MODEL FOR DETERMINING THE OPTIMAL TRAJECTORY OF MOVEMENT OF CONSIGNMENTS

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ABSTRACT

The suggested model for determining the optimal trajectories of moving consignments that form cargo flows in transport and logistics systems (TLS) is based on a combination of dynamic systems and multi-criteria optimization methods. This approach develops a methodology for solving applied control problems in TLS. Its main result is the principle of finding the maximum, subject to the criterion preferences, based on methods for determining the set of effective plans (Pareto set). At the same time, management in TLS should form models of cargo traffic taking into account the location of transport and storage complexes within the boundaries of the system being studied or designed, as well as should provide for movement of consignments according to specified performance criteria and the most rational trajectories using analytical modeling. Analytics together with digital technologies help to consider the core sense of TLS as of a subsystem of intelligent transport systems.

Keywords: management system, transport and logistics system, analytical model, cargo transportation, transport and storage complex, dynamic programming, digital technology.

Background. *The management model in the transport and logistics system (TLS) has a complex multi-level and multicomponent structure [1, p. 36, 2, p. 52]. Therefore, causal relationships in organization of the transportation process in TLS with a developed infrastructure of transport and storage complexes (TSC) should be formalized through an adequate mathematical description that optimizes development of rational decisions on formation of a single directional interaction of transport infrastructure operators (road transport enterprises, TSC, etc.). The development of analytical management models in TLS as part of an object-oriented methodology for obtaining optimal solutions in complex organizational and technical systems will allow implementing the process of cargo traffic management as a separate service domain or a subsystem of an intelligent transport system (ITS) in accordance with the requirements of standards (e.g. Russian state standard GOST [3, point 4.1.1, p. 12]).*

Objective. *The objective of the authors is to consider model for determining the optimal trajectory of movement of consignments.*

Methods. *The authors use methods of analysis of dynamic systems, multicriteria dynamic programming, Pareto set.*

Results. *To solve the problem of determining the optimal trajectories of movement of consignments in TLS, we adopt the following provisions:*

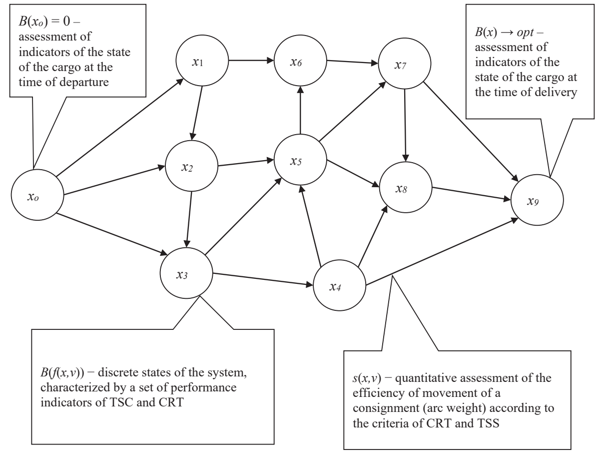
1. The cycle of the transport process in TLS should not be viewed as a discrete type multiphase mass service system with a finite set of states, but as a discrete dynamic system operating in conditions of insufficient information or an unspecified state of the environment, which requires multi-criteria dynamic programming methods for evaluating its effectiveness [4, p. 33].

2. Depending on the goals and, accordingly, the tasks of forecasting the process, the efficiency criteria in the network may differ fundamentally both for different sections of TLS and for one of them when the state of the environment changes, determined by time-discrete transport and warehouse service parameters (TSS) and cargo road transportation (CRT) parameters.

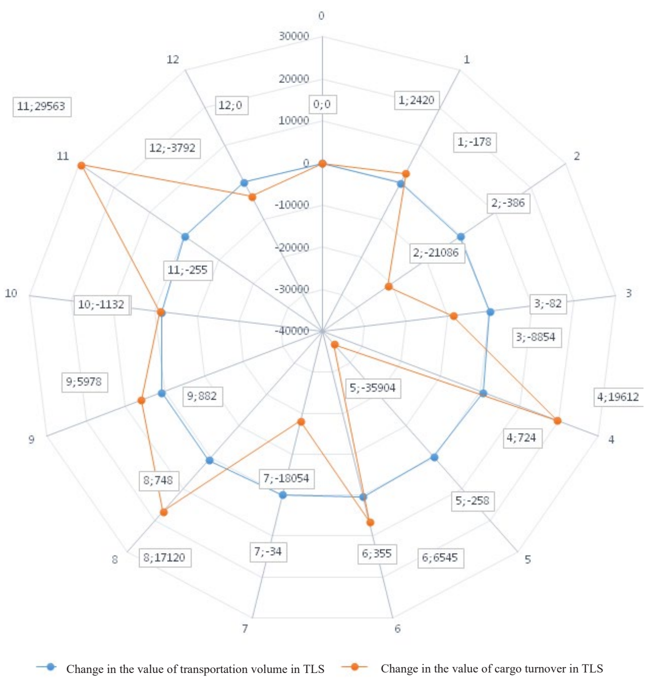
3. The solution of optimization problems should be based on a set of effective Pareto-optimal plans for individual sections of TLS, depending on the degree of importance or domination of one or another criterion [5, p. 89; 6, p. 148].

The technique. *As it is known, the principle of the consecutive analysis of the process changing in time is the cornerstone of a dynamic programming method. Usually, when determining the recurrent relations of dynamic programming, the discreteness of the controlled system is taken into account and the optimal trajectory of sequential solutions is synthesized, which allows us to build the optimal trajectory of load in TLS [7, p. 11]. The main disadvantage of using dynamic programming is the lack of a single solution algorithm that is absolutely suitable for all applied tasks. This method provides only a general direction for solving a specific problem, and therefore in each case it is necessary to find the most suitable method for optimizing the process according to reasonable performance criteria. Besides, dynamic systems with only one criterion taken as controlled parameter are usually considered, while for a dynamic system with discrete states in TLS, it is necessary to take into account numerous indicators grouped into sets of TSS and CRT criteria. Therefore, applying the dynamic programming method as an optimization method in TLS, it is necessary to realize simultaneous consideration of the values of a significant number of TSS and CRT indicators in solving extremum problem, sequentially applying each of them (according to a number of criteria) depending on the conditions and state of TLS environment at the moment of time. Consequently, the procedure for identifying the values of variables in the model being created can be interpreted as a multi-stage control process in the integrated system of TSS and CRT indicators.*

TLS system (Ω) can be represented by a finite weighted directed graph $G(\Omega)$, whose vertices correspond one-to-one to the system states (TSS and CRT parameters), arcs correspond to controlled movements of the load, arcs weight correspond to quantitative estimates of the effectiveness of the corresponding transitions (Pic. 2). The construction of the optimal trajectory of movement of a consignment in TLS is based on the Bellman's principle (Pic. 1):



Pic. 1. The finite conditional graph of possible movements of a consignment in a dynamic system with discrete states in TLS.



Pic. 2. The distribution diagram of changes in the values of the mathematical expectation of effective indicators in normalized units for discrete states of the parameters of cargo traffic in TLS.

$B(x) = \min_{v \in V(x)} \{s(x, v) + B(f(x, v))\}, (x \in D|F)$. (1)

The identification of rational trajectories of shipments of consignments is based on the Bellman's principle and on the analytical solution of a multicriteria optimization problem for individual elements of the system (2). In this case, the procedure of identifying the values of variables is interpreted as a multi-step process of managing the movement of shipments of TLS.

1. Each TSC corresponds to a set of possible states depending on the effective indicators of CRT and TSS, combined into a single cycle of the transport process.

2. Management in the system is implemented step by step for a separate batch of cargo after determining the effective solution and applying it as one of the finite number of possible distributions of cargo at TSC.

3. The successive actions will finally result in a change in the state of the system, determined by the degree of congestion of individual TSC. The obtained results of the discrete rationalization solution using the dynamic programming method are made out in the form of a rational trajectory of moving the consignment in TLS.

$$\begin{cases} B(x) = \max\limits_{v \in V(x)} \left\{ D_{i_{(t)}} + B\left(f\left(D_{i_{(t)}}\right)\right)\right\}, (x \in D|F) \\ D_{i_{(t)}} = \sum_{j=1}^{n} b_{ij} c_j \to opt, \\ \sum_{j=1}^{n} c_j = 1,\ 0 \le c_j \le 1, c_j \ge c_{j+1}, i = \overline{1, n-1}, \end{cases} \quad (2)$$

where $D_{i_{(t)}}$ – quantitative assessment of the efficiency of movement of the consignment (the weight of the arc) according to the criteria CRT and TSS;

$B\left(f\left(D_{i_{(t)}}\right)\right)$ – *discrete states of the system, characterized by a set of performance indicators of TSC and CRT;*

b_{ij} – *normalized values of the performance indicators TSS and CRT;*

c_i – *relative importance coefficients of TSS and CRT indicators.*

Example. The formation of a rational trajectory of movement of one consignment of cargo in TLS allows determining the general structure of cargo traffic with regard to the declared traffic volumes in the system (the volume of cargo transported and planned for transportation). Further, the absolute cargo turnover of individual TSC is determined as the sum of goods of various lots processed through TSC for a certain period of time (day, month, year):

$$C = \sum \frac{Q_i}{K_{convi}}, \qquad (3)$$

where C – cargo turnover, m³;

Q_i – *volume of cargo passing through TSC for the period of time and belonging to i-th cargo group;*

K_{convi} – *coefficient of conversion of cargo volume in tons (transportation volume of CRT) to cargo volume m³ (storage volume in TSC) in expression, t/m³.*

The total amount of loading and unloading operations per unit of time at TSC or cargo handling is simplistically determined by the formula:

$$CH = \sum_{i=1}^{n} Q_{ci} k_i, \qquad (4)$$

where CH – annual cargo handling, thousand tons-operations / year;

Q_{ci} – *annual cargo traffic of the i-th cargo, thousand tons/year;*

k_i – *transshipment coefficient of the i-th cargo, operations;*

n – number of different items (groups) of goods entering the warehouse.

The results of the computational experiment for obtaining optimal trajectories carried out for 100 batches in TLS system are presented in Pic. 2 in the form of a diagram of distribution of changes in the values (increase, decrease) of the mathematical expectation of effective indicators (transportation volume and cargo turnover) in standard units for discrete states of the parameters of TLS.

Conclusions. *The results obtained when applying the methodology for determining the optimal trajectories of cargo traffic are the values of the input information flows entering the cargo processing systems of individual TSC and are the basis for formation of a digital information-analytical control system in TLS. The solution of the problem of determining rational parameters of TSS, as of a fuction situated in the same logistics chain with CRT parameters, will reduce vehicle downtime and rationalize the production capacity of TSC.*

The principal feature of the obtained solution of the problem is that when solving an applied problem of constructing dynamic systems, not one criterion, but several criteria are considered as a controlled parameter. Consequently, a model of an analytical solution in dynamic problems is implemented, based on the search for a reasonable compromise, which consists in choosing such a control, which satisfies the extremum values of all considered TSS and CRT criteria.

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