Actualization of technological interaction managing methods in portside transport systems

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Abstract. Methodological approaches to the assessment of the portside transport and technological system development prospects in terms of interaction management in the "railway station - port" system are being studied. The method of port wagon flow distribution on the basis of combined application of analytical and simulation modeling, probabilistic-statistical and censorological approach is presented. An algorithm for the formation and assessment of the transport process axiom in the "railway station - port" system is formed. The approximations of power functions in the technocenosis of port station parameters are determined. Scientific methods, based on linear and dynamic programming, mass service theory, reliability theory, graph theory, probability theory, simulation modeling, etc. are widely used in the management of traffic flows. To describe the regularities of transport processes, the notions: individual, species, population, etc. are used in CA of the system "railway station - port". The structural elements of the portside transport system, evaluated by means of CA, are presented in article. Keywords: Transport technological system; port railway station; port; analytical modeling; cenological analysis; approximation of power functions; cargo flows management; time indicators parameterization; multimodal freight transportation; cargo; rolling stock.

1 Introduction

The North Caucasus economic region is the most important transport complex of Russia, including ice-free deep-water and small ports of the Azov-Black Sea basin (ABB). For 8 months of 2020 cargo turnover of ABB seaports amounted to 163.8 million tons. Main cargoes are oil - 32.8%, coal - 22.3%, ferrous metals - 14.4%, grain - 12.5%, iron ore - 6.5%, and fertilizers - 4.5%. Cargo turnover in ABB sea-ports in January-February 2021 amounted 39.2 million tons (- 0.7% compared to the data of the period of 2020), including dry cargo transshipment of 17.3 million tons (+20.3%) and liquid cargo - 21.9 million tons (- 12.7%) (All-Russian Transport Weekly Information and Analytical Newspaper, 2021; Association of Russian Seaports, 2021).

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In conditions of economic instability, restrictions due to the causes of the pandemic and uneven cargo flow, traditional methods of managing transport and technological interaction in port systems often do not give a tangible result.

This is reflected in the complexity of organizing multimodal transport with the participation of rail, road and water transport, as well as in the problems of developing the infrastructure of many historically formed southern ports for reasons of cramped development.

It should be noted that, in fact, the volume of export-import traffic is not decreasing and it is likely that in the near future the southern ports of ABB may reach the limit of their processing capacities.

Scientific methods, based on linear and dynamic programming, mass service theory, reliability theory, graph theory, probability theory, simulation modeling, etc. are widely used in the management of traffic flows.

2 Literature review

Further development of theories and methods of cargo traffic management in portside transport systems requires the development and implementation of completely new innovative management principles based on adapted intelligent systems, fuzzy logic systems, neural networks, cenological analysis, morphological models, cluster strategies, Big Data systems, Data Mining, etc. For example, research on the organization of multimodal cargo transportation systems is being carried out (Combes et al., 2016; Kolesnikov et al., 2020; Lyabakh et al., 2020; Chislov, Zadorozhniy et al., 2019; Knoop and Hoogendoorn, 2015; Simon, 2020; Zhao et al., 2016; Ivaldi and McCullough, 2008; Kuzminov, A.N., 2009. Management in Socio-Economic Systems Based on Modeling Cenoses: Theory, Methodology, Tools: Thesis Abstract for the Doctor’s Degree of Economics. RSTU, Rostov-on-Don, pp. 55) queuing networks in the system of organizing railway freight transportation with non-deterministic parameters are being developed (Combes et al., 2016), combined models of cargo transportation and logistics chains of delivery (Kolesnikov et al., 2020; Chislov, Zadorozhniy et al., 2019; Simon, 2020), decision support models (Kolesnikov et al., 2020), a cluster approach to the functioning of seaports (Chislov, Zadorozhniy et al., 2019), methods for selecting optimal management structures in the transport sector (Kolesnikov et al., 2020), cenological analysis and morphological modeling of processes are being formed (Kuzminov, 2009).

3 Materials and methods

Simulation modeling is widely used in the creation of digital twins of transport objects, despite its positive aspects, although it does not solve a number of problems: ensuring stochastic convergence; reducing the number of experiments variants on the model without decreasing the number of obtained results; dependence of the experiment plan choice on the experimenter’s skill; the complexity of identifying the main variable model.

It is possible to eliminate these shortcomings by combining methods of analytical and simulation modeling with probabilistic-statistical and cenological analysis of transport processes in the system (Kolesnikov et al., 2020). Combined modeling in the analysis and synthesis of transport systems allows you to combine the advantages of these methods. When constructing combined models, a preliminary decomposition of the object functioning process or system under study is carried out into constituent sub-processes, and for those of them, where possible, analytical models are used, and for the remaining sub-processes, simulation models with probabilistic-statistical and cenological analysis are built.
The algorithm for solving the problem is presented as a sequence of phases:

Phase 1 - evaluation of the portside station scheme and its technical and technological parameters by means of probabilistic-statistical and cenological analysis;

Phase 2 - formation of a transport and technological model of the station, consisting of transport process control units (Kolesnikov, 2008);

Phase 3 - formation of the station model scheme to select a finite set of options for the organization of transport processes for given operating conditions;

Phase 4 - formation of one-dimensional data arrays of technological blocks parameters;

Phase 5 - formation of a probabilistic matrix of links between station processes and station track development modules;

Phase 6 - formation of variants array of station transport and technological processes - axiomat (ASTTP);

Phase 7 - cenological analysis of ASTTP axiomat according to the accepted criteria of minimum downtime of the rolling stock, maximum throughput capacity at a rational infrastructure load, etc;

Phase 8 - parameterization of the ASTTP axiomat by means of computer algebra and the author's software package in the Maple environment;

Phase 9 - evaluation of the system "portside railway station - port" performance indices for the given operating conditions;

Phase 10 - input of new portside station and port infrastructure data, values of car and cargo flows, etc., transition to Phase 1.

Within the scope of this article, we will examine in detail the application of the cenological analysis (CA) at the strategic level of the transport process research in the system "railway station - port". According to (Kolesnikov et al., 2020), the essence of CA is that all complex systems under the influence of universal natural laws tend to form stable states. Finding the system in such a state is called a cenosis. According to Kolesnikov et al. (2020), technocenosis is an artificial system, limited in space and time, with weak links and common goals, allocated for design or construction purposes.

With regard to the object of research, the structure of CA can be described by distributions:

1 - species distribution - the dependence of the block number of the station model structures on the number of transport and technological processes (ASTTP axiom);

2 - rank-type distribution (rank is a sequential number when the ASTTP axiom is in the order of decreasing their execution frequency (importance);

3 - rank distribution by the execution time parameter (process speed) when the ASTTP axiom is arranged in the order of decreasing execution time parameter (process speed).

To model the non-increasing function of all three distributions, a hyperbola of the form (Fig. 1) \( N(r) = \frac{A}{rG} \) is used, where for the rank type distribution \( N(r) \) is the number of ASTTP axioms with rank \( r \), pcs; the coefficients \( A \) and \( G \) are constant distributions.
Fig. 1. An example of cenological curves.

With regard to the axiomatics of transport and technological processes at port side stations, the model calculation is performed as follows:

1. The research parameter is selected - these are the parameters of the station scheme and the ASTTP axiom.
2. A statistical database, characterizing the axioms of the ASTTP, is formed (indicators of the station scheme, the number of ASTTP, the number of the station model scheme blocks, the idle time of the car in the system, the speed of transport processes, etc.).
3. These statistical data are used to build histograms of the distribution of the studied parameters (Fig. 2-4). Distribution histograms of the studied parameters are constructed (Fig. 2-4).

Fig. 2. Power function approximation of the arrival and departure tracks number at the portside stations of ACHB.

\[ y = 32.226x^{-0.979} \]

\[ R^2 = 0.9639 \]
4. Histograms are approximated by a curve of a power function.
5. The approximation error is estimated.
6. Procedures 1-4 are repeated for different operating conditions (time moments $t_1$, $t_2$, $t_3$, ...
   $t_i$).
   The family of curves and series of parameters $A_i$ and $G_i$ are obtained.
   In the context of transport processes, the CA model explains a number of indicators in the system "railway station - port":
   - existing disparities in the number of station model scheme blocks, in the number of ASTTP axioms and their execution time, the total dawn time of the rolling stock in the
system, which are estimated by the value of the approximation error. The smaller the error, the more the model scheme of the station is a technocenosis, since the points of the histogram in this case "more precisely" lie on the approximated curve;

- the degree of the station model scheme development as a system (by the change in the coefficients of dependence A and G). The optimal case is value G = 1. If G value differs from 1, then technotsenosis is absent.

According to the change of CA parameter G, its dynamics is evaluated: a) if G = 1 - the technocenosis is optimal; b) if G < 1 and G → 1 or G > 1 and G → 1, then there is a positive development of technocenosis; c) if the dynamics of the parameter G contradicts the dynamics described in b), the technocoenosis is destroyed.

CA methods usage will allow to evaluate additionally the stability degree of the plant scheme, perspectives of development, trends of ASTTP axiom by time and correct them at changing conditions of operation.

4 Results

To describe the regularities of transport processes, the notions: individual, species, population, etc. are used in CA of the system "railway station - port". The structural elements of the portside transport system, evaluated by means of CA, are presented in Table 1.

<table>
<thead>
<tr>
<th>№</th>
<th>Individuals of the technocenosis</th>
<th>Types of technocenosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Portside railway stations</td>
<td>Class level: Extracurricular, 1, 2, 3, 4, 5 class</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Type: sorting, section, freight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Track development scheme: stub and through stations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Location of yards: parallel, sequential, combined</td>
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<tr>
<td></td>
<td></td>
<td>Type of cargo operation: loading, unloading, loading-unloading, reloading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of tracks in the yards: arriving-departing, sorting, loading and unloading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of maintained enterprises: 1, 2, 3, 4, etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Performance indicators: fright turnover, car turnover, track development capacity, processing time, rolling stock downtime, carrying capacity, etc.</td>
</tr>
<tr>
<td>2</td>
<td>Ports</td>
<td>Port and berth layout: berths, piers, buckets</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Port station arrangement schemes of mutual placement of the portside station and the portside territory: at an angle, sequential, parallel</td>
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<tr>
<td></td>
<td></td>
<td>Transport service scheme: with district parks, without district parks</td>
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<tr>
<td></td>
<td></td>
<td>Type of cargo operation: loading, unloading, loading-unloading, reloading</td>
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<tr>
<td></td>
<td></td>
<td>Performance indicators: fright turnover, car turnover, track development capacity, processing time, rolling stock downtime, carrying capacity, etc.</td>
</tr>
<tr>
<td>3</td>
<td>Model scheme of a port-side transport system</td>
<td>Transport and technological model: the number of blocks, the reliability of connections, the scheme of interaction between the phases of service</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Schedules of transport processes: sequence, probability of execution, duration, variability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parameters of track development modules: number of tracks, total length, number of switches, useful length, processing time, etc.</td>
</tr>
</tbody>
</table>
track development capacity, carrying capacity, direction of work, delivery-cleaning time, length, speed of shunting operations, number of shunting locomotives, etc.

| 4 | ASTTP axioms | Options for station movements of ASTTP: sequence-1, sequence-2, sequence-3, ..., sequence-n |
|   |               | ASTTP parameters: capacity, time of occupation, time of use, probability of occupation, number of modules, etc. |
|   |               | Modified dynamic indicators of ASTTP: the average speed of transport processes, the dimension of the transport action along the station infrastructure, the dimension of the transport action by time, the density of the car traffic, the freight pressure on the transport infrastructure, the number of track development modules per one recycled local car. |

5 Rolling stock

|       | Mainline freight locomotives: VL-80, 2ES4K, TEP70, 2TE116, etc. |
|       | Shunting locomotives: ChME-3, TEM-7A, TEM-14, etc. |
|       | Freight wagons: box cars, gondola cars, flat cars, hopper cars, container carriers, etc. |
|       | Vessels: lighter carriers, bulky cargo ships, ro-ro vessels, etc. |
|       | Road transport: container trucks, platform vehicles, road trains, etc. |

6 Cargo (freight)

|       | Type of cargo: packaged piece, bulky cargo, etc. |
|       | The size of the consignment: route, dispatch, etc. |
|       | Shelf life: short-term, long-term |
|       | Storage conditions: indoor, outdoor, etc. |
|       | Processing method and type of handling equipment |

5 Discussion

Direct propagation neural networks are applicable for the purpose of reflecting control actions in the system. A special direction in the development of control systems are fuzzy logic systems (Kolesnikov et al., 2020; Lyabakh et al., 2020), which can operate with imprecise information and explain the decisions taken. These systems in cooperation with neural networks are applicable for the control of ASTTP parameters in the system "railway station - port" (Fig. 5). However, there is a number of problems in the application of neural networks to solve management problems: initially, the measure of complexity and size of the network for a sufficiently accurate implementation of the transport interaction mapping is not known; if the number of parameters is insufficient, it is impossible to train the neural network and the system will not work correctly; the input data must be consistent; there are many ways to represent input and output data for neural network, ranging from a simple linear transformation to a multivariate parameter analysis.

For example, a well-known way to represent the output data of a transport neural network is a vector, which components correspond to different class numbers. For example, if in the network (transport model) with four outputs we have the vector of output values (0.1, 0.1, 0.1, 0.7) - the probability of the distribution of the rolling stock on the freight fronts, then we see that the fourth component of the vector has the maximum value, so the class, this example refers to, is the 4th. Also for the considered example we can determine the network confidence that the example belongs to the fourth class, it is equal to 0.7-0.3=0.4. Methods for writing output vectors in binary form and in the form of splitting the problem with k-classes into k-(k-1)/2 subtasks with two classes (2×2 coding) each are also applied. For the transport model (Kolesnikov, 2008) with series-parallel connections of blocks with nine classes we have 36 outputs (subtasks).
\[ A_{kn} = \frac{k(k-1)}{2}. \]

The most difficult moments in organizing a direct cargo transshipment options are the discrepancy between the tonnage of the vessel and the carrying capacity of the arriving rolling stock, as well as the discrepancy between the arrival of ships and wagons at the port. The accepted form of organizing the interaction between the port and the railway station provides for the supply and removal of wagons at certain intervals. In cases of direct cargo transshipment, the principle of supplying wagons without intervals can be used, as they arrive and are processed at the port station, taking into account the intensive supply of trains.

To reflect such situations in neural networks for controlling the interaction of the station and the port, it is necessary to systematize (normalize) the parameters of the TTS and develop a way to display the situation on the input layer of the neural network. It is required to form a reference situational picture and attach it to the neuron of the output layer of the network. The development of a situational picture is a trace or reference path of excitation from the reference to the corresponding neuron.

As a method of forming a set of alternatives for management decisions, morphological analysis is often used (Kuzminov, 2009; Kolesnikov et al., 2020), according to which each option is represented in the form of its constituent elements. The measured parameters of transport processes are used as elements. The morphological model of the transport process (Kuzminov, 2009) is presented as a combination of sets: structural elements, links between structural elements (blocks) of a managerial decision option, a system of restrictions and a system of criteria to be optimized. For example, the assessment of one ASTPP option includes \( A_1^1: A_1^1 \) - the number of involved blocks of the station model scheme for ASTPP.
option; \( A_1^2 \) - possible options of stable block connections; \( A_1^3 \) - parameters of technological block usage; \( A_1^4 \) - probabilities of using blocks by types of transport operations; \( A_1^5 \) - strategy for further development of the ASTPP structure when changing the parameters of car flows in the system; \( A_1^6 \) - parameters of transport operation management, etc. A morphological matrix of probabilistic connections of structural elements is formed. In this case, the accuracy of the assessment of the transport process is determined either by the confidence interval or by the value of the standard square deviation. Thus, to develop a morphological matrix, a stochastic analysis of the parameters under consideration is required. The matrix can also include special external or internal factors that influence the choice of a managerial decision.

In this regard, in the development and assessment of methods for managing technological interaction in portside transport systems, a generalized approach to improve work efficiency is often problematic. Consequently, new criteria are needed to develop the system of traditional indicators of the port systems operation: the average speed of transport processes, the size of the transport action along the transport infrastructure, the size of the transport action by time, the freight pressure on the transport infrastructure, the utilization rate of the infrastructure capacity over the time of transport processes, the acceleration use magnitude of the loaded part of the rolling stock turnover.

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