Mathematical methods for substantiating transport routes for the movement of natural resources through the forest area

S O Medvedev¹*, A P Mokhirev², M M Gerasimova³ and A S Lyshko²

¹ Department of economic and natural Sciences, Lesosibirsk Branch of Reshetnev Siberian State University of Science and Technology, 29 Pobedy Street, Lesosibirsk 662543, Russian Federation
²Department of Technology of Logging and Wood Processing Industries, Lesosibirsk Branch of Reshetnev Siberian State University of Science and Technology, 29 Pobedy Street, Lesosibirsk 662543, Russian Federation
³Department of Information and technical systems, Lesosibirsk Branch of Reshetnev Siberian State University of Science and Technology, 29 Pobedy Street, Lesosibirsk 662543, Russian Federation

*E-mail: medvedev_serega@mail.ru

Abstract. The use of modern mathematical tools is an integral part of the development of business and society. Their application allows planning the activities of various institutions and forecasting the development of many complex processes. In particular, such tools are used to substantiate routes for the movement of natural resources. The article shows that the use of graphic-analytical methods can be one of the most optimal solutions in this direction. The graphic-analytical model (simplified) and mathematical models are presented. The paper presents the results of a study of individual features of the use of the mathematical substantiation of the routes of industrial enterprises when moving natural resources (including wood resources delivered from the forest area).

1. Introduction
Transport is the most important infrastructural element that ensures the vital activity and vitality of almost all sectors of the country. The transport system is located throughout the country. It includes such types of transport as rail, sea, river, road, air and pipeline.

Transport service is only a sub-type of transport activity. It is aimed at meeting the needs of consumers and is characterized by the presence of the necessary economic, technological, informational, as well as legal and resource support [1]. Transport services include not only cargo transportation, but also loading and unloading operations (loading, reloading, unloading and internal warehouse operations).

The importance of transport services has been growing noticeably lately. The service industry is expanding, and an increasing number of companies provide services that are closely related to the promotion and sale of goods. The rapid development of this area at the current time is associated with the main changes in the economic conditions caused by the transition of the world economic system to the service economy.
The development of transport infrastructure affects the realization of the potential of any territory. It ensures the movement of financial, material and information flows. Its condition determines the development of trade and thereby increases the GDP. Higher added value is also being developed.

The development of transport infrastructure is associated with a fairly large territory of the country. At the same time, the transport system needs to regulate cargo flows, determine the shortest route for transportation and draw up plans for goods transportation. The main goal of logistics is to minimize costs when performing operations of domestic and international trade. The economic foundations of transport infrastructure in the scientific direction are characterized by interdisciplinarity. It means the interconnected consideration of the enterprise, region, industry, as well as the entire national economy, transport systems and the world economy [2].

2. Solution of problems and discussion of the results
Mechanisms for adapting transport systems to the interests of consumers and market in a highly competitive environment are currently becoming priority areas in solving many problems of enterprise development. The importance of the time factor as a managerial resource is increasing. Risks are growing; therefore, it is necessary to determine the causes of their occurrence and the possibilities of reducing them. The specificity of the transport system also affects the approaches to assessing its effectiveness.

As part of the study, the authors considered the problems of using some mathematical tools to substantiate transport routes for the movement of natural resources (in particular, wood). In theory and practice, various tools are offered [3]. However, their use is significantly limited by the range of tasks to be solved and the achieved effect. On the basis of a number of studies and modeling, the authors have chosen a graphic-analytical method, the use of which makes it possible achieve sufficient business efficiency and effectiveness. At the same time, the tasks to be solved can be successfully combined with the need to achieve other goals (the presence of restrictions): environmental, social, legislative, etc.

Below is an example of a graphic-analytical model (figure 1). According to this model, within the framework of the economic justification of transport routes, it is required to identify a sequential route for the movement of a given volume of goods along the arcs of the presented graph, at which the maximum profit will be obtained. In this case, the vertex S is the producer (sender) of the product that must be delivered to the consumer (vertex Q). Other vertices indicate various terminals providing warehousing, loading and unloading and other operations carried out on the route from S to Q. Their designations may vary. In this case, the markings B and L are used with indices meaning the order of the vertices. The vertices are also characterized by the type of operations: P - loading, T - transportation, R - unloading. To characterize the mode of transport, symbols are used: g - river, y - road, w - rail. Arcs are labeled to characterize their throughput and the cost of performing the corresponding operations. Each arc has a caption representing two vertices: the end and the start for that arc.

Direct substantiation is traditionally carried out by economic, mathematical and logistic methods [4]. It should be noted that modern science supplements the traditional tools with geoinformation tools, as well as various software products that optimize the set of calculations required to solve various tasks.
\( f_{ij} \) – throughput along an arc from vertex i to vertex j
\( C_{ij} \) – cost of operations performed per unit of time

**Figure 1.** Graphic-analytical model of transport routes (simplified model)

Obviously, the most important goal is to maximize profits from product sales:

\[
\sum_{x \in X} C_{it} \xi_{it} \rightarrow \max.
\]

where \( x_i, x_j \) – graphic-analytical model vertices,
A – graphic-analytical model arcs,
\( \xi_{it} \) – flow volume moved from the i vertex.
The flow volume \( \nu \) must be equal to the flow leaving the source:
\[
\sum_{x_j \in X} (\xi_{sj} - \xi_{js}) - \nu = 0.
\] (2)

Reached the vertex \(x_i\) the flow volume \(\xi_{ji}\) is equal to the number of units of the flow \(\xi_{ij}\) that leave the vertex \(x_i\):

\[
\sum_{x_j \in X} (\xi_{ij} - \xi_{ji}) = 0, \ x_i \neq s, t. \tag{3}
\]

This dependence is observed for all vertices \(x_i\).

The flow volume \(\nu\) moving along the arcs of the graph is equal to the flow entering the stock:

\[
\sum_{x_j \in X} (\xi_{ij} - \xi_{ji}) - \nu = 0. \tag{4}
\]

The reasonable flow value that flows through the arcs of the graph, taking into account the sum of the volumes exported from the producer \(S\), should not exceed the volume \(V\) that the producer has:

\[
V \geq V_w + V_c + V_t. \tag{5}
\]

The flow value \(\left(\xi_{S(j=b)}\right)\), passing along the arc \((S, x_j=b)\) from the vertex \(S\) corresponds to the presented inequality:

\[
0 \leq \xi_{S(j=b)} \leq V - \sum_{j \in [1; b] \cup (b; g]} (\xi_{sj} - \xi_{sb}). \tag{6}
\]

The sum of the volumes for the products transported to the consumer \((Q)\) must not exceed the maximum volume desired by this consumer. The flow value to the consumer \((Q)\) passing along the arc \((x_{(i=b)}, x_{j=Q})\) from the vertex \((i = b)\) corresponds to the inequality presented below:

\[
0 \leq \xi_{(i=b)(j=Q)} \leq U_Q - \sum_{t \in [1; b] \cup (b; g]} (\xi_{iq} - \xi_{bq}). \tag{7}
\]

The key task in optimizing transport routes is to increase profits. Given that the price of products is formed on the market and for most enterprises cannot be changed, the key factor in improving the efficiency of activities is the cost (the cost of performing some operations).

\section{Conclusion}

In conclusion, it should be noted that in addition to the most significant costs for the transportation of various resources, when building transport routes, other costs are also important: loading and unloading and warehousing, costs of maintaining infrastructure, etc.

Loading and unloading costs are calculated according to productivity. When planning these costs, it is necessary to study the possibility of achieving the set goals for cargo handling results at the lowest possible cost, primarily due to the optimal use of internal reserves.

Planning the costs of loading and unloading operations involves the widespread use of standards for the performance of some elements of loading operations, as well as cost standards for some types of them. Among the costs of such operations, the largest share is the basic and additional wages of production personnel. Payment for labor depends on the type and weight of the cargo. Complex teams can be created to carry out loading and unloading operations by means of complex mechanization. Payment for labor of the mechanics of complex loading and unloading operations depends on the types of processed goods.

Warehousing and handling of goods is one of the important components. The costs of their application take from 12 to 40\% of the company's expenses [5]. Access to warehouse space in industry is an important component in the competition between producers, wholesalers and retailers to become
an intermediary and deliver goods to the end consumer at the lowest cost, while still making the most of the profit.

Operation of the organization in real time and at a reasonable cost requires the creation of storage facilities for raw materials and finished products. Even knowing the customer's requirements and having everything necessary to fulfill his order, instant delivery is impossible.

Basically, the demand for products is determined only with a certain degree of accuracy, so enterprises use inventory to improve supply and demand management, as well as reduce overall costs. In addition, due to the accumulation of stocks, enterprises can reduce production costs, creating a uniform output of products in volumes that ensure rational loading, capacity and transportation by moving goods in large volumes [6].

Building storage facilities at the points of interaction between industrial and transport systems, they are used to transform the flow of goods for the purpose of more efficient subsequent transportation and storage of goods. Warehousing of goods increases customer value by providing the funds necessary to ensure that goods reach the right place at the right time.

Transportation costs include all components of the costs of elementary technological operations that make up them, and the overwhelming part of these costs, as a rule, falls directly on the transportation process.

Transportation costs are the basis for determining tariffs for the services of intermediaries: transport and transport-forwarding (stevedoring) companies, operators of multimodal transportation, agents, etc. Calculations that are made between senders, recipients and intermediaries according to the transport tariff system directly depend on the method transportation and mode of transport. The level of tariffs is determined from the condition of reimbursement of transport costs and obtaining a planned (normative) profit.

Settlements for international transportation between cargo owners and transport organizations of sea and rail transport are carried out at the current freight and tariff rates on the basis of agreements or at negotiated prices based on bills of lading.

Also, the costs include the costs of transport infrastructure development, including the acquisition of fixed assets, construction and installation works, etc. Transport infrastructure today plays an important role in the interaction of business entities. It is a technological complex designed to organize the movement of goods and provide transport services [5].

The economic substantiation of transport routes is a complex task based on mathematical tools. The presented graphical-analytical model of transport and logistics routes and the corresponding mathematical models characterizing the optimal routes are only a small part of the possible solutions to the complex problem of finding optimal solutions.

A key increase in costs for the transportation of goods is associated with factors affecting the cost of transportation (distance, weight of goods, type of transport, quality of transport infrastructure, etc.), loading and unloading operations (type and weight of cargo, number of transshipment operations, level of automation and mechanization etc.), warehousing (the need for additional equipment for the safety of goods, the cost of security, energy supply, etc.). The importance of each of these factors varies significantly depending on the specific transport task. There is also a significant differentiation in the possibilities for reducing the described costs. Thus, the choice of alternative routes, vehicles, warehouses and other elements can, to a certain extent, reduce individual costing items, which can affect the optimal route for the delivery of goods [6].

Thus, the article presents the results of a study of some features of applying a mathematical substantiation of the transport routes of industrial enterprises when moving natural resources (including wood resources delivered from the forest area).

**Acknowledgement**
The project “Substantiation of transport and logistics routes through the territory of the Arctic and the Far North of the Krasnoyarsk Region using graphic-analytical methods and geoinformation systems” is supported by the Krasnoyarsk Regional Science Foundation.
References
[1] Kovács P 2013 Minimum-cost flow algorithms: An experimental evaluation. *EGRES Technical Report* 4
[2] Cashore B, Auld G and Newsom D 2004 *Governing Through Markets* (New Haven & London: Yale University Press)
[3] Borisov G A, Kukin V D and Kuzina V I 2001 Methods of search of the most favorable option of a network of logging roads *Journal of Forest [Lesnoy zhurnal – in Russian]* 3 63
[4] Starikov A V, Kushcheva I S 2008 *Economic-mathematical and computer modeling* (Voronezh) p 132
[5] Pletnev Y A 2019 Methods of decision-making optimization of transport-logistics schemes of cargo delivery. *Modern aspects of the economy [Sovremennye aspekty jekonomiki – in Russian]* 12-1 62-70
[6] Gerasimova M M, Medvedev S O, Mukhiev A P and Rukomojnikov K P 2019 Optimization of material flows of a logging enterprise based on graph theory. *Logistics and supply chain management* 6 (95) 50-7