which, by virtue of their functions and tasks, play an important role in the cargo movements. It is also important to enter the different modes of transport in multimodal transport technologies to provide comprehensive logistic services, including not only cargo conveying, but the whole process of movement from the place of origin that generates the cargo stream to its mouth (according to the principles of service delivery "just in time" and "just in place ").

2. TECHNICAL AND ENVIRONMENTAL CONDITIONS OF TRANSPORT SYSTEM IN IMPLEMENTING THE CARGO MOVEMENTS

All documents expressing position of the European Union countries – together with Poland – include the concept of *sustainable transport*. For example, the Polish Constitution stipulates that "the Republic of Poland shall ensure environment protection, guided by the principle of sustainable transport". Sustainable transport system is the one that provides a balance between social and economic factors and the spatial development and environmental protection in each country. Therefore, the proper form of the transport system is the one in which there is a balance between economic and social aspects of a spatial development and environmental protection. The formation of transport system can't be based solely on the consideration of economic or social factors, but must also include the issues of environmental protection. The principle of integrating environmental objectives with the tasks of economic development should apply especially in the transport sector[1].

This means that a sustainable transport system should be[2] safe for human health and life, energy saving and environmentally friendly, i.e. no air, water or land polluting. To include these aspects in the infrastructure investments all participants of the transport process must come to an agreement. This is not an easy task, especially since the development of transport infrastructure requires not only the right decisions, but most of all major financial outlays. The main problems that must be resolved by the year 2020 are:

- congestion, especially on main roads and in large cities;
- growing negative impact on the natural environment and civilization;
- threat to life and health especially in road transport;
- poor condition of technical infrastructure, particularly roads;
- low productivity and low competitiveness of railways;
- risks arising from market opening.

Planning the development of transport system should rely on determining the relationship between the anticipated tasks, equipment and the cost of these tasks. However, the modernization and development can't rely only on building integrated transport network and increasing flow capacity – although it is very important – but must come together with improving safety and environment protection and the quality of the services provided.

Intermodal transport appears as a solution to many problems in the development of sustainable transport. Intermodal transport allows user to combine the strengths of different types of

[1] Ecological Development of the Country, Council of Ministers, Warsaw
[2] National Transport Policy for the years 2005-2020

transport, and thus gain synergy effect emerging in transport efficiency increase and reduce external costs of transport. One of the fundamental dilemmas of modern transport policy is the question of the relationship between road transport and other transport modes, especially railway transport.

Taking into account previously mentioned co-modality of transport, special attention should be paid to increasing the share of rail transport in national transport system[3]. Unfortunately, at present poor quality of rail infrastructure affects the low efficiency and low competitiveness of this mode of transport. As a consequence potential users of rail services give up using it and turn to other modes of transport.

Therefore, models must reproduce dependences between size of the task performed by transport system, its equipment and operational costs, and on the other hand relations between quality and investment inputs for the tasks directed from system surroundings to realization within it. The consequence of a proper distribution of resources is modification of technical and environmental parameters of logistics facilities and transport system (involvement resources in transportation infrastructure and equipment modernization). Obviously, assessing the quality of resources allocation is strongly connected with the level of adapting transport infrastructure to the ongoing tasks and organizing cargo flows throughout the transportation system.

3. FUNDS ALLOCATION IN MODELS OF TRANSPORT SYSTEM DEVELOPMENT

Study on the impact of different strategies performed by managing authority (e.g. transport policy) on the behavior of transport services providers who form transport network infrastructure, is subject to disposal by the authority of the relevant research tools enabling this research. It is necessary to generalize the model of apportioning cargo flows in transport system in such a way as to permit sufficient evaluation of adaptation infrastructure characteristics for ongoing transport tasks.

Studying development of transport system infrastructure requires solving a set of partial problems corresponding to the subsequent stages of investment process changing characteristics of the infrastructure elements. A common analysis of investment results is required at all stages. In case of variable demand, study on the transport system requires solving partial problems where demands are fixed.

Modelling apportioning cargo flows to the transport network requires relevant criteria for assessing the quality of transport system:

- from the perspective of management authority, transport policy, etc. it can be:
  - criterion of average costs – studying predicted behavior of buyers,
  - criterion of incremental cost – examining the expected behavior of suppliers and assessing system "sustainability",
  - criterion of amount of traffic – assessing system usage,
- from the perspective of a buyer of transport services it can be:
  - criterion of time – evaluating the quality of transport services realization,
  - criterion of average cost – evaluating the quality of transport services.

The criterion of time is a component of quality assessment of the transportation system from the perspective of management authority. When referred to the element of the system, it becomes a component of the customer service assessment. It is assumed that measurable values of components describing quality of all the ways of providing transport services within a given part of network do not differ. This allows us to predict behavior of buyers, leaving them the choice of a variant of fulfilling demand for transport services.

Cost criterion, like the time criterion, is also a quality assessment of the transport system from the perspective of management authority but unlike the time criterion it uses all measurable elements of quality. When referred to the fragment of the system, it becomes the criterion used by buyers and allows anticipating buyers' behavior as above.

[3] Green Paper on 'Towards Fair and Efficient Pricing in Transport'. European Commission. COM (95) 691 final Brussels 20-12-1995.
Fair Payment for Infrastructure Use: Aphased approach to a common transport infrastructure-charging framework in the EU. COM (1998) 466 final. Brussels. 27-07-1998

Modeling cargo flows apportioning from the perspective of average costs, allows for the assessment of predicted behavior of transport services buyers' while in terms of incremental costs, to assess the level of investment in the system done by providers of these services.

From the perspective of transport policy it is essential to assess transportation system infrastructure and superstructure adaptation to the range of transport services. This assessment is the basis for making decisions on transport policy aiming to achieve a sort of "balance" between tasks to be performed and equipment of the system (condition and quality of infrastructure). Equilibrium state is the lowest cost of system operation understood as a smallest total sum of costs incurred by purchasers and providers of transport services within a condition of known size of demand or known dependence between demand and prices of transport services.

Thus, one can assume that allocation financial resources is closely related to the apportioning of cargo flows, which is an organization of cargo flows in the transport network. This means that the problem of allocating resources to the tasks should be considered in two shots – the two criteria for optimal apportioning of cargo flows in the transportation network, this is for a apportioning with minimal cost and apportioning securing flow balance.

The selection of transport system equipment to the size of tasks is equivalent to sizing transportation system equipment. Sizing transportation system equipment means matching the proper equipment to transportation tasks. Evaluation of the equipment selection suitability to the transport tasks from a general point of view requires mapping equipment characteristics in the models. These characteristics integrate the characteristics of network elements and vehicles realizing cargo flow. Developing transportation system requires determining relations between estimated size of the task, equipment and task realization costs.

4. SUBJECT OF RESEARCH

GENERAL ASSUMPTIONS

Due to the purpose of research, detail modeling will focus on apportioning cargo flows into transportation network with regard to various types and forms of transport in terms of adaptation infrastructure to the tasks according co-modality of transport.

Many variants of cargo flows apportion must be worked out in a purpose of selecting the solution that meets optimization criteria best. Elements of the transport system can be divided into following types:

- points of origin (the sources of cargo flows);
- places to change means of transport, to consolidate/deconsolidate or store (process) cargos, along with associated point-wise transportation infrastructure, called the transition points;
- collectors (mouth of the cargo flow, receiving points);
- transport relations (connections) between all of these points occurring as existing line-wise transportation infrastructure;
- means of transport determined by infrastructure parameters (sizes, capacities, speeds of movement) and economic parameters (unit-costs);
- organization and information network.

We assume that the points of dispatch and receipt of goods tend to be gravity points for logistics facilities such as transshipment terminals, logistic centers, intermodal terminals, etc. So, it is assumed that all traffic is created and seeks these sites. Thus, the demand for cargo movement can be performed from any object in the transportation network to another located along the same or different passageway. Therefore, for particular transport relations different routes can be chosen, and hence different modes of transport.

The mathematical formulation of adopted findings provides a description of the model of transportation system development (**MDST**) as a set:

$$\mathbf{MDST} = \left\langle \boldsymbol{GD, FD, QD, OD} \right\rangle$$

where:

MDST – the model of transportation system development,

GD – a graph mapping transportation system infrastructure (elements and connections),

FD – a set of parameters (characteristics) of infrastructure elements (point and linear objects),

QD – the matrix mapping sizes of transportation tasks between the origins and destinations points,

OD – all organization rules of performing transportation tasks – routing (transport connections).

Due to the diversity and complexity of processes performed in the entire transportation system many types and variations of infrastructure elements can be distinguished. An important aspect in this regard is to clarify the functions that individual elements can perform in the process of moving loads. This is related to types of cargo flow transformation provided through all the way from the point of origin to point of receipt.

THE STRUCTURE OF TRANSPORT AND LOGISTICS NETWORK

Among the logistics facilities processing cargo flows, as it was mentioned above, we can distinguish in principle: transshipment points, intermodal terminals and logistics centers. For each of these objects several varieties can be found, such as transshipment points serving one, two or three modes of transport. Transport infrastructure that is essential for cargo flow movement is [1, 2, 5, 6, 10]:

- line infrastructure: existing transport connections (railways, roads, sea and air connections),
- point infrastructure: spatially separated facilities for cargo handling equipment (such as transshipment points, logistic centers, intermodal terminals, etc.),
- data communication infrastructure (IT infrastructure): all means of communication, data exchange standards and safety means,
- adequate transport means determined by infrastructure and economic parameters.

Manufacturing and mining facilities, points of recycling and border crossings in import (export) are on the one hand points where cargo flows start, and on the other hand, collectors of these flows. The logistics facilities such as transshipment points, logistic centers or intermodal terminals are the points of changing modes of transportation, places of consolidation/de-consolidation and places of storage (processing) of cargos.

Formally, the structure of the transport system for its development has been enshrined in a graph:

$$\boldsymbol{GD} = \langle \boldsymbol{WD}, \boldsymbol{LD} \rangle$$

in which:

WD – a set of nodes representing sources and mouths of cargo flows and intermediate nodes representing various logistics facilities $\boldsymbol{WD} = \{1, ..., w, w' ..., W\}$,

LD – a set of transport connections (different modes of transport) between the elements of set ***WD*** such as: $\boldsymbol{LD} = \{(w, w'): w, w' \in \boldsymbol{WD} \times \boldsymbol{WD},\ w \neq w'\}$.

According to earlier assumptions, the point elements of transport infrastructure are as follows: points of origin, collection points and points of transition. In order to define a set of numbers of individual elements, it was assumed that function γ assigns elements of set {0, 1, 2} to the elements of set ***WD***:

$$\gamma\colon \boldsymbol{WD} \longrightarrow \{0, 1, 2\}$$

wherein, if $\gamma(w) = 0$ then the w ($w \in \boldsymbol{WD}$) is the number of point of origin, if $\gamma(w) = 1$, then w ($w \in \boldsymbol{WD}$) is the number of collection point, and if $\gamma(w) = 2$, then w ($w \in \boldsymbol{WD}$) is the number of transition point.

Therefore, we can define sets of numbers of point elements of transport infrastructure:

– points of origin (sources):

$$\boldsymbol{N} = \{w \equiv n\colon\ (\!(w) = 0, \qquad \textbf{for } w \in \boldsymbol{WD}\}$$

– points of collection (receivers):

$$\boldsymbol{O} = \{w \equiv o\colon\ (\!(w) = 1, \qquad \textbf{for } w \in \boldsymbol{WD}\}$$

– points of transition:

$$\boldsymbol{P} = \{w \equiv p\colon\ (\!(w) = 2, \qquad \textbf{for } w \in \boldsymbol{WD}\}$$

Points of origin and points of collection are raw materials sources, industrial plants, seaports, recycling plants, etc. These points differ according to types of products they send or receive (groups of products) and according to the loading equipment, technology and internal infrastructure they dispose. Origin and collection points have a specific location described in geographical coordinates. Central Statistical Office gathers the data on the production of 488 articles grouped in 25 or 16 homogeneous groups of assortment.

The following types of points of origin were distinguished:

- set of numbers of material sources,
- set of numbers of production plants,
- set of numbers of recycling plants, etc.,

Similarly, following types of points of cargo flow collection were distinguished:

- set of numbers of border crossings identified depending on the type of transport,
- set of numbers of industrial plants identified depending on the sector,
- set of numbers of logistics facilities identified depending on their types, etc.

With regard to transition points such as different types of logistics facilities it was assumed that these objects can be an interface among different modes of transport involved in the process of cargo movement. Logistics facilities concentrate cargo flows and distribute them to the different modes of transport. This requires equipping these objects with appropriate infrastructure and loading equipment determined by:

- the type of loading units serviced on entry and on exit of the point;
- the type of supported modes of transport;
- annual cargo loading volume and cargo flow unevenness;
- diversification of cargo flow structure
- the scope of physical transformation taken on cargo;
- time of storage of individual material groups (average storage time, etc.).

Following types of transition points were distinguished:

- set of numbers of loading points identified depending on the number of served modes of transport,
- set of numbers of terminals identified depending on the number of served modes of transport,
- set of logistics centers identified depending on the performed tasks.

Connections between the elements of the structure are operated in the direct transport connections between:

- points of origin and points of transition (logistics facilities) of cargo flows;
- selected transition points (logistics objects);
- points of origin and points of collection of cargo flows (direct connections).

Assuming that cargo movement may be performed by different modes of transport, including road, rail, sea, inland waterway, air and others (eg, pipelines, cable railway, etc.) the set of transport connections was defined. The set of modes of transport will be $\boldsymbol{T} = \{t_a: a=1, \ldots, A\}$, where: railway transport (t_1); road transport (t_2), inland waterways (t_3), air transport (t_4), maritime transport (t_5) and another (t_6) (pipelines, cable railway, etc.). Thus $A = 6$.

Between specified points of origin and points of collection and logistics facilities many transport connections exist, so different modes of transport must be taken into account while mapping of transport connections within a multimodal transportation corridor[4]. For this purpose function α assigns elements of the set $\{0, 1\}$ to the Cartesian products $\boldsymbol{WD}\times\boldsymbol{WD}\times\boldsymbol{T}$:

$$\alpha\colon \boldsymbol{WD}\times\boldsymbol{WD}\times\boldsymbol{T} \longrightarrow \{0, 1\}$$

wherein, if $\alpha(w, w', t_a) = 1$ then transport connection t_a exists between point elements w, w', ($w, w' \in \boldsymbol{WD}$) of transportation infrastructure and $\alpha(w, w', t_a) = 0$ otherwise.

Research on rational apportioning of cargo flows demands defining a set of databases:

- point infrastructure of transport database,
- line infrastructure of transport database,
- interfaces between databases,
- central database.

[4] Multimodal transportation corridor is a sequence of transportation nodes (logistics centers) connected by different types of communication roads [4].

Databases containing parameters of infrastructure should base on geographical coordinates describing the point and linear elements of transport infrastructure supporting logistics system. This will enable the transfer of and use parameter values in the practical handling of the model. In addition, results obtained from the model apply to the periods corresponding to database updates.

CHARACTERISTICS OF STRUCTURE ELEMENTS

Analyzing or evaluating any process or a system, it is crucial to find a clear standpoint from which this analysis or evaluation can be done. Transportation network can be evaluated by indicators such time of travel (transportation, supplies), cost or quality of task realization, etc. the aim of this study is to develop tools for multivariate analysis of rationalization the cargo flows apportioning at both the national transport network and in conjunction with foreign markets, from the perspective of transport co-modality.

The technical and economic parameters of transport connections and major transshipment hubs are important. In order to minimize cargo flow cost and to maximize transport service quality [3, 4, 5] following technical and economical parameters of line infrastructure are important:

- maximum axle load, maximum total weight, maximum displacement;
- dimensions of loading gauge restricting sizes of loads that can be moved;
- geometric parameters of the route (lengthwise inclination, radius of arcs);
- technical and maximal speed limits;
- selected transport route time of travel
- flow capacity of each connection.

and parameters of point infrastructure:

- number of vehicles which may be served simultaneously at the point;
- storage capacity and permissible unit-pressure on ground;
- capacity of loading equipment;
- flow capacity of loading points;
- flow through-time (time to move cargo through the system),
- cost of cargo pass through the loading point, etc.

The parameters mentioned above depend on how modernized and developed the infrastructure is and on the current operation. However, in the first case, their values are corrected, while in the latter case, usually values of technical parameters are reduced (eg speed limits, etc.).

The loading point capacity, defined as ability to receive and dispatch a certain volume of cargo per unit time, is determined by equipment and work organization patterns. Throughput of transition point is associated with costs that are a function of handled cargo flow volume and type of used equipment. Thus, the flow capacity of logistics objects can be changed by the modernization of equipment due to its type and quantity. This entails adequate investment and affects the total labor costs. In these conditions co-modality can be seen as a way of increasing the flow capacity of transition points for selected groups of materials and modes of transport while reducing labor costs at these points.

The cargo flow volume for a fixed transport relation (n, o) is denoted by $\boldsymbol{x}^{\boldsymbol{no}}$, where $n \in \boldsymbol{N}$, $o \in \boldsymbol{O}$ and $\boldsymbol{N}$ is a set of numbers of cargo flow sources, while $\boldsymbol{O}$ is a set of numbers of collection points (receivers) of cargo flow. A set of transport relations is denoted as $\boldsymbol{E} \subset \boldsymbol{N}\times\boldsymbol{O}$, where $(n, o) \in \boldsymbol{E}$. The volume of cargo flows (transportation tasks) between points of origin and points of receipt can be represented as three-dimensional matrix $\mathbf{X}$ with elements $x(gp, n, o)$ tj.: $\mathbf{X} = [x(gp, n, o)]$, where gp is the number of group of transported material (see Table 1).

5. OPTIMIZATION TASK OF APPORTIONING CARGO FLOWS IN ASPECT OF TRANSPORTATION INFRASTRUCTURE DEVELOPMENT

In order to provide apportioning cargo flow it is crucial to select routes which comply with technical and economical restrictions. Among the technical limitations of transportation network the flow capacity is the most important one. Minimal usage of route flow capacity is associated with high unit-costs of transport. This is economic limitation imposed on cargo flow. Excessive but still allowed usage of route flow capacity is associated with high transport costs resulting from high cost of congestion. With a funding volume S, we can make appropriate modifications to individual parameters.

The problem of transport system development is formulated as an optimization task of simultaneous apportioning of cargo flows and financial resources available. The values of decision variables that meet defined conditions and restrictions for which the criterion function has extreme value are sought.

As conditions for apportioning of cargo flows in the transport network we take the volume of traffic **X**=[$x(gp, n, o)$] in particular transport relations $(n, o) \in \boldsymbol{E}$, the structure of transportation system given as a graph GD = $\langle \boldsymbol{WD}, \boldsymbol{LD} \rangle$, and funding volume S for infrastructure modernization.

As constrains steering an optimal apportioning of cargo flow we assume limitations from functions described on the graph nodes $\boldsymbol{F}_{\mathbf{WD}}$ and (or) edges $\boldsymbol{F}_{\mathbf{LD}}$. Among the constrains for transportation network, we distinguish constrains dealing with nonnegative cargo flows **NP**, additivity of cargo stream **AP**, constrain for so-called cargo flow preserving **ZP**, and constrain for limited financial resources S staying at the disposal.

We assume that alternative options for the cargo flows apportioning in the transport network will be numbered by r. Let $\boldsymbol{R}$ be a set of numbers of al alternative apportioning of cargo flows in the transport network:

$$\boldsymbol{R} = \{1, ..., r, ..., R\}$$

where R is a total number of alternative apportioning of cargo flows.

Tab. 1. Classification of groups of material, loading units, vehicles and equipment used

Types of material by CSO classification[5]		**Loading units classified according to susceptibility to transport**		**Types of means of transport according to loading capacity and mode of transport**		**Types of infrastructural equipment of logistics facilities**
Number of gp	***Group of materials***	***Type of unit***	***Unit name***	***Mode of transport***	***Mean of transport***	***Equipment type***
1.	Products of agriculture, hunting, forestry, fish and fishing products	**Piece units**	Pieces, packed pieces	**Road**	Selecting means of transport due to the type of loading unit, material groups and individual needs of receivers such as; vans, low, medium and high tonnage trucks and lories, etc.	Equipment allowing to change mean of transport and other operations such as storage, consolidation etc.
2.	Hard coal and lignite, crude petroleum and natural gas		Crates, boxes, plastic containers			
3.	Metal ores and other products of mining and quarrying		Bags			
4.	Food products, beverages, tobacco products		Barrels, bottles, kegs, buckets			
5.	Textile products and clothing, leather and leather products		Bales, rolls, drums			
6.	Wood, wood and cork products, paper products		Packages, bundles	**Railway**[6]	Selecting types of rail cars depending on the type of loading unit and material group such as; open rail cars, tanks, platforms, tankers, etc.	Equipment allowing to change mean of transport and other operations such as: road terminal, inland terminal, pallet warehouse, air-conditioned warehouse, storage yard etc.
7.	Coke, briquette and products of petroleum refining	**Standardized units**	Palletized load units 1200x800 mm			
8.	Chemicals and chemicals products		Standard transportation basket/crate			
9.	Other non-metallic products		Pallet-tank based on standard palletized load unit			

[5] Classification by „Transport – activity results in 2009" by Central Statistical Office.

[6] Types of used locomotives or traction units are not considered.

Types of material by CSO classification[5]		**Loading units classified according to susceptibility to transport**		**Types of means of transport according to loading capacity and mode of transport**		**Types of infrastructural equipment of logistics facilities**
Number of gp	***Group of materials***	***Type of unit***	***Unit name***	***Mode of transport***	***Mean of transport***	***Equipment type***
10.	Metals, metallic finished goods		Transportation bags (big bags)			
11.	Machines, tools, electric and electronic equipment		Universal standardized container (20 ft)	**Inland water**	Selecting types of inland means of transport depending on types of loading units and material group such as; barges type BI and AI etc.	Equipment allowing to change mean of transport and other operations such as: floe storage yards, tanks for liquids etc.
12.	Transportation equipment		Swap bodies			
13.	Furniture and other finished goods		Bimodal trailers	**Air**	Selecting types of aircraft depending on types of loading units and material group; such as transport aircraft with a capacity of 65 tons, etc.	Equipment allowing to change mean of transport and other operations such as: customs warehouses etc.
14.	Recyclable and municipal waste	**Mass units**	Bulk – in tones			
			Bulk – in cubic meters			
			Bulk – in liters (hectoliters)			

Source: compiled on the basis of *[7]*

Furthermore, we assume that transport relation (n,o), $(n,o)\,\boldsymbol{E}$ consists of set $\boldsymbol{P}^{no}$ of routes numbered by index d, $d\in\boldsymbol{P}^{no}$.

The formulation to the problem of transport system development cost minimization can be presented as follows:

For data:

$$\boldsymbol{G}=\langle \boldsymbol{W},\boldsymbol{L}\rangle,\ \boldsymbol{P}^{n\,o}\ ,\boldsymbol{E},\boldsymbol{GP},\boldsymbol{R},$$

$$\boldsymbol{X}^{no}=\left[x^{no}\left(gp,r\right)\right],\ \mathbf{S}(r);\boldsymbol{C}_1=\left[c_{ij}\left(x_{ij}\ (gp,r),s_{ij}(r)\right)\right],$$

$$\boldsymbol{C}_2=\left[c_i\left(s_i(r)\right)\right]$$

where:

$s_{ij}(r)$ – funds used to modify the connection $(i,j)\in\boldsymbol{L}$;

$s_i(r)$ – funds used to modify the node $i\in\boldsymbol{W}$;

$\mathbf{S}(r)$ – funds available in variant r;

$x_{ij}\left(gp,r\right)$ – volume of cargo flow on connection $(i,j)\in\boldsymbol{L}$,

$c_{ij}\left(x_{ij}\ (gp,r),s_{ij}(r)\right)$ – cost of cargo unit movement through transport connection $(i,j)\in\boldsymbol{L}$ with volume of cargo flow on connection $x_{ij}\left(gp,r\right)$ and funds $s_{ij}(r)$,

$c_i\left(s_i(r)\right)$ – cost of cargo unit movement through the node $i\in\boldsymbol{W}$ with funds $s_i(r)$,

$\boldsymbol{P}^{n\,o}$ – set of routes in transport relation $(n,o)\in\boldsymbol{E}$,

$\boldsymbol{P}$ – number of routes in transport relation $(n,o)\in\boldsymbol{E}$,

$\boldsymbol{N}^{o}$ – set of cargo sources (origin points) sending cargo to o-th collection point,

$\boldsymbol{O}^{n}$ – set of collection points receiving cargo from n-th source.

Determine:

Funds distribution: $\mathbf{S(r)}^{*}=\left[s_{ij}(r)\right]$, $\mathbf{S(r)}^{**}=\left[s_i(r)\right]$ and cargo flow apportioning: $\boldsymbol{X}(r)^{*}=\left[x_{ij}\ (gp,r)\right]$ in transport network.

At constraints:

1° spending funds for modernization:

$$\forall r\in\boldsymbol{R}\ \sum_{(i,j)\in\boldsymbol{L}} s_{ij}(r)+\sum_{i\in\boldsymbol{W}} s_i(r)\le S(r)$$

2° realization of the demand for transportation

$$X^{no} = \left[x^{no}(gp,r)\right]:$$

$$\forall gp \in \boldsymbol{GP}, \forall r \in \boldsymbol{R},$$

$$\forall (n,o) \in \boldsymbol{E}$$

$$\sum_{p\in \boldsymbol{P}^{no}} x^{p,no}(gp,r) = x^{no}(gp,r)$$

3° flow capacity of transport connections:

$$\forall gp \in \boldsymbol{GP},\ \forall r \in \boldsymbol{R},$$

$$\forall (i,j) \in \boldsymbol{L} \quad \sum_{(n,o)\in \boldsymbol{E}} \sum_{p\in \boldsymbol{P}^{no}} x_{ij}^{p,no}(gp,r) \le d_{ij}$$

$d_{ij}\in \boldsymbol{R}^+$ has the interpretation of the (i,j)-th transport connection flow capacity, $(i,j)\in \boldsymbol{L}$.

4° flow capacity of transport nodes:

$$\forall gp \in \boldsymbol{GP},$$

$$\forall r \in \boldsymbol{R},$$

$$\forall i \in \boldsymbol{W} \setminus \boldsymbol{N} \quad \sum_{j\in\Gamma_i^{-1}} x_{ji}(gp,r) \le d_i$$

$$\forall gp \in \boldsymbol{GP},\ \forall r \in \boldsymbol{R},\ \forall i \in \boldsymbol{N}$$

$$\sum_{j\in\Gamma_i} x_{ij}(gp,r) \le d_i$$

$d_i\in \boldsymbol{R}^+$ has the interpretation of the i-th transport node flow capacity, $i\in \boldsymbol{W}$.

5° conditions applied to the cargo flow:

(a) – nonnegative cargo flow (NP):

$$\forall gp \in \boldsymbol{GP}, \forall r \in R, \forall (n,o) \in \boldsymbol{E},$$

$$\forall p \in \boldsymbol{P}^{no}, \forall (i,j)\in \boldsymbol{L} \quad x_{ij}^{p,no}(gp,r) \ge 0$$

(b) – cargo flow additivity (AP):

$$\forall gp \in \boldsymbol{GP}, \forall r \in R, \forall (i,j) \in \boldsymbol{L},$$

$$\sum_{(n,o)\in \boldsymbol{E}} \sum_{p\in \boldsymbol{P}^{no}} x_{ij}^{p,no}(gp,r) = x_{ij}(gp,r)$$

(c) - cargo flow preserving (ZP):

$$\forall i \in \boldsymbol{W}$$

$$\left(\sum_{j\in\Gamma_i^{-1}} x_{ji}(gp,r) - \sum_{k\in\Gamma_i} x_{ik}(gp,r) \right) =$$

$$= \begin{cases} -\sum_{o\in O^n} x^{io}(gp,r) & \text{dla } \ i \equiv n \in \boldsymbol{N} \\ 0 & \text{dla } \ i \equiv l \in \boldsymbol{PL} \\ \sum_{n\in N^o} x^{ni}(gp,r) & \text{dla } \ i \equiv o \in \boldsymbol{O} \end{cases}$$

So as objective function

$$f\left(\mathbf{X}^*, \mathbf{S}^*(r),\ \mathbf{S}^{**}(r)\right) =$$

$$\sum_{(i,j)\in \boldsymbol{L}} \left(x_{ij}(gp,r) \cdot c_{ij}\left(x_{ij}(gp,r), s_{ij}(r)\right) + \right.$$

$$\left. + \sum_{i\in W} \left(\sum_{j\in\Gamma_i^{-1}} x_{ji}(gp,r) \cdot c_i\left(s_i(r)\right) + \left(s_i(r)\right) \right) \right)$$

was minimal.

6. COMPUTATIONAL EXPERIMENTS

The methodology of planning the transportation system infrastructure development has been verified on the example of TEN-T network with regard to road, rail and inland transport. For the purposes of research into the impact of transport infrastructure development on the apportioning cargo flows in the transport network we've constructed the model of Polish Transportation System using proprietary computer software and *PTV Visum* tools, [9]. The new approach to this problem bases on building a proprietary computer application that interacts with *PTV Visum* allowing modeling of transport modes concurrence.

The base variant of transport network structure is presented in Figure 1a. Structure graph of transport network is described as:

$$GD = \langle WD, LD \rangle$$

where:

WD – a set of numbers of studied transportation network nodes, *LD* – a set of practical transport connections between the nodes of studied transportation network.

The following assumptions for transport network structure are taken:

1. The freight road, rail and inland transport held on railways and roads of TEN-T network and Oder River is a subject of analysis.
2. The transport connections are divided into categories and classes described by characteristics (such as; number of traffic lanes in each direction, the average width of traffic lane, the hourly throughput in each direction, the connection speed, the maximum or technical speed, etc.).
3. Only main transport hubs for rail, road and inland transport are considered. These hubs allow to change means of transport and are points of origin and points of collection of cargo flows (Figure 1).
4. The structure of transportation network is linked with to the transportation networks of neighboring countries through border crossings and seaports.

The research consisted of four alternatives of transportation infrastructure development, and for these variants the cargo flow apportioning was executed. We assume that structure of analyzed transportation network:

- does not change – first and second variant.
- is modified (modernized) in selected edges and transportation hubs – third and fourth variant.

We assume that total costs of transport services realization are the evaluation criterion for evaluation solution quality.

In the first variant cargo flows are apportioned through edges of Polish transport infrastructure without considering additional constraints, arising from fixed characteristics of individual connections. Only direct transport connections are considered, what excludes possibility of changing the mode of transport during transition. The graphical representation of results is presented in Figure 1b.

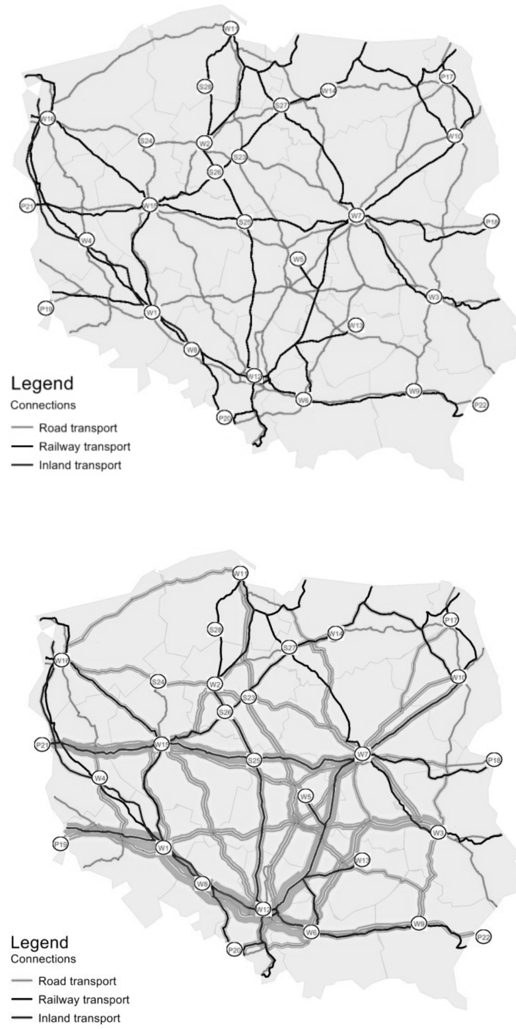

Fig. 1. a) The TEN-T transportation network structure for Poland applied in *PTV Visum;*
b) The results of cargo flow apportioning for first variant.

Source: Own material.

The second variant of cargo flow apportioning includes constraints resulting from flow capacity and speed limits on network connections. This variant, as the first one, uses only direct relations without transshipment operation.

In the first variant of transportation infrastructure shape, the total daily cost of cargo movements through the transportation network in all relations amounted to about 156 660 206 PLN, while the second was higher compared to first variant and amounted to 165 360 955 PLN. The share of different modes in transport volume for variants 1 and 2 is presented in Table 1. In addition, the share of road and inland transport in total number of performed tonne-kilometers slightly increased in second variant. The share of rail transport decrease (Table 2).

Tab.2. Share of different modes in transport volume in 1 and 2 variant of transport infrastructure shape

Mode of trans-port	Percent share in transport volume		Total cost of reali-zation [PLN]	
	Variant 1	Variant 2	Variant 1	Variant 2
Road	57,03 %	59,02 %	156 660 206	165 360 955
Rail	42,34 %	40,21 %		
Inland	0,63 %	0,77 %		

Source: Own material.

Comparison of traffic on particular edges of transportation network in first and second variant allowed finding the critical connections, so-called "bottlenecks". The results are presented in Figure 2. The largest observed differences are highlighted in red. Adequate funds were allocated to the critical sections of transportation network in order to modernize and reorganize it. This allowed to improve their technical parameters and especially to increasie flow capacity and average speed (so called trade-speed increased).

Tab.3. Share of different modes in transport volume in third variant

Mode of transport	Percent share in trans-port volume	Total cost of realization [PLN]
Road	53,84 %	153 117 874
Rail	45,35 %	
Inland	0,81 %	

Source: Own material

Within these changes we made cargo flow apportioning again and determined the total costs of cargo movement. It turned out that modernization and reorganization of critical connections decreased the total cost by about 12 243 081 PLN. Due to fact that a greater modernization was done on the rail connections, the share of railways in transport volume increased (at the cost of road transport) to about 46%. Other results obtained in this variant are presented in Table 3.

In the fourth variant we examined the impact of modernization point infrastructure in network nodes on the cost of cargo movement and handling. Analysis of the results obtained in third variant reveals that four nodes are burdened with highest cargo flows, nodes; W12, W1, W7 and W15. Upgrading these nodes by building new or modernization of existing logistic objects is the next step which allows the consolidation, deconsolidation and handling of cargo flows (changing the mode of transport) on a larger scale. Allocation the funds to the designated network nodes allows to reduce total cost of moving and handling cargo flows by 115 342 PLN. Summary results of the analysis of all tested variants are presented in Table 4.

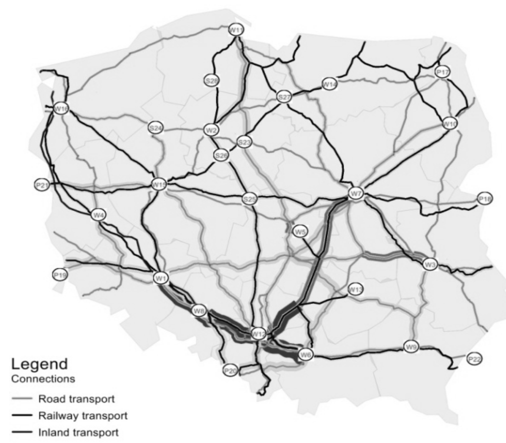

Fig. 2. Sections of transportation network on which adequate funds were allocated
Source: Own material.

Tab.4. Share of different modes in transport volume in all tested variants

Variant	Percent share in transport volume			Total cost of realization [PLN]
	Road	Rail	Inland	
First	57,03 %	42,34 %	0,63 %	156 660 206
Second	59,02 %	40,21 %	0,77 %	165 360 955
Third	53,84 %	45,35 %	0,81 %	153 117 874
Fourth	54,09%	45,10%	0,81%	153 002 531

Source: Own material.

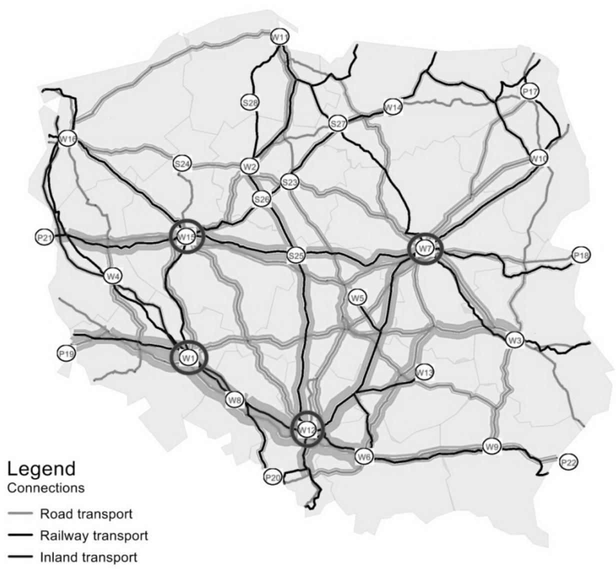

Fig. 3. Cargo flow apportioning with modernized infrastructure in nodes of network
Source*:* Own material.

Therefore, proposed modernizations of the transport network reduce costs of cargo distributions by almost 12.5 mln PLN

7. CONCLUSIONS

Analysis of the results of impact of transport infrastructure development on the cargo flow apportioning reveals that modernization of transport infrastructure elements improves its technical parameters and in effect reduces the total cost of shipment. As a result, rail transport takes over this part of the freight traffic.

With regard to considerations set out in this paper one should note that:

1. Developing the transportation system should base on finding dependences between forecasted workload, equipment and costs of tasks realization.
2. Modernization and development consists not only of creating an integrated transport network and increasing flow capacity – although it is very important –but other elements have to be considered as well, such as improving safety, environment protection and quality of provided services.
3. The model of transportation system development can be a tool supporting decision processes concerning the ways of developing particular modes of transport in aspect of co-modality.
4. The main strategic areas for which proposed model could be a supportive tool are:
   - problems of location modal points of transportation network such as: logistics centers, loading points, intermodal terminals,
   - adjusting parameters of built transport connections to the tasks,
   - the range of modification of roads and railways resulting in changing technical parameters
   - changing the organizational patterns and rules (such as: closing railway line for freight transport).
5. The application of developed model with regard to all assumptions should make it possible to provide impact analysis for strategic decisions, traffic distribution and related indicators of transport co-modality. Thus, the application will be a tool verifying accuracy of all decisions taken and their consistency with transport policy.
6. In apportioning the distribution of cargo flows it is extremely helpful to offer to the companies tools for comparative analysis of solutions that comply with market criteria and take into account the criteria for transport modality.

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