METHOD OF CONSTRUCTING A NETWORK GRAPH OF THE LOGISTIC OBJECT STRUCTURE

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ABSTRACT

The quality of solutions in the design and operation of individual logistic objects influences the efficiency of the entire terminal-storage infrastructure of the country's railways. In the proposed research method the structure of a logistic object in the form of a graph of its structure, the positions of the general theory of systems, graph theory, dynamic programming and the search for the shortest distance are synthesized. A distinctive feature is the universality of the method when using indicators of different dimensions (cost, time, relative expression). The theoretical basis of the methodology is a combination of economic and mathematical methods and conceptual provisions that make it possible to find an optimal solution from a set of feasible solutions. The categorization and classification of logistics objects was carried out, a parametric description and a formalized modeling of their structure were given.

Keywords: general theory of systems, graph theory, logistic object, logistic district, logistic area, mathematical model, network graph of a structure, parameters of logistic objects, classification, railways, transport, terminal-warehouse infrastructure.

Background. *Further development of terminal-warehouse infrastructure of the country's railway transport envisages the formation of logistic objects (LO), which will ensure the effective implementation of transport and logistics services and the infrastructure basis of transport systems for the delivery of goods to consumers.*

Obviously, the results of the entire terminal-warehouse infrastructure of railways depend on the quality of design and operation of LO at the regional level. The relevance of the topic is also evidenced by the following: 1) the absence of a generally accepted, unified hierarchical approach to the classification of logistics facilities, which complicates the understanding of all participants in the transport process of the role of LO; 2) the need for comprehensive planning for the development of LO for a number of parameters with different dimensions in conditions of insufficient consideration of the question of a universal methodology for multi-criteria design of the optimal structure of a logistic object [2].

Objective. *The objective of the study is to develop a methodology for forming a graph of LO for formation of its structure with the best parameters. The following tasks are solved: 1) categorization and classification of LF; 2) parametric description and formalized modeling of the structure of the logistics facility; 3) development of a network graph of the LF structure for selecting the best parameters.*

Methods. *The authors use general scientific and engineering methods, mathematical apparatus, graph construction, categorization and systematization methods.*

Results.

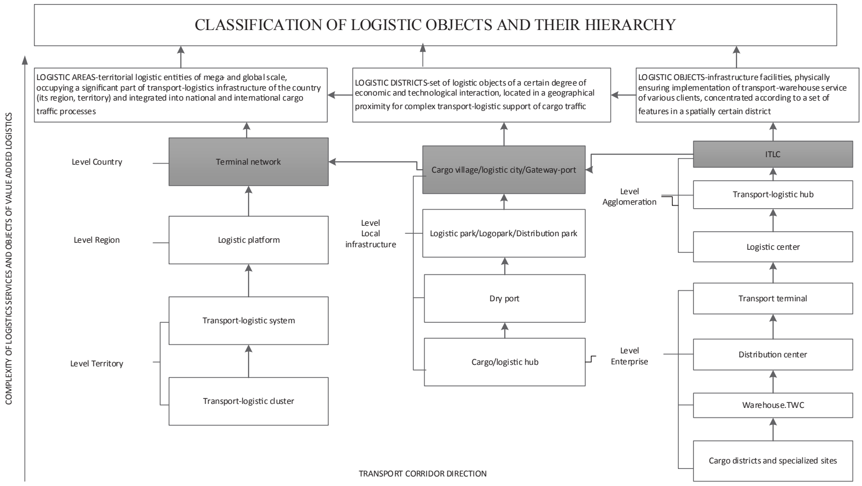
1. Categorization and classification

Under the logistic object we understand any object included in the transport-warehouse infrastructure of a local scale, physically providing the implementation of transport and warehousing services for various clients and focused on the totality of the characteristics in a spatially defined area.

Taking into account the hierarchy of its position in the transport and logistics system, the object is transformed into more complex entities – district and area. (See Pic. 1).

Logistic district is a combination of LO of a certain degree of economic and technological interaction located in geographical proximity for integrated logistic support of transportation processes.

Logistic area is a territorial logistical entity of a global scale that occupies a significant part of the country's transport and logistics infrastructure and is integrated into national and international transport processes [3].



Pic. 1. The proposed system of hierarchy and classification of LO.

In accordance with these definitions, the authors developed a classification of LO, depicted in Pic. 1.

Thus, according to the classification, the objects that are at the level of individual enterprises (cargo areas and specialized sites, warehouses, terminal-warehouse complexes and transport terminals) and at the level of the city / node agglomeration (logistic center, transport and logistics hub, multimodal transport and logistics center) belong to logistic objects (in the order of increasing the hierarchical value, taking into account the quantitative indicators and complexity of the logistics service, see the arrow on the left). The darkened blocks connected by an arrow represent the sequence of the transformation (evolution) of the logistics object to the logistics area and the entrance to the global level according to the scheme «Logistic Object (ITLT)» → «Logistics District (Gateway)» → «Logistic Area (Terminal Net)». This corresponds to the direction of the development of the transport corridor (see arrow below).

It is proposed to attribute to the logistics districts objects of the level of the local infrastructure: cargo / logistics hub, dry port, logistics / distribution park and gateway.

The logistic areas are objects of the territory level (transport and logistics cluster, transport and logistics system), region (logistics platform) and countries (terminal network).

This classification can be used for: 1) identification of LO taking into account the design, type of storage, size, technical equipment, etc.; 2) the choice of LO with regard to its functional capabilities, dislocation, etc.; 3) determining the role and place of LO in the transportation processes; 4) systematization and convenience of an integrated representation of the entity and species diversity of LO; 5) unification, simplicity and convenience of identification of type of LO [4].

2. Parametric description and formalized model of structure.

The parametric structure of LO of any format can be described by the mathematical expression of a number of significant characteristics.

The formalized model of the LO structure in the general modular-block form looks as follows:

$$\sum_{i=1}^{n} S_{\mathrm{LO}\,i} = \left[S_{\mathrm{spat}}; S_{\mathrm{tran}}; S_{\mathrm{ser}}; S_{\mathrm{econ}}; S_{\mathrm{tech}}\right], \qquad (1)$$

where S_{LO} – is the modular structure of the i-th logistics object, consisting of n typical elements; S_{spat} is a spatial module-block; S_{tran} is a transport module block; S_{ser} is a service module block; S_{econ} is an organizational and economic module-block; S_{tech} is a structural and technical module-block.

In block form:

$$\sum_{i=1}^{n} S_{\mathrm{LO}\,i} = [S_{\mathrm{spat}}(S_{\mathrm{ter}}; S_{\mathrm{st}}); \begin{bmatrix} S_{\mathrm{tran}}(Q_{\mathrm{cargo}}; N_{\mathrm{tr}}); S_{\mathrm{ser}}(N_{\mathrm{ser}}; Q_{VAL}); \\ S_{\mathrm{econ}}(T_{\mathrm{st}}; T_{\mathrm{cargo}}; T_{\mathrm{tr}}); \\ S_{\mathrm{tech}}(N_{\mathrm{st}}; Q_{\mathrm{lum}}) \end{bmatrix}, \qquad (2)$$

where S_{LO} is a modular structure of the i-th logistic object, consisting of n typical elements; S_{spat} is a group of a spatial module-block; S_{ter} is a total area of the territory, occupied by the i-th logistic object, ha; S_{st} is a total storage area of the i-th logistic object, sq. m.; S_{tran} is a group of parameters of a transport module-block; Q_{cargo} is a total processing capacity of all specialized storage areas and storage facilities on the i-th logistic object, tons/year; N_{tr} is a number of modes of transport serviced by the i-th logistic object, units; S_{ser} is a group of parameters of a service module-block; N_{ser} is a range of logistics services provided by the i-th logistics objects; Q_{VAL} is a volume of added value of transport-logistics and warehouse services rendered by LO, Value added logistics is «logistics of added value», %; S_{econ} is a group of parameters of an organizational-economic module-block; T_{st} is a cost of rent of 1 sq. m of storage, rub.; T_{cargo} is a cost of processing of 1 ton of cargo at the warehouse, rub.; T_{tr} is tariffs of modes of transport to be joined in the LO (including the service of the «last mile») and the services accompanying transportation (use of cars, infrastructure, locomotives), rub.; S_{tech} is a group of parameters of the structural-technical module-block; N_{st} is a number of specialized storage areas and storage objects in the i-th logistics object, units; Q_{lum} is provision of LO with loading-unloading mechanisms LUM of appropriate capacity, %.

In the expanded form:

$$\sum_{i=1}^{n} S_{\mathrm{LO}\,i} = \begin{bmatrix} N_{\mathrm{st}}; S_{\mathrm{st}}; S_{\mathrm{ter}}; Q_{\mathrm{cargo}}; N_{\mathrm{tr}}; \\ N_{\mathrm{ser}}; Q_{VAL}; T_{\mathrm{st}}; T_{\mathrm{cargo}}; T_{\mathrm{tr}}; Q_{\mathrm{lum}} \end{bmatrix}, \qquad (3)$$

where S_{LO} is a modular structure of the i-th logistic object, consisting of n typical elements; N_{st} is a number of specialized storage areas and premises for storage of cargo in the i- th logistic object, units; S_{st} is a total area of storage volume of the i-th logistic object, t or m³; S_{ter} is total area of the territory, occupied by the i-th logistic object, ha; Q_{cargo} isa total cargo turnover of all specialized storage sites and premises for storage of cargo in the i-th logistic object, ton/year; N_{tr} is a number of modes of transport, serviced by the i-th logistic object, units; N_{ser} is a range of logistic services, rendered by the i-th logistic object, units; Q_{VAL} is a volume of added value of transport and logistics services and storage services rendered by LO, Value added logistics is «logistics of added value», %; T_{st} is a cost of rent of 1 sq. m of storage, rub.; T_{cargo} is a cost of processing of 1 ton of cargo at the warehouse, rub.; T_{tr} is tariffs of modes of transport to be joined in the LO (including the service of the «last mile») and the services accompanying transportation (use of cars, infrastructure, locomotives), rub.; Q_{lum} is provision of LO with loading-unloading mechanisms LUM of appropriate capacity, %.

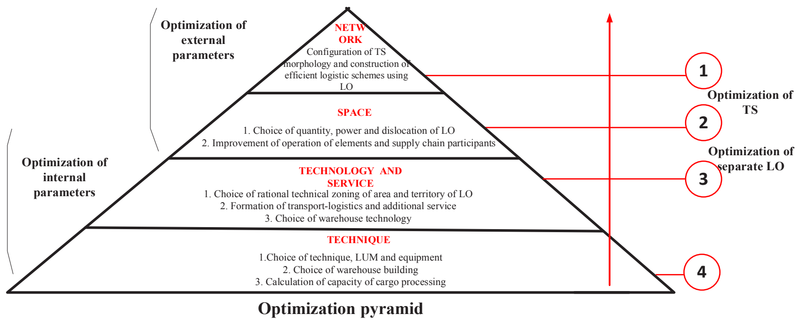
The structure of the LO as a complex modular system in the general form:

$$\mathrm{W}_{\mathrm{LO}} = \left\{\mathrm{W}_{\mathrm{technical}} | \mathrm{W}_{\mathrm{technological}}\right\}. \qquad (4)$$

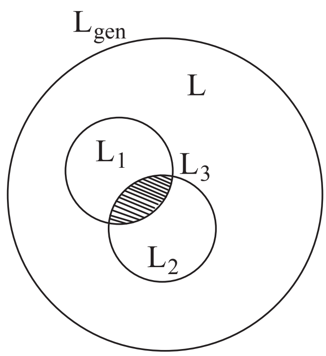
In the expanded form:

$$\mathrm{W}_{\mathrm{LO}} = \begin{Bmatrix} \mathrm{W}_{\mathrm{load/accept}}; \mathrm{W}_{\mathrm{unload/deliv}}; \mathrm{W}_{\mathrm{sort}}; \\ \mathrm{W}_{\mathrm{st}}; \mathrm{W}_{\mathrm{add}}; \mathrm{W}_{\mathrm{tran}}; W_{\mathrm{pack}}; \mathrm{W}_{\mathrm{LUM}} \end{Bmatrix}, \qquad (5)$$

where $\mathrm{W}_{\mathrm{technological}}$ is a module of a technological block; $\mathrm{W}_{\mathrm{load/accept}}$ is a module of loading (acceptance) of cargo; $\mathrm{W}_{\mathrm{unload/deliv}}$ is a module of unloading (delivery) of cargo; $\mathrm{W}_{\mathrm{sort}}$ is a module of cargo sorting; W_{st} is a module of cargo storage; $\mathrm{W}_{\mathrm{add}}$ is a module of additional service, realized by LO for a separate type of cargo; $\mathrm{W}_{\mathrm{technical}}$ is a module of a technical block; $\mathrm{W}_{\mathrm{ext}}^{\mathrm{tran}}$ is a module of external trunk transport of acceptance and delivery of cargo; $\mathrm{W}_{\mathrm{pack}}$ is a module of cargo packaging arrangement; $\mathrm{W}_{\mathrm{LUM}}$ is a module of LUM acceptance-delivery, arrangement and intra-warehouse processing of cargo.



Pic. 2. Optimization pyramid of LO.



Pic. 3. The diagram of the solution's core for the network graph of the LO structure.

The state of LO is a set of indicators that identify it in the general hierarchical system (defining its type) and characterize its work as a whole.

The state of any LO is expressed by a set of indicators (resources):

$$X_{\text{LO}\,i} = (X_1, X_2, X_3, X_4, X_5)\,. \qquad (6)$$

The parameters determining the state of LO (the factors of its evolution):

$$X_{\text{LO}}^{\text{evol}} = (Z_1, Z_2, Z_3, Z_4). \qquad (7)$$

This allows to form a multifactorial model of the evolution of the LO, consisting of meaningful signs Xj and influencing factors Zi.

$$F = X_1Z_1 + X_2Z_2 + \ldots + X_nZ_n\,. \qquad (8)$$

Optimization of LO parameters proceeds step by step in accordance with the optimization pyramid (Pic. 2). So, at the lowest level, local decisions are made aimed at optimizing internal parameters. At the highest level, global positioning of the LO in the terminal network is carried out.

Next, we will consider the technique of constructing the network graph of LO for the optimal parametric formation of its structure. As an example, the lowest level of optimization of object parameters is taken – the technical solution (selection of the best type of LUM – loading and unloading mechanisms for intra-warehouse cargo processing).

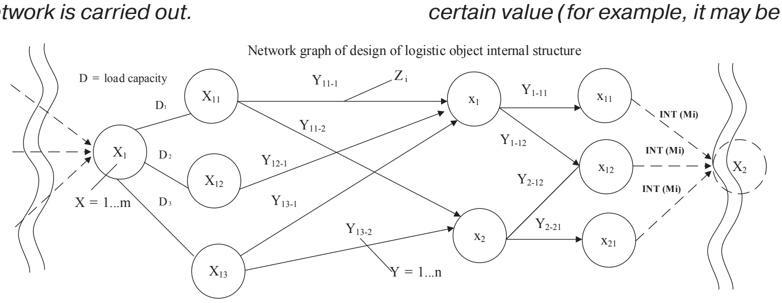
3. Methodology for studying the structure using the network graph

In the proposed method of studying the structure of LO in the form of a graph of its structure, the positions of the general theory of systems, graph theory, network graphics, dynamic programming and the search for the shortest distance are synthesized [5, 6]. The universality of the method characterizes the use of indicators of different dimensions (cost, time, relative expression), the theoretical significance – a set of economic and mathematical methods and conceptual provisions that allow one to effectively find optimal solutions from a set of feasible solutions.

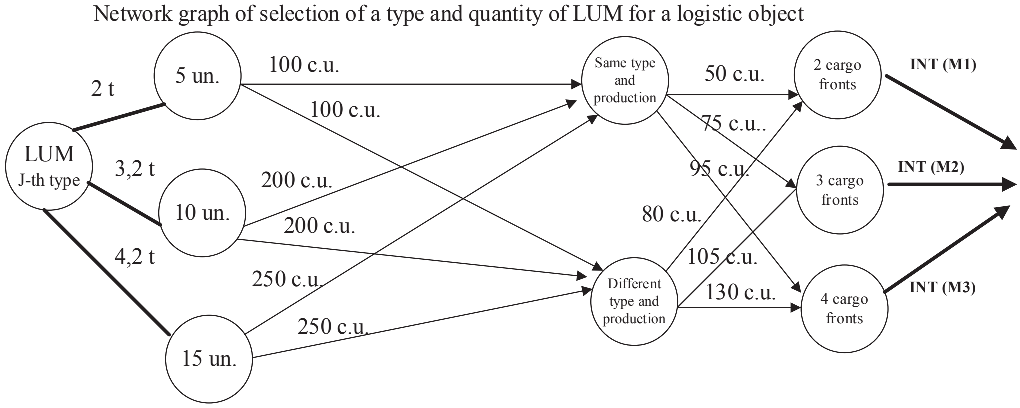
A diagram of the selection of the solution core for constructing the network graph of the LO structure is given in Pic. 3, where: L_{gen} is a set of variants of decisions of structure of LO; L is the subject area for finding solutions when building a structure; L_1 is set of options for parameter 1; L_2 is a set of options for parameter 2; L_3 is the desired domain of the decision.

The network graphs of the structure when choosing the optimal solution for the technical equipment of the facility (including cost indicators) set the permissible set of parameters and allow designing the LO with optimal parameters of the structure (Pic. 4).

The set of vertices X of such a graph is the mapping of admissible generic variants of structural elements from 1 to m, x – admissible alternative general variants from 1 to n, and the set of arcs Z – logical connections of the possibility of successive union of these elements in the optimized internal structure of LO. Each arc (arrow) Z corresponds to a certain value (for example, it may be cost, time, load



Pic. 4. The general case of the network graph of constructing the LO structure.



Pic. 5. A special case is a network graph of the type and quantity of LUM for a logistic object.

capacity, performance or another meter, depending on the specificity of the optimization task being solved) $Y(Y(_{Xm-xn}), Y(_{Xm-Xm}), Y(_{xn-xn})$. The local solution M on the i-th section of the INT graph is taken in accordance with the following condition:

INT (Mi) = min∑ [Yi]. (9)

At the same time, arcs of the lowest order (going from the key parameter X, not directed by an arrow) do not have a value, since they indicate the D–direction of optimization (in the example this is the LUM load capacity), and the higher-order arcs (the resulting sum of the cost for each alternative variant of the network graph passage) have total values equal to the sum of the minimum values of the route.

A more complex structure of such a graph can be obtained by considering several parameters of the LO structure at the same time. A simplified example is the general form of the graph in Pic. 4 (the break shows the transition to the consideration of a new parameter) and a special case of constructing a network graph for making a technical decision (see Pic. 5).

In a similar way, it is possible to build a graph to solve any issue related to LO, starting from its technical equipment and ending with internal technological zoning, planning, etc.

Conclusions.

1. Formalization of the fundamental issues of design and operation efficiency of logistic objects of any format within the terminal-warehouse infrastructure of railways makes it possible to obtain target functions and parametric descriptions of LO as complex systems, key elements of the terminal network, delivery systems for individual goods and the transport system of the country as a whole. The formalized model of the logistic object should be expressed in three aspects, grouping the main parameters of the LO as a complex system and requiring different directions of optimization.

2. For JSC Russian Railways the availability of its own classification system and the LO hierarchy will solve the systemic problem of interaction in the nodes when arranging the transportation of goods, simplify the identification of objects of the transport and logistics infrastructure taking into account the client orientation and ensure rational design of the objects of the core terminal network.

3. Mathematical modeling allows us to formalize a number of significant parameters when designing logistic objects. This will help to build a terminal network for railways, operating in a mode that is necessary and sufficient for cargo processing of the appropriate quality.

4. The proposed methodology can be applied in solving a wide range of issues in the design and operation of terminal-warehouse infrastructure facilities on any mode of transport, since it is versatile and complex.

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