Modeling of regional transport and logistics systems

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Abstract. The article examines the issue of the effectiveness of goods shipment inside the country. Progress in the methods and principles of managing transportation processes allows to increase the speed of delivery, improve the quality of service, and regulate transport tariffs. Considering the current state of Russia with its vast territory, a wide variety of natural and climatic and economic-geographical conditions, it can be noted that it needs a clear logistics system to link production procedures. The aim of the study is the formation of a developed regional transport and logistics system. To achieve this goal, we consider two main tasks: the identification of regions in terms of the priority of design and location of logistics centers; optimization of logistic schemes of cargo delivery. Creation of a developed regional transport and logistics system is the most important condition for the economic development of the country, as well as the development of interregional economic interaction, which will increase the social and economic potential of the regions. Increasing the economic efficiency of commodity exchange is achieved both through the effective organization of a system of interregional logistics centers, and through the development of interregional economic interaction.

Keywords: logistics, region, regional transport and logistics system model, cargo, route, transportation costs.

1. Introduction
Logistics as a science and as a tool of business in the civil sphere have began to form in the early 1950s, mainly in the USA. The evolution of logistics is closely related to the history and evolution of market relations in industrialized countries. The term "logistics" has taken root in business and has become ubiquitous in the world only since the late 1970s. In connection with the trend of nationalization and globalization in recent decades, the importance of logistics management is growing in various areas of the economy.

Nowadays in all sectors of the economy logistics helps to optimize existing production and distribution processes based on the same resources using management methods to increase the efficiency and competitiveness of enterprises. The key element of the logistics chain is the transport system, which combines certain activities. Transportation takes a third of the amount in logistics costs, and transport systems have a huge impact on the operation of the logistics system. Only good coordination between each component in logistics can bring maximum benefit to the state. For example, the release of traffic in urban areas, as a result of the efficient operation of logistics.

The formation and development of a market economy in Russia also led to an intensive development of logistics, which covers a wide range of activities. Logistics is used in the planning, organization and management of the movement of commodity and related information and financial
flows, both at enterprises, sectoral, intersectoral levels, and at the regional, interregional and international levels [1].

The development of logistics at the macroeconomic level is largely influenced by regional characteristics of reproduction, including regional transport factors: transport communications and transport-forwarding enterprises, transport hubs, terminals, etc. For Russia with its vast territory, a great variety of natural and climatic and economic-geographical conditions, different levels of socio-economic development and specialization of production in certain regions, the formation of regional transport and logistics systems (RTLS) is of paramount importance. RTLS with their subsequent integration with federal and international logistics systems will facilitate Russia's entry into the world community as an equal partner.

The coordinating and integrating potential of the RTLS should be aimed at solving social and economic development problems of specific regions, increasing the efficiency of customer service through high quality of transport and logistics services, bringing them closer to world standards, introducing modern logistics technologies for managing regional material and related information and financial flows.

In this paper, we consider the process of forming a developed regional transport and logistics system.

2. Formation of a regional transport and logistics system
The development and implementation of RTLS is one of the most effective ways of economic and social development, both in individual regions of Russia and in the state as a whole. Experience in the use of logistics systems in developed capitalist countries shows that transportation costs are reduced by 7-20%, the cost of handling and storage of material resources and finished products by 15-30%, total logistics costs by 12-35%, and also accelerates the turnover of material resources by 20-40% and the reserves of material resources and finished products by 50-200% [2].

RTLS is a complex economic system that is formed within the boundaries of one region under consideration, while the system provides a single process of transport servicing of regional material flows organized in an optimal way. The main elements of regional transport logistics systems are transport, freight forwarding and warehousing enterprises, which in close interaction with each other implement effective options for the delivery of goods in terms of time and total costs. According to Western experts, even in a highly organized economy, the development of a logistics transport chain can reduce total costs by more than 20%.

Each region of the country has a unique combination of socio-economic and natural-climatic factors, which, in turn, affects the types and forms of regional policy, the specificity of the logistics intermediaries, the parameters of material, information and financial flows. The regional transport factors have a decisive influence on the synthesis of logistics structures: the types and quality of the functioning of transport communications, transport hubs, terminals and the transport complex as a whole.

Logistical systems of individual regions of the country, in spite of common approaches to the analysis and synthesis of such systems, differ from each other in configuration, a set of logistic intermediaries, types and parameters of material, financial and information flows, organization of management and communication, etc. [3].

The solution of the problem of increasing the efficiency of the functioning of the transport complex, ensuring coordination and interaction in the work of various types of transport, ensuring the implementation of the transit potential of Russia requires the application of fundamentally new approaches based on the principles of logistics and logistics management, the priority of the development of the transport and logistics infrastructure and the formation of integrated transport-logistics systems, at the regional, interregional and international levels.

The formation of a regional transport and logistics system in Russia will provide [4]:
• Accessibility and quality of transport and logistics services at the level of development needs of the region;
• Implementation of the transit potential of the region;
• A close interaction of all participants in the delivery of goods. And the delivery itself means not only the actual transportation of goods, but also the provision of the entire complex of necessary services for their processing and distribution.

3. Evaluation of regions in terms of the priority ranking of the logistics centers location

The backbone elements of the RTLS are logistics centers that implement material management functions. Logistics centers coordinate material and other flows in the country's logistics transport system. There is a need to divide the regions of the country according to the priority level of designing and locating logistics centers, which will allow making an optimal decision on the choice of the region (or a specific place) for its location. It is very important for the economy to properly locate logistics centers in the country.

In the creation of the RTLS, both the state and organizations providing transport services are interested. Planning and placement of logistics centers should take into account the interests of all participants in the transport process. Lack of clear policy and institutional mechanisms make it difficult to choose the location of logistics centers [5].

The construction of a model for assessing regions in terms of the degree of priority of designing and locating logistics centers is expected to be used in the process of implementing the following steps [6]:

1. compiling a list of a set of regions-alternatives \( X = \{ x_i \}, \ i = 1,2,... ,n \) in the scale of names nominated for the model competition;
2. formation of a complete list of a set of particular criteria in the scale of names \( R = \{ r_j \}, j=1,2,\ldots ,m \), for a competitive evaluation of the expediency of locating logistics centers in terms of the enterprise's economy and economic geography;
3. mapping of a set of partial criteria to a set of alternative regions \( \tau : R \rightarrow X \) as the criterions of each alternative within the available initial data at the time of the study in any scales convenient for research (quantitative, ordinal, linguistic, etc.)

The construction of a model for assessing regions according to the degree of prioritization of design and location of logistics centers is carried out within the framework of a general formulation of the multicriteria decision-making problem, which can be presented in the following form [7]:

\[
\{ X, r_i, r_2,\ldots , r_m \}, \tag{1}
\]

where \( X = \{ x_i \}, \ i = 1,2,...,n \) - regions; \( n \) - quantity of regions;
\( R = \{ r_j \}, j=1,2,\ldots ,m \) - set of criteria indicators; \( m \) - the list of criteria indicators of the expediency of placing logistic centers in the territories of the above-mentioned regions.

The search for an optimal alternative is based on the construction of a matrix. The method of pairwise comparisons among the set of \( n \) alternatives \( (n = |X|) \) is the cardinality of the set \( X \) is based on the whole Cartesian set of the form \( (n \times n) \) by the principle "each with each". In total, such comparisons within the object-object matrix will be \( z = n(n - 1)/2 \), where \( n \) is the number of alternatives. The number \( z \) means the number of elements of the object-object matrix located above the main unit diagonal as a reflection of the matrix reflexivity, when each object of the matrix is similar to itself.

A pair comparison of the elements of the set of the investigated list of alternatives for the construction of the judgment matrices with respect to each criterion is recommended to be performed by means of the double tetram scale proposed by T. Saati as a scale (semantic grid) for determining the elements of the inverse symmetric judgments for each criterion. Thus, for each criterion it is necessary to create a separate inverse symmetric matrix of judgments of the type "object-object", that is, square matrices (the number of rows is equal to the number of columns), \( A = \{ a_{ij} \}, i=j=1,2,\ldots ,m \), where \( m \) - number of alternatives being investigated.

For example, one of the important criteria for choosing a region in terms of the priority of designing and locating logistics centers is the availability of a developed transport network that
connects the areas among themselves. Thus, the structure and intensity of the links of the base region with other subjects of cooperation can be represented in the form of a matrix. If we assume that the length of the transport network $L_1, L_2, \ldots, L_n$ corresponds to each region $X_1, X_2, \ldots, X_n$, then we get a matrix of pairwise comparisons (Table 1).

### Table 1. Matrix of stable cooperation ties.

| Region | Region 1 | Region 2 | \ldots | Region n |
|--------|--------|--------|--------|--------|
| Region 1 | $L_1/L_1$ | $L_1/L_2$ | \ldots | $L_1/L_n$ |
| Region 2 | $L_2/L_1$ | $L_2/L_2$ | \ldots | $L_2/L_n$ |
| \ldots | \ldots | \ldots | \ldots | \ldots |
| Region n | $L_n/L_1$ | $L_n/L_2$ | \ldots | $L_n/L_n$ |

In this case, the elements of the judgments matrices satisfy the requirement imposed on them by definition: the symmetric elements of such matrices are mutually in inverse relation to each other: $a_{ij} = 1/a_{ji}$, where $a_{ij} = L_i/L_j$.

When conducting pairwise comparisons, one should answer the following questions: which of the compared areas is more important or has greater impact, which region is more preferable.

Subsequently, matrices of paired comparisons are compiled for other criterial indicators, and a list of priority regions is compiled on the basis of all the matrices. The application of this method of assessing the regions in terms of the priority ranking of the location of logistics centers will make it possible to create a developed network of RTLS in Russia.

### 4. Optimization of logistic transport chain and logistic schemes of cargo delivery

Today we can say that there exists an imbalance between the demand in the transport industry and the proposals in it. Transport flows in large cities reach their limiting values and the throughput of roads falls [8].

The basis for the establishment of the RTLS should include efficient logistics delivery schemes, the parameters of which are determined on the basis of the upper limits of tariffs and terms of delivery of the goods. These schemes will correspond to certain volumes of transportation, which are defined as the sum of material resources and final finished products between the links of complex logistics production and transportation and transport-marketing systems.

From an economic point of view, the construction of a logistics transport chain, logistics schemes for the delivery of goods should be based on the basic topology of the transport network, user demand for transport services and transportation tariffs. Equilibrium occurs when the number of trips between the corresponding departure points and the arrival points of cargo is equal to the demand for shipment, taking into account the cost policy [9].

To describe the structure of the transport chain, logistic schemes for the delivery of goods apply the theory of graphs, where the transport network (through which the goods are delivered) is represented in the form of an oriented graph consisting of a set of successively numbered vertices and a set of consecutively numbered edges (arcs) symbolizing the elements and their connections. The graph $G$ modeling the delivery scheme of the goods must necessarily be bound so that there is always a path from any vertex to any other vertex. The numbers characterizing the links of such a graph usually express the length of the route, time or tariffs for the transportation of cargo.

We introduce the notation: $m$ is the set of successively numbered nodes of the graph $G$; $Z$ is the set of sequentially numbered arcs of the graph $G$; $I$ is the set of nodes that are the departure points, $i \subseteq m$; $J$ is the set of nodes that are arrival points, $j \subseteq m$; it is assumed that $i \cap j = \emptyset$; $M_{ij}$ is the set of routes between the departure points $i \in I$ and the arrival points $j \in J$.

The graph $F$ modeling the delivery scheme of cargoes is determined by the set of vertices and the set of pairs of linked vertices (Figure 1).
Figure 1 illustrates a set of three nodes connected by a set of five directed links. We can represent nodes as representing cities, and connections as representing the capacity of roads between different nodes. The two-way road is represented by two links, one in each direction. For example, from node \( c \) there are two routes to node \( a \), the driver can choose:

- The first route is straight, by connection 5 (route \( ca \));
- The second route passes through vertex \( b \) and uses two links 4, 2 (route).

Let \( Z \) be the set of links in the road network and let \( R \) be the set of possible routes. One way to describe the relationship between network links and routes is the matrix defined as follows. Let us establish that \( Azr = 1 \) if the link \( z \) lies on the route \( r \), and \( Azr = 0 \) otherwise. This defines the matrix \( A = (Azr, z \in Z, r \in R) \) as the link-route of the incidence matrix. Each column of the matrix corresponds to one of the routes \( r \), and each row to one of the links \( z \) of the network. The column for route \( r \) consists of 0 and 1: where 1 indicates which network links are on route \( r \). The rows in the matrix, where 1 occurs for the link of the network \( z \), shows which links are included in the specified route. So, for example, the incidence matrix of the road network presented in Fig. 1 will look like this:

\[
A = \begin{pmatrix}
1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\
2 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\
3 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\
4 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\
5 & 0 & 0 & 0 & 0 & 1 & 0 & 1
\end{pmatrix}
\]  

(2)

The incidence matrix shows a column for each of the two routes \( ca1 \) and \( ca2 \), between node \( c \) and \( a \). The following information is encoded in the columns: the route \( ca1 \) uses the link of the network 5, and the route \( ca2 \) uses the links of the network 4 and 2. It is necessary to pay attention that this incidence delivery matrix does not report the order of the links on the route.

The task in this case is to decide whether to include the \( k \)-th link in the cargo delivery route or not to include it. The number of links of the \( k \)-th type is indivisible and can take only two values: 0 and 1. The definition of unknown links in the cargo delivery route \( (Z_k) \) must satisfy the condition:

\[
Z_k = 0; 1 \quad (k = 1, 2, 3, \ldots) ,
\]

or

\[
Z_k = \begin{cases} 
1, \text{if the arc } z \text{ is included in the route } Mij \\
0, \text{else}
\end{cases}
\]

(4)
Let’s suppose as a criterion of optimality to take a minimum of transportation costs (fuel costs, maintenance and repair of cars, etc.). In this case, the optimal variant will be satisfied by the route with the least total length, for which the amount of transportation costs is minimal:

$$\sum_{k} D_k l_k = \min,$$  \hspace{1cm} (5)

where: $D_k$ – transport costs associated with the provision of transportation services; 
$l_k$ – is the length of the cargo delivery route; 
$k$ – number of sections (links of the road network).

If the requirements for reducing the cost of transport work or the time spent on the way to the cargo are imposed on the cargo delivery route, it is necessary to ensure all transport links by independent roads along the shortest path, i.e. direct connection between each of the corresponding points (departure and arrival points). The solution of the problem is to determine the unknown routes between points $i$ and $j (M_{ij})$ satisfying the following condition [10]:

$$M_{ij} \geq (i = 1,2,3,...,m; \ j = 1,2,3,...,m),$$  \hspace{1cm} (6)

for which the transport work on route $ij (P_{ij})$ or the time of communication between $i$ and $j (t_{ij})$ will be minimal:

$$\sum \sum i j P_{ij} = \min,$$  \hspace{1cm} (7)

$$\sum \sum i j t_{ij} = \min.$$  \hspace{1cm} (8)

Given the complexity and practical limitations of numerical programming, we can use combinatorial analysis methods in solving such problems viewing different combinations of variable values, but only for a reasonably selected part of possible combinations.

Carrying out of transportations with smaller transport expenses accepted for an estimation of an optimality at designing of a route of delivery of a cargo corresponds to the general criterion of an optimality for economy of the country. So, the most satisfying the condition of optimality of the minimum financial costs, changing with the change of routes for the delivery of goods, is:

$$\sum \sum E_{ij} = \min,$$  \hspace{1cm} (9)

where $\sum\sum E_{ij}$ - total financial costs, i.e. costs associated with the provision of transportation services for the goods and the movement of vehicles in the directions $ij$.

To fulfill the requirement (9), it is necessary that every possible route for the delivery of goods is provided with a possible minimum financial cost, i.e. to:

$$E_{1-2} = \min;$$

$$E_{1-3} = \min;$$

$$\ldots$$

$$E_{1-n} = \min;$$

$$\ldots$$

$$E_{ij} = \min.$$  \hspace{1cm} (10)

The validity of condition (10) can be proved in the following way. Let's say that there are optimal routes for cargo delivery, for which:

$$E_{1-2} = \min$$

$$E_{1,3} = \min$$

$$\ldots$$

$$E_{1-n} = \min$$
... but $E_{ij} \neq \min$.

If we replace the route for which $E_{ij} \neq \min$, by such a route that $E_{ij}' = \min$, then the sum of all financial costs on the network decreases by the amount:

$$\Delta = E_{ij} - E_{ij}'$$

and then:

$$\sum_{i} \sum_{j} E_{ij}' < \sum_{i} \sum_{j} E_{ij}.$$  \hspace{1cm} (12)

It follows that for the case $\sum_{i} \sum_{j} E_{ij}' \neq \min$, the original proposal for the optimality of the route for the delivery of cargo, for which at least one route $E_{ij} \neq \min$, is incorrect.

Thus, unlike the original proposal, the route for delivering cargo can not be optimal if inequality (12) is not met.

The general principle of constructing the optimal routes for the delivery of goods is that any corresponding point in the optimal connecting road network is connected with all other corresponding points of the links, which ensure the least specific road and transport costs for moving goods from this point to all other corresponding network points.

When compiling a mathematical model of the route for the delivery of goods, one should proceed from the following limiting conditions:

• the optimal route must be a binder; must pass through all the corresponding points without exception (there must be at least one route between each pair of points);
• for various reasons, some link $z_k$ must be excluded from the construction of the optimal route or, conversely, necessarily included in it.

This condition is expressed by equality (2), and the transport-operational level of the designed route must be such that the speed $v_{ij}$ between points $i$ and $j$ can be not less than a certain predetermined speed $v_{ij}'$, the traffic intensity $N_{ij}$ is not more than $N_{ij}'$, the safety factor of traffic $K_{ij}$ is not less $K_{ij}'$.

On the basis of the general principle, the task is reduced to the selection of such links in which routes would be formed ensuring the least specific transport costs for the carriage of goods.

5. Conclusion

The developed transport and logistics infrastructure is one of the most important conditions for the economic development of the country, as well as the development of interregional economic interaction, which allows increasing the social and economic potential of its regions and the quality of life of the population. An increase in the economic efficiency of commodity exchange can be achieved both through the effective organization of a system of interregional logistics centers, and through the development of interregional economic interaction and increasing the volume of trade.

Formation of RTLS in Russia will allow to work out the options for the investment program for creating the system (taking into account the limited land and investment resources). The main task of modeling RTLS is to ensure the development of regional economic ties. The task of determining the optimal territorial organization of the region's logistics system is decided on the basis of a multi-criteria decision-making model.

Working with RTLS will allow creating and correcting data sets reflecting possible variants of organization of cargo delivery routes, obtaining information that is most adequate to real-time conditions.

In general, the creation of RTLS will allow the regions of Russia:

• solve social and economic problems, increase the level of employment of the population, create new jobs and attract investment;
• increase receipts to the budgets of cities in the region from the functioning of RTLS and expand the consumer market of transport and logistics services;
• improve technical and economic development of the transport system and transport and logistics infrastructure in the region;
• improve the quality of transport and logistics services to consumers, through the introduction of modern integrated logistics technologies and the development of a regional production and technical base of logistics services;
• increase the efficiency of transport in the region through logistic coordination and support of its work in the implementation of multimodal and intermodal transport.

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