Procedure and algorithmization of calculation of terminal network parameters

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Abstract. It is impossible to implement trans-regional integration without a regional logistics system based on a network of storage and distribution centers. The search for the most suitable project of a terminal network is complicated by the necessity to perform a step-by-step processing of options. Decisions are made considering the economic performance of the cargo transportation process. The target function has been formulated in the article. A sequential decision-making process based on the number and dislocation of terminals has been developed with a calculation model, and an algorithm for designing a regional terminal network is proposed. A terminal network is considered as a systemically important basis to implement the integration of all transport-expediting processes in the region. The advisability of formation of the regional terminal network to support the logistics of cargo transportation has been substantiated. The paper proposes a methodology for stepwise solution of the task to determine the required number and parameters for location of the logistics storage and distribution centers (LSDCs). The basis of a calculation process is an estimation model. The application of the proposed methodology will enable improving the existing terminal network of the Russian railway transport, enhancing the efficiency of cargo transportation, and facilitating the increase in competitiveness of RZD OJSC in the cargo transportation market.

1. Introduction

The existing market conditions objectively require integration of the regional transport-expediting area, harmonization of interests of all those involved in the goods and cargo transportation process, and creation of a competitive environment for the provision of transport and logistics services [14]. Creation of a terminal (storage) network is a methodological challenge. Not only interests of all those involved in the transportation process should be taken into account, but also other aspects of the cargo transportation management should be considered (size of inventories and lots, storage capacity, spatial location and number of terminals, market analysis). Moreover, the problems of designing a regional logistics system to ensure efficient cargo transportation are inextricably connected with determination of the number and dislocation of the logistics storage and distribution centers (LSDCs) of the terminal network nodes.

Internationally, expenses for transportation and transshipment operations account for up to 15–18% of the goods final cost, with over 30% of the goods final cost in Russia [16]. The bulk of cargo operations takes place in cargo-generating areas, i.e. cargo forefronts included into the transportation and storage infrastructure of the enterprises. Maintenance of cargo and storage facilities increases the
prime cost of the finished products, which hampers the product distribution. Thus, it seems a topical issue for manufacturers to reduce their own storage infrastructure.

One of the ways to cut the costs for the transport and logistics support of cargo transportation processes is to use an LSDC network for the manufacturers’ storage and distribution operations. LSDC is an independent transportation and cargo handling specialized complex of facilities and technical devices being organizationally and technologically interrelated and intended to perform the logistics operations of cargo receipt, loading and unloading, storage, sorting, and handling, as well as commercial and information service of transportation process on the basis of the integrated economic, financial, staffing, statutory and regulatory support [17].

The purpose of this study is to develop a methodology for step-by-step making of a decision on the formation of the region’s terminal network. Primary tasks:
1) to determine the role of the terminal network in the regional cargo transportation and the sequence of getting access to national transport corridors through this network;
2) to form a target function to be used to make decisions on the terminal network creation;
3) to develop a model for complex calculation of parameters of the terminal network to be formed.

2. Research Methods
The research methodology implies the use of principles of systems theory, process approach, algorithmization methods, and synergetics. Scientific papers dedicated to the development of both global [19; 12] and regional [18] transport systems were used as a theoretical and methodological basis. To describe the terminal network operating conditions, methods of logistics, railway operation management, cluster and system analysis, option synthesis, and economic and mathematic simulation were applied.

The research rests upon the basic methods of terminalistics (“logistics” + “terminal” = logistics of terminal and terminal networks) [15] that have been described in earlier papers by the authors [16].

3. Research Results
A region’s terminal network is the set of interacting and centrally managed terminals providing trans-regional integration and access to transport corridors. Regional LSDCs, located close to commercial production units form the material basis of an agglomeration’s transport infrastructure, create conditions for advanced processing of raw materials within the region.

The integrated regional transport-expediting area is a complex incorporating the terminal network and transport and road infrastructure and providing the logistics support for cargo delivery.

If the cargo flows that are generated and consumed in the region pass through the terminal network, this will provide competitive environment in the region’s transport and logistics market and transfer of distribution, logistics, and marketing functions to cargo processing terminals. This will solve certain distribution issues:
1) monitoring of the goods requirements (both in terms of the total production volume and the range);
2) concentration of all the management and logistics work on the terminals, including cargo storage and distribution to an external network (for example, by involvement of forwarding agents or other agent companies);
3) planning of cargo delivery systems and selection of mode of transport. By uniting the market of the transport and logistics services and consumers in a unified space, the terminals will lay the groundwork for the operation of multi-transport systems, trans-regional integration and will provide access to national clusters and transport corridors.

The sequence of the region’s indirect access to transport corridors through the terminal network is shown in Figure 1.
transport links, carriers of mode of transport (a point-to-point level);

logical links; figures indicate a level number

Figure 1. Pattern of accessing the national transport corridors through the terminal network.

Figure 1 shows logical and transport links arising during cargo transportation, as well as the role of terminals in ensuring the region’s access to national transport corridors. Both incoming and outgoing cargo flows are formed in the servicing operating domain as the area within which LSDCs function.

To analyze the effect of the number and location of terminals upon the total costs for cargo transportation servicing, it is necessary to determine the total costs for each option and to make a conclusion on advisability of each option.

The target function can be formed in two aspects: a quantitative (value) and a qualitative (relative or effective) one. This paper considers the target function of a value aspect (see equation (1)).

The methodology to select the number and location of terminals is based on the selection of the most advantageous one from many options. The minimum of total costs for servicing the cargo transportation, $S_{\text{total}}$, is taken as the measure of optimality. This research makes an assumption that, in order to analyze the quantitative (value) aspect of the necessity to create the terminal network, target function $F$ should be developed and then minimized according to the selected measure of optimality, provided that the number of LSDCs is determinate and, if a network of two or more LSDCs functions in region, transportations between them are prohibited. In a particular case, the terminal network can consist of only one LSDC and, in a general case, of several LSDCs. In either case, a cargo terminal can both collect money for the services provided and distribute cargo.
where $S_{\text{trans.} \alpha}^{(0, \lambda)}$ is the total cost of cargo transportation servicing, rubles/year; $S_{\text{trans.}}$ is the total cost at the stage of servicing the transportation of cargo with the volume of $Q_{ik}$ from supplier $i$ to terminal $k$, rubles/year; $S_{\text{total}}$ is the total cost of servicing the terminal (intra-terminal and inter-terminal) transportation, rubles/year; $S_{\text{invest.}}$ is the total cost at the stage of distribution of cargo with the volume of $Q_{kj}$ by terminal $k$ among consumers $j$, rubles/year; $Q_{ik}$ is the amount of cargo delivered from suppliers $i$ to terminal $k$, tons/day; $Q_{kj}$ is the amount of cargo sent (distributed) by terminal $k$ to consumers $j$, ton/day.

The total cost of cargo $\sum_{\alpha=1}^{n} S_{\text{trans.} \alpha}^{(0, \lambda)}$ servicing at stage $\alpha$ ($\alpha_1 = ik$ – fee; $\alpha_2 = kj$ – terminal transportation; $\alpha_3 = kj$ – distribution) for cargo transportation by $\beta$ or $\lambda$ mode of transport ($\beta$ is transportation by road transport; $\lambda$ is transportation by railway; $\beta + \lambda$, is multitransport delivery) is minimized by: a dislocation type and the terminals’ location; supplier ($\sum_{i} S_{i}$), terminal ($\sum_{k} S_{k}$), and consumer ($\sum_{j} S_{j}$); $m$ and $n$ stages ($m$ is cargo delivery from the supplier to the terminal; $n$ is cargo dispatch from the terminal to a consumer) for each transport link. $\sum_{x=1}^{n} S_{\text{trans.} x}^{(y, z)}$ is calculated on the basis of the following cost types:

- $S_{\text{trans.}}$ are the purely transportation costs for cargo transportation servicing, rubles/year;
- $S_{\text{invest.}}$ is the amount of investment required to construct a cargo terminal (LSDC), inclusive of investment into infrastructure and equipment, rubles/year;
- $S_{\text{stor.}}$ are the costs for cargo storage at the terminal, rubles/year;
- $S_{\text{handl.}}$ are the costs related to warehouse cargo handling (marking, packaging, sorting, etc.), rubles/year;
- $S_{\text{cargo}}$ are the costs related to cargo operations (loading, unloading, reloading), rubles/year;
- $S_{\text{servic.}}$ are the costs related to transport-expediting and commercial and information services, cargo distribution, monitoring, and other logistics services, rubles/year.

Let us limit the research area to target function $F$, determining the basic parameters having most notable effect on making the final decision:

- $S_{\text{trans.} \alpha}^{(0, \lambda)}$ are the total costs for transportation servicing, rubles/year;
- $S_{\text{trans.}}$ are the costs for cargo transportation servicing, rubles/year;
- $S_{\text{invest.}}$ is the amount of investment to construct a certain number of LSDCs, rubles/year.

Under market conditions, the dominant factor in selecting a mode of transport is the cost of cargo delivery from a starting supplier to an end user. The scope of this research is limited by this consideration.

A transportation task, in accordance with target function $F$, is accompanied with a combinatorial problem of targeted processing of options and is complicated by an additional embedded calculation cycle (selection of a mode of transport/combination of mode of transport). It is impossible to differentiate the target function, since the amount of terminals is determinate.
When designing the terminal network, it is necessary to consider not only the full range of costs associated with cargo transportation but also the multivariance of possible spatial and quantitative solutions of the network. The necessity to analyze a large number of options is determined by the search for the most efficient one from all existing options. An efficient solution can only be obtained by varying possible combinations of both the number and dislocation of terminals, and the mode of transport to service them, and by performing their complex analysis. A change in the number and/or dislocation of terminals results in the move of each terminal servicing areas and in the costs amount change. This condition complicates the task of formalization and search for the most efficient solution of the terminal network.

LSDCs (terminals) collect and store cargo from regional product manufacturers, group the cargoes, and form cargo lots in terms of range and direction of transportation. An incoming flow consists of cargo flows, which are centrally directed to the terminal by cargo shippers (product manufacturers) with account for the areas with attraction to the terminal. An outgoing flow consists of cargo flows preliminarily grouped and distributed according to the delivery destinations being external to the region where the terminal network is designed.

An option of the number of terminals is a possible number of terminals in the region (the only one, two terminals in the region, etc.) out of all the assigned ones. An option of the terminals dislocation is a possible location of the terminal (if there is one terminal in the region) or nodes of the terminal network (if there are several terminals in the region) (in accordance with the number of terminals) out of all the assigned ones. Targeted (iterative) processing is used to estimate all the options of the terminals number and dislocation. Thus, the search for a solution is reduced to finding the best option of the number and dislocation of nodes of the terminal network and simultaneous selection of a mode of transport.

It is proposed to use an algorithm of making the decisions on the number and dislocation of LSDCs on the basis of calculation and further analysis of economic parameters according to the methodology of step-by-step decision-making. As a result, a decision is made on two aspects at once: quantitative and spacial aspect (on LSDCs number and dislocation), and transport and organizational one (on a mode of transport).

The decision-making process is as follows: A source data block is introduced and the option of the terminals number and dislocation (by a sector or the nearest point of exit from the region) is assigned; transportation costs for automobile and railway transport are calculated. Analysis of the obtained results is the basis for making an interim decision on advisability of the multi-transport delivery to collect or distribute cargo for each transport link.

The calculation is repeated for each option assigned. Based on all the calculations, a decision on efficiency of applying a certain option is made (on the terminals number and dislocation and a mode of transport with the lowest transportation costs for the cargo delivery servicing). The requirement of target function $F(1)$ is used as a criterion for the selection of the best option. The calculations are made, in parallel, for two (road and railway) modes of transport and for two delivery types. As a result, at the end of the process, we obtain an answer to the question: is it advisable to arrange multi-transport cargo transportation through the designed terminal network?

A step-by-step model for carrying out a complex calculation of the terminal network’s parameters and making a decision on formation of the terminal network in the region is shown in Figure 2.
Figure 2. Flow chart of complex calculation.
Calculation of blocks highlighted in color is not considered in detail in this paper. The calculation is enlarged. Formalization of the task is described in detail in paper [22]. The flow chart of complex calculation of the terminal network parameters (see Figure 2) enables deciding on the number and dislocation of terminals in the region as well as selecting the mode (combination of modes) of transport for their servicing.

Let us consider the composition of the flow chart (Figure 2). The calculation consists of two blocks: calculation of parameters of direct transportation (blocks 3–15) and terminal transportation (blocks 17–18) is shown in large dotted rectangles. Calculation of blocks 3–5 and 8–10 (small dotted rectangles) is the same for each level. The only difference between the direct and terminal transportation is that the costs for servicing of terminal cargo transportation $S_{\text{total term}}$ (block 14) consist of the total transportation costs $S_{\text{trans total}}$ (block 12) and investment for construction of the corresponding number of LSDCs $S_{\text{invest}}$ (block 13). The calculations are made in parallel for road and railway transport and the best mode of transport is selected. The cost for the cargo transportation servicing in direct cargo delivery consists of the total transportation costs $S_{\text{total direct}}$ (calculations are made for road transport).

The best option of the terminal network in terms of the number and dislocation of LSDCs and the mode of transport for its servicing (block 7) is selected when calculating the parameters for the terminal delivery inside the region. The total costs for servicing of the trans-regional cargo transportation through the designed terminal network and the most appropriate mode of transport for its servicing (blocks 8–14) are determined. The economic feasibility of the terminal network formation in the region and arrangement of terminal multi-transport carriage (block 19) is substantiated.

The number option (NO) for LSDCs in the region as well as the dislocation option (DO) of the terminal network nodes are selected in advance. These options of the number and dislocation are selected with due regard for the areas with attraction to terminals as region exit points, as well as for cargo-generating and cargo-consuming enterprises.

When calculating each terminal NO (blocks 3–5), a targeted (iterative) processing should be used to estimate the total costs for the cargo transportation for each terminal DO. The costs for the cargo transportation using a terminal technology comprise the costs for cargo collection in the region and the costs for cargo distribution to the region exit points corresponding to the export directions. The costs for the cargo transportation are determined for the road and railway transport. Based on this calculation, for specific NO and DO under each transport link with the minimum of the total transportation costs $S_{\text{total}}$ (for cargo collection and distribution to the borders of the region under consideration), a type/combination of mode of transport (TM) is selected. The result of calculation of each NO, $S_{\text{total NOj}}$, is the value of total costs for the cargo transportation servicing. The results for each NO are stored in block 6. This allows for parallel selection of both a mode of transport and a rational number and dislocation of LSDCs. Therein lies the complexity of the calculation and the decisions made. The same calculation sequence is used for each of blocks 3–5 (not shown in Figure 2).

This calculation is performed for all NO of LSDCs in the terminal network. Analysis of the results based on the total costs $S_{\text{total}}$ enables making the first decision within the region, i.e. to identify the advisability of applying a particular assigned option of the region’s terminal network (the best option of the terminal network in terms of NO, DO, and TM) (block 7). The best combination of NO, DO, and TM that ensures implementation of the cargo transportation volume with the minimum total costs is the sought best option of the terminal network (block 7).

Upon finding the best option of the terminal network within the region, parameters for the best option of the cargo terminal transportation through the designed network are calculated (blocks 8–14 in Figure 2). The results for calculation of each block (8–10): $S_{\text{tran coll}}$, $S_{\text{tran main}}$, $S_{\text{tran coll}}$ — transportation costs for the cargo collection, distribution, and mainline traffic are stored in block 11 and summarized in block 12. Then (block 13) $S_{\text{invest}}$ is determined — the investment amount for construction of the required NO of terminals (the cost of one LSDC construction is defined in the source data). The results of the transportation cost and investment calculation are summarized in block 14 and recorded in the internal memory $S_{\text{total term}}$ (block 15). At this calculation stage, total costs for
servicing the cargo transportation through the designed terminal network and the best mode of transport for its servicing are determined.

Then the parameters (total costs for the transportation servicing) of direct transportation without the use of the terminals (block 17) are calculated. The calculation results are recorded in the internal memory $S_{\text{tot. term.}}$ (block 18). Then the recorded results (blocks 15 and 17) are compared in block 19. Based on the calculation of the economic effect, a conclusion on advisability of transportations through the terminal network is made. This way the third (final) decision is made. If the inequality checked in block 19 is met, then the formation of the terminal network seems to be advisable (block 20). The calculations are finished after this decision (block 21). If the terminal transportation is unfavorable (inequality in block 19 is not met), no terminal network is formed (block 22). The calculation can be repeated (block 23) for the new source data (block 24) (for example, for the new direct delivery layout, carrying capacity of rolling stock, LSDC dislocation options).

4. Results and Discussion

The problems of development of the regional transport-expediting area are studied in the papers aimed at examination of the transport geography, regional studies, transport economics and logistics. The effect of transportation costs on the development of regional economics was studied in the paper by E. Glaeser [7]. The cost management as an important focus area in the enhancement of efficiency of railway transport operation was investigated in the paper by I. Solskaya and S. Belomestnykh [21].

The development of a terminal network is considered in a large number of modern studies. The papers by foreign authors present the analysis results of the new technologies for operating sea transport terminals [1, 6], road freight transport [8, 13], aircraft transport [9, 23], and combined cargo transportation [11, 25]. In the article by E. Kreutzberger [10], interaction between port and railway terminals was considered as the main problem. At the same time, the features of specifically railway terminal operation are studied in the modern scientific articles indexed in the Scopus or Web of Science databases much less frequently.

Calculations of parameters of operation of the cargo terminals and transport and logistics systems have been carried out by both Russian and international authors. For example, in the research by Q. Zeng [24], an algorithm for optimization of cargo cranes operation in the container terminals is developed. In the work by G. Gefan [5], the results of application of probability and statistics methods in the arrangement of railway transportation are provided. The role of mathematic tools in simulation of interaction between individual entities of logistics servicing is described in the paper by R. Fedorenko [3]. T. Garcia in the article [4] shows the result of forecasting the parameters for utilization of logistics capacities in container terminals through bayesian networks. The application of mathematical simulation methods to study the features of operating the railway transport terminal network is considered in the paper by H. Sarhadi [20] and S. Caballini [2].

This paper proposes a methodology for stepwise solution of the task to determine the required number and parameters for location of logistics storage and distribution centers (LSDCs), by processing possible options. The basis of a calculation process is an estimation model.

The number and dislocation of LSDCs in the terminal network and a mode of transport for its efficient servicing determine its quantitative, spacial, and transportation parameters, respectively. There can be a different type of transport servicing for each transport link. The most efficient combination of the terminals number and dislocation, as well as modes of transport for their servicing will contribute to rationalization of the cargo transportation (implementation of the minimum of target function $F$).

The operation of LSDC will offer the following advantages: for customers: efficient distribution of the finished products, for carriers: decrease in the transport component in the cargo flow cost, for an administrative area: preparedness of the infrastructure for the trans-regional integration. In minimizing of the target function, the number and dislocation of LSDCs as well as a mode of transport for servicing the terminal network are taken into account. It means that the task of formation of the region’s terminal network has been solved comprehensively.
The application of the proposed methodology will enable to improve the existing terminal network of the Russian railway transport, enhance the efficiency of cargo transportation, and facilitate increase in competitiveness of RZD OJSC in the cargo transportation market.

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