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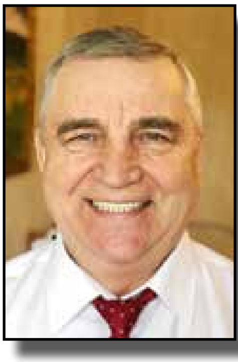
Resource-Saving Approach to Cargo Delivery in Regional Supply Chains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ABSTRACT

The objective of the article is to select and justify an approach to formation of a regional resource-saving model of cargo distribution based on determining the economically feasible number of transport and logistics centres that ensure a reduction in delivery costs.

The study used methods of economic and mathematical modelling, statistical and comparative analysis, correlation and regression, abstract logical, theoretical and empirical and structural analysis.

The paper analyses scientific approaches to cost reduction when choosing an economically feasible number of transport and logistics infrastructure facilities from the standpoint of more efficient spatial selection of infrastructure facilities of the transport and logistics network, contains a correlation and regression analysis of the impact of the number of transport and logistics centres on transport costs when distributing goods in supply chains and estimate of an analytical relationship between these indicators, as well as substantiates the influence of the cargo delivery price level on resource-saving indicators in the cargo distribution system.

The results of the conducted research can be used to determine the level of logistics costs and their impact on the prices of final goods and services, which is one of the ways to implement the goal of resource conservation for commercial companies and executive authorities.

Keywords: *resource-saving model, warehouses, transport and logistics centres, infrastructure, region, resources, correlation and regression analysis.*

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INTRODUCTION

The implementation of innovative approaches to formation of regional resource-saving model of cargo distribution based on determining economically feasible number of transport and logistics centres (TLC), which should ensure a reduction in the costs of these operations, is an obvious priority not only for company management, but also for executive authorities at all levels of administration. In this regard, the focus of corporate and state economic policy is on development and implementation of resource-saving mechanisms for organising economic space, with one of the priority goals being the development of approaches to formation and of actual models of the cargo delivery network, considering their impact on the pricing mechanism of final goods and services.

The regional logistics chain was chosen as the object of analysis and optimisation. The choice of such an object is due to the dedicated orientation of this work, which is part of the scientific research within the framework of the state assignment of the Federal Agency for Railway Transport.

Obviously, besides regional supply chains, there are others, for example, industry, transnational or global chains, etc. The specifics of each of them are characterised, first, by the targets, the scale of involvement of the participants in the delivery of goods and the result, which can be not only economic.

As a basis for improving the quality of transport and logistics services, which involves, among other things, a reduction in its cost, the authors propose a resource-saving approach, which provides for a decrease in the use of a set of economic resources for the delivery of goods using a transport and logistics network with the unchanged requirements of customers. In contrast to the cost-saving approach, the resource-saving approach provides for a reduction in the number of resources used to achieve the target indicators.

Therefore, the task of reducing the number of TLCs in transport and logistics networks, on the one hand, provides for the choice of a route with a smaller number of them, on the other hand, ensures a reduction in the cost of cargo delivery.

The task of designing the parameters of these networks is quite trivial, but insufficient consideration of the characteristics of the territories of their formation, of the development of the network of transport and logistics centres, and the effect of scale often cause failure in meeting customer expectations and opposite results, the main ones of which are additional capital investments and growth in prices for final goods and services.

The analysis of several regional strategies for formation of TLC networks shows, on the one hand, big attention paid to their development, but, on the other hand, first, that their implementation is not always at high level, second, a significant excess of the planned budget for creation of TLC networks and, finally, increased logistics costs cumulated in the price of goods and services.

For example, the developed strategy for formation of a TLC network in Samara region has not been implemented[1] in full. The strategy for socio-economic development of the Saratov region until 2025 and its new version with deadlines for implementation of the main activities until 2030[2] assumes creation of a network of transport and logistics centres (Saratovsky, Rtishchevsky, Petrovsky, Khvalynsky, Balakovsky, Ozinsky, Krasnoarmeysky TLCs) and in terms of implementing the plan for their creation has not yet been implemented. The forecast for socio-economic development of Orenburg region[3], regardless of integrated of state program «Development of transport system», does not include a detailed section on transport and logistics. The strategy for socio-economic development of Penza region[4] does have a section on transport, where the focus is on passenger transportation, but there is no plan for development of the transport and logistics complex in the form of a cluster or network. Unlike these strategies, the strategy for socio-economic development of

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[1] Resolution of the Government of Samara Region dated September 23, 2010, No. 422 «On the Concept for Development of the Regional Transport and Logistics System of Samara Region for 2011–2015». [Electronic resource]: https://docs.cntd.ru/document/945029027. Last accessed 05.05.2024.

[2] Strategy for social and economic development of Saratov region until 2030. [Electronic resource]: https://investinsaratov.ru/files/docs/321-p.pdf.PDF. Last accessed 05.05.2024.

[3] Forecast of socio-economic development of Orenburg region for 2023 and the planning period of 2024 and 2025. [Electronic resource]: https://mineconomy.orb.ru/documents/active/11493/. Last accessed 05.05.2024.

[4] Strategy for socio-economic development of the Penza region for the period up to 2035. [Electronic resource]: https://pnzreg.ru/open-government/nekommercheskie-organizatsii/etnokonfessionalnye-otnosheniya/Стратегия%202035.pdf. Last accessed 05.05.2024.

the Republic of Tatarstan[5] provides for spatial development of productive forces, industrial clusters, including transport and logistics, which shows the understanding and interest of the republic's leadership in the development of this sector of the regional economy. The analysis of the strategy for socio-economic development of Ulyanovsk region[6] shows that because of significance of the transport system the goals and objectives of its development are highlighted in a separate section. The list of regional strategies is obviously far from being complete, some of those strategies being scrupulously developed, nevertheless have shortcomings from the point of view of detailed specification of the plans of development of transport and logistics systems (hereinafter referred to as TLS).

At the same time, the demand for formation of effective resource-saving TLSs from the population and business sets the task for government bodies to create commodity distribution systems integrated with other sectors of the economy and having balanced parameters of transport and terminal infrastructure. In these conditions, the search for new sources of savings on transport and logistics services becomes a priority task with a relatively small number of alternatives for reducing costs and ensuring the competitiveness of the industry.

The task of resource saving is often associated with the generally accepted concept of «lean production». However, the boundaries of resource saving go beyond a single enterprise or group of enterprises, while «lean production» is usually spoken of as a concept of reducing costs within the boundaries of an enterprise.

Underestimation of implementation of resource saving programs at the level of corporations, industries and regional economies obviously reduces not only the efficiency of economic activity, but also the quality of goods and services as a result of the use of resources in production activities.

However, understanding the importance of implementing resource-saving technologies that can reduce costs and increase benefits by itself is not enough. The implementation of resource-saving technologies itself requires significant costs to move to a more efficient organisation of production that can increase labour productivity and reduce resource costs.

Within the boundaries of the proposed study, as indicated above, the models for calculating the number of TLC objects are used as resource-saving technologies, which in total ensures a reduction in resource costs for the cargo delivery function.

At the same time, there are other methods of resource saving in TLS that have proven their effectiveness to a greater or lesser extent. It is to note an approach based on the methodology of inventory management in supply chains, in which, in each subsequent TLC of the system, the calculation of inventory parameters is provided for considering the same parameters at the previous TLC. This helps to reduce the costs of maintaining and immobilising investments in inventory, increase the rate of capital turnover and, consequently, minimise the volume of unshipped goods. Therefore, with such an integration of TLC into the system, the main indicator of resource-saving will be not so much the amount of warehouse stocks in all links, but accounting of the methods of managing them at previous TLCs.

In addition to the listed approaches, the conditions for resource saving in TLC refer also to the applied cargo handling technologies and the level of automation of logistics processes. It is obvious, for example, that a high level of automation of logistics processes of a single TLC within the system will not give a general system effect, since in this case the resource-saving effect provides for the balance and harmonisation of the applied cargo handling technologies in all the TLCs of the system.

In this regard, a rational choice of locations and calculation of the number of infrastructure facilities of the transport and logistics system is just one of such alternatives for reducing the costs of transport and logistics services.

Accordingly, *the objective* of the study, the results of which are describe in the article, is to present the rationale to the approach of the regional resource-saving model of cargo distribution based on identification of economically feasible number of transport and logistics centres that ensure minimisation of logistics costs for the provider and minimisation of the price of transport and logistics service for the customer.

[5] Strategy for socio-economic development of the Republic of Tatarstan until 2030. [Electronic resource]: https://eco.tatarstan.ru/strategiya-sotsialno-ekonomicheskogo-razvitiya.htm. Last accessed 05.05.2024.

[6] Strategy for socio-economic development of Ulyanovsk region until 2030. [Electronic resource]: https://docs.cntd.ru/document/463710828. Last accessed 05.05.2024.

LITERATURE AND RESEARCH REVIEW

TLCs which play a key role in the system of delivery and distribution of large volumes of cargo and form a logistics supply chain, as a rule, do not provide the required level of efficiency in the implementation of the functions of delivering cargo to the end consumer. The formed TLC systems within the boundaries of «supplier – customer» according to the developers' plan should ensure a reduction in the costs of transportation, cargo handling and distribution under the conditions of consolidation of large volumes of cargo. However, a large (excessive) number of TLCs on the route from supplier to customer leads to an increase in the costs of transport and logistics services, which entails a growth of the cost of final goods and services. In this case, a non-linear parabolic dependence takes place, which requires calculating the impact of the number of TLCs on logistics costs, where the share of transport costs is the highest.

The analysis of scientific papers devoted to the concepts of reducing transport and logistics costs shows their great diversity both in quantity and in functional areas. Thus, the eLibrary.ru database contains over one thousand works on this issue, and international databases such as Web of Science and Scopus contain over 2.5 thousand. However, there are significantly fewer works that study the impact of the number of TLCs and the procedure for linking consumers to them.

Nevertheless, it is possible to highlight several works that deserve attention in the context of the chosen research topic. Thus, the work of D. J. Bowersox and D. J. Closs [1] analyses the impact of the number of warehouses on total transport costs and provides an example of determining the areas served by TLCs based on the criterion of the lowest total costs. The study proves that with an initial increase in the number of TLCs in the supply chain, transport costs decrease, and then as their number grows, costs increase. However, such a dependence is observed with a sufficiently large cargo flow.

In addition, the procedure for assigning consumers to a specific TLC is explained through the ability to ensure the delivery of goods with minimal total logistics costs.

However, when focusing efforts on restructuring the logistics system and striving to minimise costs, the authors do not show the relationship between the tasks of calculating the optimal number of TLCs and linking an economically justified number of consumers to the corresponding facilities. Therefore, resource-saving tasks are solved locally without considering the influence of the current result on the next one.

Donald Waters's study [2] provides examples of fairly trivial methods for making decisions on choosing the best location for a logistics facility, which should provide better access conditions for consumers compared to other existing ones. The technology for planning the locations of infrastructure logistics facilities is disclosed in detail, but there is no assessment and comparison of the total logistics costs when re-assigning consumers to other supply centres. Just as in [1], the author substantiates the dependence of transportation costs on the number of infrastructure elements, but the assessment is based on expert analysis.

Jeffrey H. Schutt in his work [3] examines the problems of planning the flow of products, evaluates modern logistics technologies for managing the flow of products, such as Materials requirements planning (MRP), Distribution requirements planning (DRP), Just-in-time (JIT), Theory of Constraints (TOC). The analysis proposed by the author is based on the flows of materials, which are mainly estimated in production in various industries from the standpoint of their possible forecasting and planning using traditional and modern methods. Improved planning solutions and methods for their implementation in business practices constitute the methodological basis of the work. Obviously, the problem of logistics costs is one of the central ones, but spatial network planning of cargo flow in the context of referring to consolidation and distribution points, as well as quantitative parameters of infrastructure facilities are not considered.

In similar works, comparable concepts and approaches are presented by studies aimed at the methodological aspects of planning, including planning of cargo flows in logistics, using mathematical apparatus and are disclosed in the form of successive stages of transformation of the existing scientific tools into new methods and approaches. Such works include the works of A. J. Clark and H. Scarf [4], S. Shingo [5], S. Tayur, R. Ganeshan, M. Magazine [6], J. M. Reeve [7] and others.

The basis for designing cargo flow distribution systems is economic and mathematical modelling, therefore a significant number of works are devoted to the possibilities of using mathematical apparatus in solving local and system problems of supply chain management. For example, Jeremy Shapiro in the work [8] proposes methods for planning and modelling supply chains, starting from the stage of choosing the configuration of supply chains and up to their formation and management. In terms of content, the work is a scientific manual with a pronounced methodological focus, which analyses and evaluates various information technologies used in practices, as well as models and methods for making supply chain management decisions. The work proposes methods for an integrated approach to supply chain management using corporations and companies as examples. However, the problems formulated within the objective of this article are not considered in a direct formulation.

It is worth noting several other works that provide mathematical approaches to management and optimisation of functions and operations in supply chains. Such studies include the works of J. C. Turner [9], V. S. Lukinsky[7], P. M. Simonov[8], G. I. Prosvetov[9], O. O. Zamkov, A. V. Tolstopiatenko, Yu. N. Cheremnykh[10], N. Sh. Kremer[11] and other authors.

Significantly fewer works relate to developed methodological approaches to designing logistics systems, where the main parameters are the number of TLCs and the economic feasibility of attaching a consumer to a particular TLC. Obviously, the task of resource saving is central here. These studies include the works of A. Lösch [10], D. J. Bowersox, [1], E. V. Bolgova, M. V. Kurnikova [11], B. A. Anikin, A. P. Tyapukhin[12] [12] and other works.

[7] Models and methods of logistics theory: Study guide. 2nd ed. Ed. by V. S. Lukinsky. St.Petersburg, Piter publ., 2007, 448 p.

[8] Simonov, P. M. Economic and mathematical modelling [Electronic resource]: Study guide in 2 parts. Perm, 2019, Part 1. – 230 p.

[9] Prosvetov, G. I. Mathematical methods in logistics: problems and solutions: Textbook and practical manual. Moscow, Publishing house «Alfa-Press», 2014, 304 p.

[10] Zamkov, O. O., Tolstopiatenko, A. V., Cheremnykh, Yu. N. Mathematical methods in economics: Textbook. Moscow, Lomonosov Moscow State University, Publishing House «DIS», 1998, 368 p.

[11] Kremer, N. Sh. Operations research in economics: Study guide. Moscow, UNITY publ., 2005, 407 p.

[12] Anikin, B. A., Tyapukhin, A. P. Commercial logistics: Textbook. Moscow, TK «Velbi», Publishing house «Prospect», 2005, 432 p.

The problems of rational distribution of productive forces are reflected in the formation of state socio-economic policy. Thus, the Strategy for Spatial Development of the Russian Federation for the period up to 2025, approved by the order of the Government of the Russian Federation, dated February 13, 2019, No. 207-r[13], formulated the main problems, trends, challenges, goals and objectives, both at the federal and regional level. The main objective of this document is to ensure balanced and sustainable development of the socio-economic space of the Russian Federation. It envisages the directions for reducing interregional differences in terms of the economy, social sphere, technology and elements of the national security system.

MATERIALS AND METHODS

The materials for the study comprise the scientific, methodological and methodological apparatuses that were analysed in the section «Literature and research review» of this work, as well as the results of implementation of strategies and programs for formation of spatial models of TLC networks of government agencies and businesses. The methodological approach proposed in the study consists in the application of analytical models and dependencies for determining the quantitative and geographical parameters of creating cargo distribution systems in supply chains based on the use of a TLC network. For this purpose, to achieve the effect of resource saving, it was necessary to solve problems on calculating and justifying a cargo distribution system with a minimum sufficient and economically feasible number of TLC facilities. This made it possible to achieve a more efficient model of cargo delivery, which ensured a reduction in transportation costs in the context of the planned positive expectations from the proposed activities.

As a priority theoretical base, the article uses mathematical methods, in particular, the regression-correlation analysis. The rationale of the use of this type of analysis is based on the choice of a rather complex object of optimisation which is the regional transport and logistics network and of the universality and

[13] Strategy for spatial development of the Russian Federation for the period up to 2025. Approved by the Order of the Government of the Russian Federation, No. 207, dated 13.02.2019 (as amended on 16.12.2021). [Electronic resource]: http://www.consultant.ru/document/cons_doc_LAW_318094/. Last accessed 05.05.2024.

availability of the very method of analysis and optimisation which is regression-correlation analysis. Due to its relative simplicity and versatility, the mathematical apparatus used for the selected object of study has several drawbacks, the main of which are the assumptions made on the volume of cargo processed and transported, the incomplete structure of logistics costs used in the calculations, and the errors inherent in this method. In addition, the model does not provide for the choice of the mode and type of transport for each batch when exporting goods from the TLC, which can be attributed to certain limitations of the model used in the article. Nevertheless, having defined the objective function, a system of constraints and assumptions, this method can be used to solve such problems.

Besides, the work used the fundamentals of formation and development of industry and regional economies. The works of Russian and foreign scientists were used to analyse and evaluate cargo distribution systems.

The empirical basis of the study comprise reports on the costs of companies performing the functions of transportation and cargo handling, industry statistical reporting documents, regional and federal planning documents of the main socio-economic indicators.

The analytical prerequisites for using the proposed research methods to form a resource-saving mechanism in distribution of goods are the need to use a special mathematical apparatus adequate to the specifics of the problem being solved in the conditions of the prevalence of random variables. Since transport costs in the cargo distribution system change non-linearly, considering such a dependence requires calculating the economically advantageous number of TLCs.

The regulatory prerequisites for the study are the stipulations of the Federal Law «On Strategic Planning in the Russian Federation» [14]. The practices of industry strategies for development of TLCs can be summarised in development and implementation of a package of documents consisting of: the Transport Strategy of the Russian Federation until 2030 with a forecast for the period up to 2035 [15]; the Strategy for Development of Railway Transport in the Russian Federation until 2030 [16]; the Strategy for Development of Automobile Transport and Urban Ground Electric Transport (draft) [17], as well as the Federal Project «Transport and Logistics Centres» (a structural component of Section 1 «Transport Infrastructure» of the Comprehensive Plan for Modernisation and Expansion of the Mainline Infrastructure) [18].

RESEARCH RESULTS

The analysis of reporting data on TLC facilities by regions and federal districts and their comparison with the dynamics of changes in regional transport indicators does not answer the question of the dependence of transportation costs on the number of TLCs. Such a relationship is visible when analysing the designed system of distribution through a TLC network of goods of a certain nomenclature and volumes.

Nevertheless, the analysis of reporting documents, for example, the reference book «The Guide of Warehouses of the Russian Federation» [19] on warehouse real estate, in comparison with the dynamics of transportation costs of a conditional region taken from the reports of the Federal State Statistics Service [20], is of obvious scientific and practical interest.

Pics. 1 and 2 show the dynamics of the volumes of commissioning of warehouse space and the dynamics of the volumes of transactions

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[14] Federal Law of June 28, 2014, No. 172-FZ «On Strategic Planning in the Russian Federation». Adopted by the State Duma on June 20, 2014. Approved by the Federation Council on June 25, 2014.

[15] Transport Strategy of the Russian Federation until 2030 with a forecast for the period until 2035. Approved by the Order of the Government of the Russian Federation of November 27, 2021, No. 3363-r. [Electronic resource]: http://static.government.ru/media/files/7enYF2uL5kFZlOOpQhLl0nUT91RjCbeR.pdf (last accessed 05.05.2024)

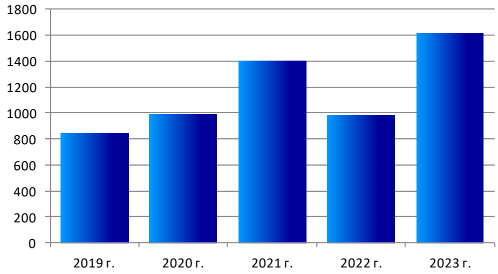
[16] Strategy for Development of Railway Transport in the Russian Federation until 2030. Approved by the Order of the Government of the Russian Federation of 17.06.2008, No. 877-r. [Electronic resource]: http://www.consultant.ru/document/cons_doc_LAW_92060 Last accessed 05.05.2024.

[17] Strategy for Development of Automobile Transport and Urban Ground Electric Transport. Draft. [Electronic resource]: https://www.mintrans.ru/documents/7/9306. Last accessed 05.05.2024.

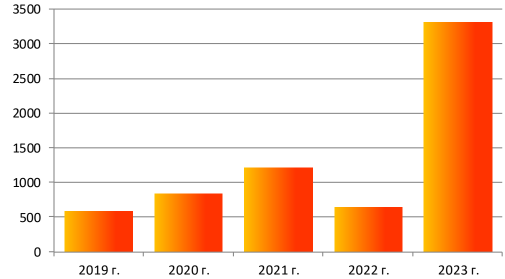
[18] Comprehensive plan for modernisation and expansion of the mainline infrastructure for the period up to 2024. Approved by the Order of the Government of the Russian Federation of September 30, 2018, No. 2101-r. http://gov.garant.ru/SESSION/PILOT/main.htm. Last accessed 05.05.2024.

[19] Electronic reference book «The Guide of Warehouses of the Russian Federation». [Electronic resource]: https://гидсклады.рф.

[20] Regions of Russia: socio-economic indicators. 2023: statistical collection. Moscow, Rosizdat publ., 2023, 1126 p.



Pic. 1. Dynamics of the volume of warehouse space commissioning in the regions of Russia, thousand sq.m. [Source: developed by the authors using the data of Electronic reference book «Guide of Warehouses of the Russian Federation 2024»19].



Pic. 2. Dynamics of the volume of transactions with warehouse real estate in the regions of Russia, thousand sq.m. [Source: developed by the authors using the data of Electronic reference book «Guide of Warehouses of the Russian Federation 2024»[19]].

with warehouse real estate in the regions of Russia.

The analysis of the data in the diagrams shows the linear nature of the dynamics of the indicators. The dynamics of the indicator in Pic. 1 generally repeats the dynamics of Pic. 2. This overlapping is due to the dependence of the input volume on the increasing values of transaction volumes, the worst indicator being 2022. There is an almost twofold excess of the input volume over the transaction volumes, except for 2023. In 2023, the transaction volumes more than twice exceeded the input volumes. That is, the increasing volumes of transactions stimulate an increase in offers on the warehouse real estate market and construction of new facilities. In addition, there is a significant decrease in the values of the indicators in 2022, and a sharp increase in 2023, due to the import substitution process. Comparison of the indicators in Pic. 1 and 2 with transportation costs and commissioning of new facilities[20], using the example of Samara region, indicated in Table 1, shows the presence of a seemingly obvious correlation between these time series.

However, a more detailed analysis of this relationship may show a negative correlation, since the analysis of the dependence of transportation costs on the number of logistics infrastructure facilities (TLC, warehouses) and the procedure of attaching consumers to TLCs should be assessed by product nomenclature groups and their volumes when delivered to consumers in supply chains.

The developed approach, based on determining the dependence between transportation costs and the number of TLCs, allows us to form a more economical configuration of the cargo delivery system with the minimum required number of TLCs. The approach is based on the model being shaped: «location of the supplier – location of TLC – location of the recipient». The method for calculating this dependence includes several stages.

First, the modes of cargo delivery without TLC (a direct mode) and with TLC are assessed. For direct delivery, we use formula (1):

$$R^1 = R_T + R_{lu} + R_{pack} + R_s, \qquad (1)$$

where R^1 – transportation costs for cargo transportation;

R_T – transportation costs;

R_{lu} – loading and unloading costs;

R_{pack} – cargo packaging costs;

R_s – expenses for storing cargo at the starting and ending points.

For delivery using TLC, costs will be calculated using formula (2):

$$R^2 = R_T + R_{lu} + R_{pack} + (n*R_s), \qquad (2)$$

where n is the number of TLCs.

It is essential to consider the constraint (3) [1] for the mode of cargo delivery:

$$\Sigma \frac{P_{\bar{V}} + T_{\bar{V}}}{N_{\bar{X}}} + W_{\bar{X}} + L_{\bar{X}} \le \Sigma P_{\bar{X}} + T_{\bar{X}}, \qquad (3)$$

where P_V – consolidated cargo handling costs;

T_V – transportation costs for consolidated cargo shipments;

W_X – warehouse storage costs for an average cargo shipment;

L_X – local transportation costs for medium cargo shipment;

N_X – number of average shipments in a consolidated shipment;

P_X – average shipment handling costs;

T_X – transportation costs for direct delivery of medium shipment.

That is, the volumes of transportation must be large enough – so large that their size allows for an effect of scale with the ability to cover TLC handling costs.

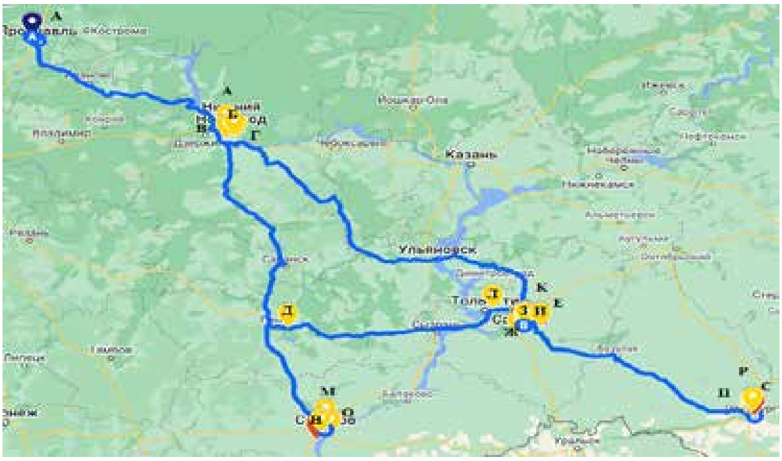
Then, using a simple enumeration method, delivery routes are selected considering the

Table 1

Aggregated regional economic indicators of Samara region [developed by the authors based on [20]]

Indicators	Years					
	2017	2018	2019	2020	2021	2022
Construction (as compared with the previous year %)	104,5	80,7	116,2	86,8	121,8	102,1
Transportation and storage (as compared with the previous year %)	104,0	103,0	100,8	92,1	104,2	105,2

Pic. 3. Delivery of goods directly from the manufacturer (B1 – B7 are business customers).



Pic. 4. Delivery of goods from the manufacturer using TLCs (A – S).

geography and number of TLCs for each supply chain option. Table 2 shows examples of calculations for two conditional routes.

Table 3 shows the results of calculations for the selected routes.

Based on the calculated average values for each route, graphs of the dependence of transportation costs on the number of TLCs are constructed using an Excel table.

Next, an analysis of sensitivity of the increase in the number of TLCs to changes in transportation costs is carried out. Calculations are carried out to determine the nature of this dependence. Obviously, this dependence is of a nonlinear parabolic type, where the equation of nonlinear regression of the parabolic type has the form (4)[21]:

$$y = ax^2 + bx + c, \quad (4)$$

where a, b, c – regression coefficients.

After calculating the regression coefficients and assessing the studied dependence, the

[21] Zadorozhny, V. N., Zalmezh, V. F., Trifonov, A. Yu., Shapovalov, A. V. Higher Mathematics for Technical Universities. Linear Algebra: Study guide. Tomsk, TPU Publishing House, 2009, 310 p.

Table 2

Selecting routes and calculating the cost for each route

Route	S-A-D-L-K-I–C1								
Departure	Reception	L, km	R_T	R_s	R_{pack}	Loading	Unloading	R_{lu}	R
S	A	L_1	R_{T1}	Rs_1	$Rpack_{1-5}$	$Load_1$	$Unload_1$	Rlu_1	R_1
A	D	L_2	R_{T2}	Rs_2		$Load_2$	$Unload_2$	Rlu_2	R_2
D	L	L_3	R_{T3}	Rs_3		$Load_3$	$Unload_3$	Rlu_3	R_3
L	K	L_4	R_{T4}	Rs_4		$Load_4$	$Unload_4$	Rlu_4	R_4
K	I	L_5	R_{T5}	Rs_5		$Load_5$	$Unload_5$	Rlu_5	R_5
								Total	$\sum$
Route	S-A-D-L-K-I–C1								
Departure	Reception	L, km	R_T	R_s	R_{pack}	Loading	Unloading	R_{lu}	R
S	A	L_1	R_{T1}	Rs_1	$Rpack_{1-6}$	$Load_1$	$Unload_1$	Rlu_1	R_1
A	D	L_2	R_{T2}	Rs_2		$Load_2$	$Unload_2$	Rlu_2	R_2
D	L	L_3	R_{T3}	Rs_3		$Load_3$	$Unload_3$	Rlu_3	R_3
L	K	L_4	R_{T4}	Rs_4		$Load_4$	$Unload_4$	Rlu_4	R_4
K	C1	L_6	R_{T6}	Rs_6		$Load_6$	$Unload_6$	Rlu_6	R_6
								Total	$\sum$

where S is the supplier C1 is the customer No. 1; A, D, L, K, I are the TLCs on the selected delivery routes, R are transportation costs for cargo transportation; R_T are transportation costs; R_{lu} are the costs of loading and unloading operations; R_{pack} are the costs of packaging the cargo; R_s are the costs of storing the cargo.
Source: developed by the authors.

Table 3

Results of calculations for cargo delivery along the S-C1 route considering the TLC system [developed by the authors]

Route	R, rub
S-A-D-L-K-I–C1	R_1
S-A-D-L-K-C1	R_2
S-A-D-L–C1	R_3
S-D-L–C1	R_4
S-D-C1	R_5
S-G-D-M–I-C1	R_6
S-D-M–I-C1	R_7
S-D-M–C1	R_8
S-M–C1	R_9

correlation and determination indices are calculated[21].

To conduct the computational experiment, a delivery of medicines to several regions of the Russian Federation was selected – Samara, Saratov and Orenburg regions from one of the manufacturers of Yaroslavl region (city of Yaroslavl). Pics. 3 and 4 show the schemes for delivery of medicines directly without TLCs and using a TLC system, respectively.

After selecting the routes, the cost of direct delivery for various customers from one of the manufacturers in Yaroslavl region is calculated.

Using the data in Table 2, we will calculate the transportation costs for several delivery routes selected for the example using TLCs. Table 4 shows the calculation results (fragment).

Calculations are made similarly for the remaining routes.

Table 5 shows the calculated values for transportation along route S-B4 taking into account the TLC system.

Pic. 5 shows the results of calculations of the dependence of transportation costs on the number of TLCs.

It is obvious that there is a dependence between transportation costs and the number of TLCs, the nature of which is nonlinear parabolic. Using correlation-regression analysis, we will determine the closeness of the relationship between these indicators with the derivation of a nonlinear regression equation.

Table 6 shows the required values for calculating the regression matrices.

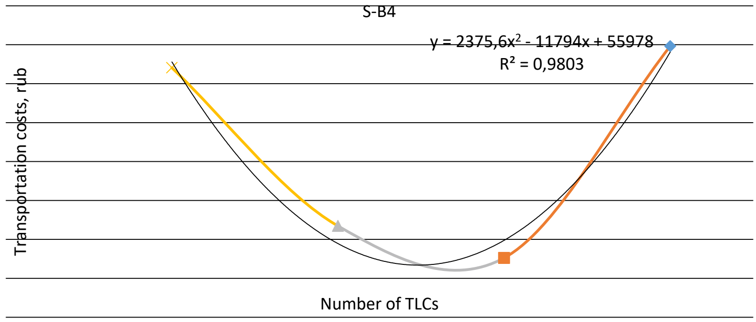
The resulting nonlinear regression equation has the form:

$$Y = 2375,64x^2 – 11794,14x + 55977,78. \quad (5)$$

The correlation and determination indices are r = 0,99 and R^2 = 0,98, respectively. Pic. 6 shows the results obtained using the regression equation.

SHORT CONCLUSIONS

Thus, the computational experiment confirmed the assumption of a nonlinear parabolic relationship between transportation costs and the number of TLCs. The indices of correlation and determination confirm the closeness of the relationship between the



Pic. 5. Dependence of transportation costs on the number of TLCs when transporting cargo along the S-B4 route [developed by the authors].

Table 4

Results of calculations of the cost of cargo delivery along several routes S-B4 considering TLC system [developed by the authors]*

Route	P-G-D-M-N-B4								
Departure	Reception	L, km	**R_T, rub**	R_s, rub	R_{pack}, rub	Loading, rub	Unloading, rub	R_{lu}, rub	R, rub
S	G	405	8 100	156	8 437	2 230	948	3 178	19 871
G	D	417	8 340	669		948	1 450	2 899	11 908
D	M	256	5 120	223		1 450	1 394	2 788	8 131
M	N	31	622	145		1 394	836	1 673	2 439
N	B4	22	432			836	3 345	4 181	4 613
								Total	46 962
Route	P-G-D-M-B4								
Departure	Reception	L, km	**R_T, rub**	R_s, rub	R_{pack}, rub	Loading, rub	Unloading, rub	R_{lu}, rub	R, rub
S	G	405	8 100	156	8 437	2 230	948	3 178	19 871
G	D	417	6 255	134		948	1 450	2 899	9 288
D	M	256	3 840	223		1 450	1 394	2 788	6 851
M	B4	52	776			1 394	3 345	4 739	5 514
								Total	41 524
Route	P-D-M-B4								
Departure	Reception	L, km	**R_T, rub**	R_s, rub	R_{pack}, rub	Loading, rub	Unloading, rub	R_{lu}, rub	R, rub
S	D	807	16 140	669	8 437	2 230	1 450	3 680	28 926
D	M	256	5 120	223		1 450	1 394	2 843	8 186
M	B4	52	1 034			1 394	3 345	4 739	5 773
								Total	42 885
Route	P-G-M-B4								
Departure	Reception	L, km	**R_T, rub**	R_s, rub	R_{pack}, rub	Loading, rub	Unloading, rub	R_{lu}, rub	R, rub
S	G	405	8 100	781	8 437	2 230	948	3 178	20 495
G	M	609	12 180	446		948	1 394	2 342	14 968
M	B4	52	1 603			1 394	3 345	4 739	6 341
								Total	41 804

*Price indices are indicated as for late 2023.

empirical and theoretical values, which did not fall below 0,89. This confirms that the theoretical model corresponds to the real situation with acceptable accuracy. Consequently, the approach can be used to calculate and forecast the dependence of transportation costs on the number of TLCs on the route, and that is practically important for both suppliers and customers.

The results of the study, within the boundaries of which the problem of finding an approach to reducing the costs of cargo delivery in the context of a resource-saving paradigm, helped to confirm the put forward assumption about the obvious dependence of transportation costs, including storage costs and loading and unloading operations in TLCs on the number of TLCs the routes.

Table 4

Results of calculations of the cost of cargo delivery along several routes S-B4 considering TLC system [developed by the authors]*

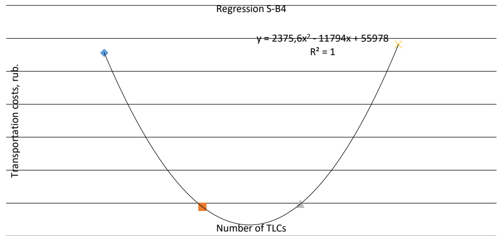
Route	P-G-D-M-N-B4								
Departure	Reception	L, km	$R_{т}$, rub	R_{s}, rub	R_{pack}, rub	Loading, rub	Unloading, rub	R_{lu}, rub	R, rub
S	G	405	8 100	156	8 437	2 230	948	3 178	19 871
G	D	417	8 340	669		948	1 450	2 899	11 908
D	M	256	5 120	223		1 450	1 394	2 788	8 131
M	N	31	622	145		1 394	836	1 673	2 439
N	B4	22	432			836	3 345	4 181	4 613
								Total	46 962
Route	P-G-D-M-B4								
Departure	Reception	L, km	$R_{т}$, rub	R_{s}, rub	R_{pack}, rub	Loading, rub	Unloading, rub	R_{lu}, rub	R, rub
S	G	405	8 100	156	8 437	2 230	948	3 178	19 871
G	D	417	6 255	134		948	1 450	2 899	9 288
D	M	256	3 840	223		1 450	1 394	2 788	6 851
M	B4	52	776			1 394	3 345	4 739	5 514
								Total	41 524
Route	P-D-M-B4								
Departure	Reception	L, km	$R_{т}$, rub	R_{s}, rub	R_{pack}, rub	Loading, rub	Unloading, rub	R_{lu}, rub	R, rub
S	D	807	16 140	669	8 437	2 230	1 450	3 680	28 926
D	M	256	5 120	223		1 450	1 394	2 843	8 186
M	B4	52	1 034			1 394	3 345	4 739	5 773
								Total	42 885
Route	P-G-M-B4								
Departure	Reception	L, km	$R_{т}$, rub	R_{s}, rub	R_{pack}, rub	Loading, rub	Unloading, rub	R_{lu}, rub	R, rub
S	G	405	8 100	781	8 437	2 230	948	3 178	20 495
G	M	609	12 180	446		948	1 394	2 342	14 968
M	B4	52	1 603			1 394	3 345	4 739	6 341
								Total	41 804

*Price indices are indicated as for late 2023.

Table 5

Calculated values for transportation along the route S-B4 considering the TLC system [developed by the authors]

Route	R, rub
S-G-D-M-N-B4	46 962
S-G-D-M-B4	41 524
S-D-M-B4	42 885
S-G-M-B4	41 804
S-G-B4	43 808
S-M-B4	49 009



Pic. 6. Calculation of the studied dependence using the regression equation [developed by the authors].

Table 6

Necessary values for calculating P-B4 regression matrices [developed by the authors]

№	X	Y	x^2	x^3	x^4	xy	yx^2	y	$(Y-y)^2$	$(Y-yav)^2$
1	1	46408,45	1	1	1	46408,45	46408,45	46559,28	22750,44	4404699,09
2	2	42344,55	4	8	16	84689,10	169378,20	41892,05	204753,99	3861863,65
3	3	41523,6	9	27	81	124570,80	373712,40	41976,10	204753,99	7762422,86
4	4	46962,25	16	64	256	187849,00	751396,00	46811,42	22750,44	7035955,19
Σ	10	177238,85	30	100	354	443517,35	1340895,05	177238,85	455008,86	23064940,80

Table 7

Economic effect of using the proposed approach [developed by the authors]

Delivery routes	Costs reduction, rub.	Economic effect, %
S-B1	25 286,7	5,1
S-B2	22 126,6	8,8
S-B3	16 146,7	26,9
S-B4	28 017,9	10
S-B5	23 121,1	16
S-B6	14 084,5	5,6
S-B7	7 257,5	6,1

In addition, it was possible to identify the problem of not considering this dependence into account by government authorities and the business community. The lack of due attention to the problem of high costs in direct delivery compared to delivery through a TLC system significantly reduces the efficiency of economic activity of enterprises providing transport and logistics services.

Knowledge and implementation of the proposed approach within the framework of the resource-saving strategy can help reduce the cost of these services, which is economically beneficial for all participants in the logistics chain.

The main results of the study include the developed scientific and practical approach to reducing costs in the context of the resource-saving strategy, which is based on the principle of rational organisation of the spatial selection of infrastructure facilities of the transport and logistics network and the resulting economic effect compared to direct delivery, shown in Table 7.

The developed approach with the justification of the rational quantity and location of TLCs, ensuring the reduction of costs in the cargo delivery system, can be used in making management decisions and calculating delivery costs for different configurations of the TLC network with different numbers of TLCs.

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