OPTIMAL DISTRIBUTION AND DEVELOPMENT OF FLOWS IN THE TRANSPORT NETWORK OF THE REGION

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The article presents the analysis of the development and problems of the transport sektor and transport communikations, new requirements to it in a growing economy.

As well as the issues of posing challenges and the development of models of assimilating goods traffic in the best use of the means of automobile and rail transport and transport networks and their development taking into account the perspective growth of goods traffic, making analysis of the criteria for the optimalsolution of transport network development.

Keywords: *Transport, automobile, railway, network, multiset, evelopment, road scheme, optimal, mathematical model, freight traffic.*

ОПТИМАЛЬНОЕ РАСПРЕДЕЛЕНИЕ ПОТОКОВ В ТРАНСПОРТНОЙ СЕТИ РЕГИОНА И ИХ РАЗВИТИЕ

В статье привидении анализа развитие и проблемы транспортного сектора и транспортных коммуникаций, новые требования к нему в растущим экономике.

А также рассмотрены вопросы постановки задачи и модели освоение грузопотоков при наилучшем использование перевозочных средств автомобильного и железнодорожного транспорта и транспортной сети и их развития с учётом перспективного роста грузопотоков, приведены анализ критерии оптимальности решении задачи развития транспортной сети.

Ключевые слова: транспорт, автомобиль, железная дорога, сеть, мультисеть, развитие, схема дороги, оптимальный, математическая модель, грузовые перевозки.

1. Introduction The growth of the production sector in our country in strategically significant and promising directions, as well as the rapid establishment and commencement of operations of international joint ventures based on foreign investments, is increasing the demand for transportation. This necessitates the development of the technical and technological capabilities of the transport system, and requires various modes and networks of transportation to efficiently and timely meet consumers' needs for freight volumes.

In order to optimize the delivery of prospective freight flows to domestic and international markets and to reduce their cost, it is necessary to develop the transport and logistics sector. One of the key factors in the development of transport logistics is the extent to which a region is adequately provided with transportation, meaning the presence of a well-developed economic infrastructure.

A highly developed and efficient transport system is considered a major factor in the creation of logistics centers and the attraction of investments.

Improving the region's transport accessibility, in turn, enables the establishment of multimodal transportation, the efficient management of flows within the supply chain, and the minimization of transport-related costs. To achieve this, it is essential to develop a scientifically grounded methodology.

2. Literature Review

An analysis of literature dedicated to the planning of multimodal freight transportation shows that researchers typically address three main levels of planning: strategic, tactical, and operational. Among these, tactical level issues have been studied most extensively, followed by strategic and operational levels [1].

The methodological foundations of designing multimodal transport networks and their throughput capacities have been examined [2].

In Slovakia, methods for increasing transport capacity have been analyzed, including the construction of reloading stations ("Increasing Transport Capacity in Slovakia, Construction of Reloading Stations") and the prospects for building wide-gauge railways in Europe to shorten the transit time of freight flows arriving from Eastern Europe and Asia [3].

At present, multimodal transportation is considered one of the main methods for delivering oversized and heavy cargo from the sender to the final consumer [4].

Many studies have addressed the problems of planning multimodal transport routes, focusing on optimization in terms of cost, time, risk, and environmental protection (Chang, T.-S., 2008; Sawadogo, M., Anciaux, D., Roy, D., 2012; Xiong, G., Wang, Y., 2014; Sun, Y., Lang, M., Wang, D., 2016; Dib, O., Moalic, L., Manier, M.-A., Caminada, A., 2017; Fazayeli, S., Eydi, A., Kamalabadi, I.N., 2018).

In solving problems related to multimodal route planning, various algorithms have been widely used, including genetic algorithms (Sun, Y., Lang, M., Wang, D., 2016; Dib, O., Moalic, L., Manier, M.-A., Caminada, A., 2017; Fazayeli, S., Eydi, A., Kamalabadi, I.N., 2018), ant colony optimization algorithms (Sawadogo, M., Anciaux, D., Roy, D., 2012), hybrid algorithms (Kai, K., Haijiao, N., Yuejie, Z., Weicun, Z., 2009), and shortest path algorithms (Idri, A., Oukarfi, M., Boulmakoul, A., Zeitouni, K., Masri, A., 2017).

The use of the K-shortest path (KSP) algorithm in planning multimodal transportation routes is considered effective and yields optimal solutions. The KSP algorithm has advantages in providing optimal and stable solutions. In recent years, many researchers have worked on solving shortest path problems using KSP algorithms (Eppstein, D., 1998; Yen, J.Y., 1971; Martins, E.D.Q.V., Pascoal, M.M.B., Santos, J.L.E.D., 1999; Aljazzar, H., Leue, S., 2011; Chen, B.Y., Li, Q., Lam, W.H.K., 2016; Liu, H., Jin, C., Yang, B., Zhou, A., 2018).

In solving the multi-route problem of transporting oversized and heavy cargo via multimodal transport, the transport network has been transformed into a virtual network—presented as a multi-prism network solution—and Yen's algorithm (Yen, J.Y., 1971) has been improved [5].

It is known that research dedicated to multimodal transport based on the shortest path is still insufficient. This article uses a multi-network method to solve the multi-route problem in multimodal transport. The developed model simultaneously determines the transport modes and directions of delivery, while also identifying nodes and lines to be reconstructed in order to minimize total costs.

A general scheme for forming a land-based road and rail multimodal network in the Surkhandarya region has been developed, with attention given to the problem of optimally distributing freight flows within this network [6].

Despite the significant attention paid to the above-mentioned issues, many unresolved problems and challenges remain in this area. In particular, the main difficulties in organizing multimodal transport include: first, the interaction and coordination of different transport modes; second, legal and regulatory issues; and third, the lack of established permanent routes.

3. Research Methodology

In the course of this research, the multi-network method for delivering freight flows to consumers within a region was analyzed. The optimization of freight flows is carried out within an expanded unified land-based transport multi-network. This

AMERICAN JURNAL OF ADVANCED SCIENTIFIC RESEARCH
ISSN 2195-1381 Volume- 4 May 2025
https://journal-index.org/index.php/ajasr

unified transport multi-network differs from a standard network by the presence of multiple transport segments and additional (fictitious) nodes.

To explore the topic, various methods were applied, including mathematical modeling, multi-network analysis, graph theory, statistical analysis, and other relevant approaches.

4. Analysis and Discussion of Results

In this article, the optimization of freight flows is carried out within an expanded transport multi-network. This transport multi-network differs from a simple network by having multiple transport segments and additional (fictitious) nodes. It is constructed as follows: the existing points of each type of transport (such as dispatch, reception, economic-technical characteristics, throughput capacity, and other indicators) are represented as nodes of a graph.

Locations where different types of transport connect — i.e., points where transshipment from one transport mode to another is possible — are represented as multiple nodes accordingly. This approach allows for a more comprehensive accounting of transport costs when delivering flows "door-to-door" (Figures 2 and 3).

A real point where different transport modes connect is divided into conditional and neutral segments 1, 2, and 3, denoted as B (sender) and C (receiver). The conditional segments reflect the costs associated with the initial and final operations of the respective transport modes, as well as the costs related to transshipment from one transport mode to another.

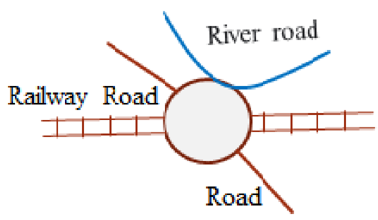

Figure 1. View of the Transport Network

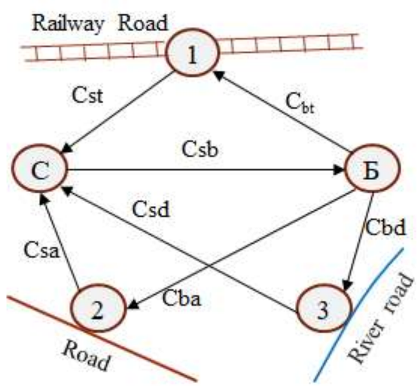

Figure 2. View of the Multi-Network

Therefore, SBA and SSA denote the initial and final operation costs for road transport, SBT and SST for rail transport, SBD and SSD for river transport, while SSB indicates additional costs related to cargo storage (see Figure 3). Other transport modes, such as air transport, can also be incorporated into the network.

To formulate the problem and develop the model, we include the key concepts and indicators related to the transport network.

The main concept of the road and rail transport network is the locations (nodes) where different road segments (links) converge (join). We call such points connection locations (CL). CLs are places where cargo is dispatched or received, where freight is transferred from one mode of transport to another, and where road or rail links intersect in various directions.

In the future, CLs may also include potential cargo dispatch, reception, or transfer points that could be put into operation.

Network

N	set of nodes
S	**consignor**
t	consignee
S , $t \in N$	This set S includes the set of destinations t

Parameters

$X^{p}_{ij,l}$	Parameter variable characterizing the transport flow
ij	Link (arc) connecting node i of the transport network with node j
$\boldsymbol{i}$	i=1,2,…,n - **consignor**
j	j=1, 2, ...,m - consignee
l	The type of cargo related to this flow
p	Development level of the transport flow arc
a_i^l	The volume of cargo dispatched from each node i
b_j^l	The volume of cargo received at each node j
l	l=1,2,…,k - Set of indices indicating cargo types
$X^{p}_{ij,l}$	Flow of transported cargo
$D_{ij}^{p\max}$	The maximum possible number of vehicles passing through the road section ij per day on average

$X_{ij,l}^{p} \cdot \frac{1}{Д_{к} \cdot q_{ij}^{p}} \cdot K_{ij}^{p}$	Conversion of the transported cargo flow parameter into the maximum possible number of vehicles passing through arc section *ij* per day
q_{ij}^{p}	Average load capacity (in tons) of vehicles passing through arc *ij* at development level *p*
K_{ij}^{p} –	Coefficient indicating the share of non-freight vehicles in the composition of the traffic flow passing through the section
$Д_{к}$ –	Number of calendar days
C_{ij}^{p}	Indicator, i.e., the unit cost of transporting one unit of cargo

Now let us proceed to analyze the characteristics of a transport network arc related to the transmission of freight flows.

In general, the objective function of the considered problem can be defined as the sum of the products of parameters C_{ij}^{p} (transportation cost per unit of cargo for development level *p*) and X_{ij}^{p} (freight flow on arc *ij* over all arcs *ij* and all cargo types *l* in the network.

However, in this case, it is necessary to determine the composition of the parameter C_{ij}^{p} differently, depending on which development level *P* of the transport network the given issue is being considered for

For example, if the problem is being solved for the currently existing network, that is, when $P = 0$, then $C_{ij} = C^{(p(j))}$, which represents the current cost per unit of transportation.

Conversely, if $P > 0$, then $C_{ij,l}^{p} = C_{ij}^{p}$, where $C_{ij}^{(p(jk))}$ consists of the sum of current operational costs and capital expenditures per unit of cargo transported.

The analytical expressions for the formation of current and total transportation costs for various transport networks and operations will be analyzed in detail in subsequent articles.

Another important issue in formulating the mathematical model of the problem is to ensure that the optimization parameter $X_{ij,l}^{p}$ representing the cargo flow on arcs *ij*, does not exceed the constraint values determined for each arc according to its level of network development. Such constraints are expressed through different parameters depending on the mode of transportation.

For instance, in the road transport network, the level of development is determined by road categories. Each arc *ij* in a given category is characterized by the maximum number of vehicles that can pass per day, denoted as $D_{ij}^{(p\ max)}$. To represent this

ISSN 2195-1381 Volume- 4 May 2025
https://journal-index.org/index.php/ajasr

constraint in the model, the cargo flow parameter $X_{ij,l}^{p}$ must be converted to the number of vehicles passing through the arc per day, and this should not exceed $X_{ij,l}^{p}$. This conversion can be achieved using the expression:

$$X_{ij,l}^{p} \cdot \frac{1}{Д_{к} \cdot q_{ij}^{p}} \cdot K_{ij}^{p}$$

Here, D, q, and K_{ij}^{p} are coefficients reflecting the vehicle load capacity, conversion factors, and other related parameters.

In the case of railway arcs, the limiting capacity for cargo flows is defined by the maximum daily throughput of the segment, denoted as $Q_{ij}^{(p\,max)}$.

Since the constraint parameters differ across various transport networks, the set of arcs *ij* in the region must be subdivided into local arc subsets for each transport type: for example, IJ_{ay} for road arcs and IJ_{ty} for railway arcs.

Thus, the formulation of the problem and its mathematical model are formed as follows: determining $X_{ij,l}$, the flows of non-negative freight *l* to be transported along the connected inter-location arcs *ij* given within the economic region, i.e.:

$$X_{ij,l}^{p} \geq 0,\ ij \in IJ \text{ and} \qquad (3.1)$$

In this case, the intensity of traffic passing through all road arcs must not exceed the maximum traffic flow capacity $D_{ij}^{p\max}$ of that section.:

$$\sum_{l=1}^{k} X_{ij,l}^{p} \cdot \frac{1}{Д_{к} \cdot q_{ij}^{p}} \cdot K_{ij}^{p} \leq D_{ij}^{p\max}, ij \in IJ_{АЙ} \qquad (3.2)$$

For all arcs of the railway network, the freight flow for all types of cargo being transported must not exceed the maximum freight throughput capacity $Q_{ij}^{p\max}$ of that section.

$$\sum_{l=1}^{k} X_{ij,l}^{p} \leq Q_{ij}^{p}\ ,\ ij \in IJ_{ТЙ}; \qquad (3.3)$$

For all arcs, the volume of flows sent from the origin points must be equal to the volume of flows received at the destination points.:

$$\sum_{i} a_i = \sum_{j} b_j \qquad \begin{cases} i = 1,2,\dots,n; \\ j = 1,2,\dots m; \end{cases} \qquad (3.4)$$

For each node $i=1,2,\dots,n$ and for each type of cargo $l=1,2,\dots,k$;

$$\sum_{j}\sum_{l} X_{ij,l} - \sum_{j}\sum_{l} X_{ji,l} = \begin{cases} a_{i,}, агар, i \in S; \\ 0, агар, i \notin S,t; \\ b_j, агар, i \in t. \end{cases} \qquad (3.5)$$

The current $(F_{Ж})$ or full (F_{T}) costs of transporting regional freight flows are at a minimal level.

$$F_{Ж} = \sum_{ij}\ \sum_{l} C_{ij,l}^{p(Ж)} \cdot X_{ij,l} \rightarrow MIN; \qquad (3.6)$$

$$F_T = \sum_{ij} \sum_{l} C_{ij,l}^{p(ЖК)} \cdot X_{ij,l} \to MIN . \qquad (3.7)$$

Such a formulation of the optimal transport network development problem allows for consideration of various options, including the expansion, reconstruction, or new construction of existing network links.

It also accounts for the possibility of integrating new segments from different types of transport networks into the overall model. In general, any transport segment can be included in the model as a link characterized by a specific transportation cost, provided that this cost is determined based on sound and justified calculations.

Conclusion. The development of the transport network is primarily carried out in stages, based on the operational condition of the roads. This approach enables the rational allocation of capital investments designated for the improvement of the regional transport infrastructure.

The results of this study provide significant opportunities for planning and designing the future development of the freight transport network. In our view, simultaneously solving the issue of efficient distribution of flows within the economic region's transport system allows for a more accurate and comprehensive justification of transport network development in the province. As a result, it can lead to considerable savings in transportation costs for production capacities. This, in turn, increases the competitiveness of both the products being manufactured and the economy as a whole.

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