UDC 656.2.08
DOI: 10.15587/1729-4061.2020.195071

DEVISING AN AUTOMATED TECHNOLOGY TO ORGANIZE THE RAILROAD TRANSPORTATION OF CONTAINERS FOR INTERMODAL DELIVERIES BASED ON THE THEORY OF POINT PROCESSES

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Значна кількість проблем та пов'язані із ними додаткові витрати операторів виникають внаслідок недосконалості існуючої технології оперативного планування роботи залізничного транспорту у складі системи інтермодальних перевезень. Джерелом цих проблем виступає не лише процес транспортування контейнерів залізничними шляхами, значний вклад у їх виникнення та розвиток вносять також і процеси, що протікають безпосередньо до та після нього. Ці процеси характеризуються певним рівнем невизначеності, який є наслідком їх імовірнісної природи. Їх випадковий характер провокує перепростої рухомого складу, які спричиняють додаткові операторські витрати та зниження якості обслуговування клієнтів. Однак безпосередній вплив на них є дуже ускладненим або економічно недоцільним.

Показано, що врахування імовірнісної природи цих процесів з метою зменшення їх негативного впливу є найбільш ефективним саме на етапі оперативного плануванні роботи залізничних підприємств, що задіяні в процесі інтермодальних перевезень. Зазначено, що для підвищення якості такого планування необхідне одночасне врахування випадкових чинників процесів формування і обробки контейнерних поїздів на станціях, їх просування по дільницях та передачі до порту. Однак особливої уваги потребує процес надходження контейнерів до термінальних залізничних станцій.

Було доведено, що ключовим моментом у вирішенні проблеми синхронізації цих процесів є формування автоматизованої технології організації транспортування контейнерів залізницею.

З цією метою було формалізовано технологічний процес формування і просування контейнерних поїздів до морських портів у вигляді моделі стохастичної оптимізації із використанням математичного апарату теорії випадкових потоків. Критерій оптимізації даної моделі представляє експлуатаційні витрати оператора при організації залізничної частини інтермодальних перевезень. Стохастичний характер моделі дозволяє відшукати оптимальні параметри оперативного плану організації контейнерних перевезень одночасно контролюючи рівень впевненості у можливості реалізації цього плану враховуючи імовірнісну природу складових процесів.

На основі розробленої моделі створене програмне забезпечення у середовищі Matlab та сформовано автоматизовану технологію просування контейнерних поїздів. Застосування запропонованої моделі при формуванні автоматизованої технології залізничних контейнерних перевезень дозволить зменшити експлуатаційні витрати залізничної частини інтермодальних контейнерних перевезень щонайменше на 10 %

Ключові слова: інтермодальні контейнерні перевезення, випадкові точкові процеси, стохастична оптимізація, залізничні контейнерні перевезення

Received date 06.01.2020
Accepted date 11.02.2020
Published date 24.02.2020

1. Introduction

Management of intermodal transportation is a complex and responsible process. Operators use railroads in combination with maritime transport in international and intercontinental container shipping traditionally. The task of railroad transport is to provide transportation on the so-called "land bridges" land sections, where a route begins or ends, or through which it passes as transit. Delays in the delivery of goods in the field of container intermodal transport do not decrease despite a considerable level of computerization and informatization. A poor speed of container trains is a significant factor in delays. The problem is common. It concerns not only intermodal operators, who use Siberian and Eurasian continental land bridges, which cross Russia and Kazakhstan, respectively, to deliver goods from Japan, South Korea, and Taiwan to Eastern Europe. It also applies to the US and Canadian land bridges through which Japanese goods reach consumers in the US and Canada, and through ports in Germany and the Netherlands to consumers in Western Europe. The reason is a lack of effective approaches to the formation of control systems that would demonstrate a high level of efficiency under uncertainty, which is a natural component of the transportation process. The issue of the coordination of the delivery of containers to a port with the arrival time of ships is also important in the case of railroad delivery of containers to a port.

Thus, the expedient task is the formation of automated technology for the organization of container railroad transportation, which would provide a high level of reliability and competitiveness for intermodal container transportation systems by the creation and use of a system effect in the interaction of railroad and maritime transport enterprises.

2. Literature review and problem statement

One of the main areas for the study in this area is the statement and solution of problems related to optimization of the topology of intermodal transportation routes based on logistics. In particular, paper [1] proposes the task of selection of the best of 36 intermodal transport routes, which begin in mainland China and go across the Indian Ocean, based on the target programming methods. The proposed methods make it possible to analyze competing decisions based on several criteria, but the route selection does not take into account time-related criteria, such as, for example, the arrival of ships at a port. Work [2] proposes a model based on the application of fuzzy logic to evaluate the effectiveness of existing intermodal transportation routes. However, the model is useful for making strategic decisions on changing routes only. Paper [3] proposes an integer programming model to determine the best railroad route for container delivery. The model operates with delivery times as probable variables, but it does not take into account the random nature of initial container flows. The authors of paper [4] assess the possibility of opening new routes for intermodal container transportation between Europe and Asia. They analyze reasons for the creation of new Velvet routes, but there is no specific model or method for laying of routes. Work [5] solves the problem of the efficient location of intermodal container terminals with the involvement of the mathematical apparatus of genetic algorithms. However, it proposes direct expenses for freight transportation as a criterion only. It does not take into account contemporary container concepts such as “a dry port”, etc. in the determination of a location of container terminals. Paper [6] suggests a solution to the problem of the geographical location of container hubs to increase the efficiency of interaction between railroad and sea transport in the European intermodal transport system. However, it proposes only rail express trains for the railroad connection between hubs. There are no trains in other categories. Work [7] provides models for the development of strategies for additional preparation of container flows to optimize a complex process of container transfer from trains to ships taking into account uncertainty. However, the assumption about the distribution of a random value of quantity by the uniform law made in the work is doubtful. Work [8] proposes a model, which makes it possible to control the process of placement of containers in a port during loading and unloading of trains and ships in online mode. The model makes it possible to optimize a process of container transfer by taking into account the estimated arrival information on trains and ships and a number of available seats in them. However, the application of a planning horizon longer than 7 days indicates that the probabilistic nature of container flows is not accounted for properly in the model.

3. The aim and objectives of the study

The objective of the study is formation of the automated technology for organization of moving of container trains in intermodal transportation under conditions of interaction of railroad carriers with a seaport.

We set the following tasks to achieve the objective:

– analysis of the problems related to the technology of railroad container delivery to a port and formulation of requirements for the automated technology to organize a container transportation process, which can solve them;

– determination of a mathematical apparatus, which gives the possibility to model numerical characteristics of container flows over time adequately when trains form and move under conditions of intermodal transport, based on the analysis;

– formation of a mathematical model of the process of operational planning of the work of railroad directions under conditions of transportation of containers taking into account interaction of enterprises of railroad and sea transport in the form of an optimization task;

– modeling using the developed model and analysis of its results.

4. Formalization of the process of transportation of containers in the form of an optimization model of stochastic programming

4. 1. Analysis of problems of railroad delivery of containers to a port and formation of requirements for the automated technology of its organization

Fig. 1 shows the typical scheme of a polygon, which corresponds to a land part of a way crossed by containers to a seaport by railroad.

The reduction of the cost of movement containers on all sections of a route is a key element of the intermodal transportation system, as the cost is their main competitive advantage. The use of containers, despite the inconvenience of handling them, should provide a reduction in the use of human labor, duration of freight operations, reduction of expenses for security and reduction of the freight delivery time. The freight delivery time is also an important economic basis for freight owners. Even a slight increase in international freight rates has a significant economic effect on medium and large companies. The essence of this effect is to accelerate the circulation of working capital because freights in containers mostly have a high specific value.

The main disadvantage of a sea section of a route is the considerable delivery time because of the slow speed of movement of cargo ships, time spent on checking and processing of documents at ports, the possible necessity of container ships to visit optional ports for cargo operations. At the same time, sea transportation is the cheapest type of transport and its further optimization is possible both through organizational measures, such as improvement of systems for management of operation of ships, as well as through the introduction of new technical solutions, for example, improvement of efficiency of power installations of ships, etc.

Another issue is to move containers by the Ukrainian railroad, where organizational factors are crucial. The use of imperfect transportation management technologies leads to potential significant non-production time losses and increased operating expenses for intermodal operators due to additional idle time for trains containing fitting platforms with containers at switchyards and port stations. Recently, all these negative phenomena are intensifying against the background of such increasing trends as lack of traction rolling stock, shortage and poor condition of a container park and fitting platforms. Gradual degradation of railroad infrastructure, which reduces the capacity of lines and processing capacity of switchyard stations, complicates the situation also. In addition, the late loading of ships with containers also leads to a significant increase in operational expenses in intermodal container transportation due to the excessively high cost of idle time for ships. Thus, the process of organization of a land part of intermodal transportation has considerable reserves for its optimization. However, it is necessary to develop modern automated technology for the organization of railroad container transportation, which will ensure a proper speed of delivery of containers by railroad to a port taking into account a timetable.

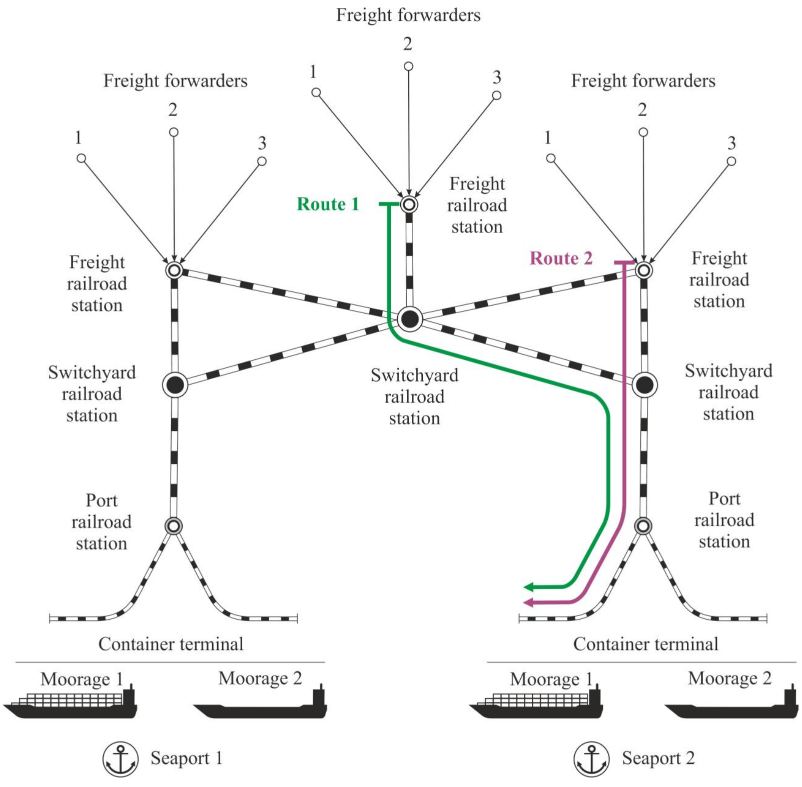

Fig. 1. The scheme of organization of delivery of containers by railroad to seaports in intermodal transportation

It is necessary to formalize processes of container accumulation at terminal stations, formation, and moving of containers on railroad connection to seaports under conditions of intermodal transportation system functioning within a single model to develop such technology.

The main task for the management of the process of formation and moving of container trains by railroads is to choose a strategy for the accumulation of containers at terminal points for timely transshipment to ships. The strategy of accumulation of routes, that is, of full-stock trains, which contain fitting platforms with containers only and go without alterations to a port station, seems to be the most rational at first glance. The absence of alterations of direct trains at switchyard stations should not only reduce operating costs but also minimize the time for container transportation from a terminal to a port station.

However, a detailed study reveals that it can also lead to significant losses. Accumulation of a route from containers may take much longer than planned due to the unsteadiness of the market or other factors. Delivery of a batch of containers to a port may occur not in time in such circumstances. It, in turn, may cause additional idle time for a loaded ship. Another strategy is that even a few containers, which arrive at a terminal station, go to a port station on trains, which stay at the station or pass it. However, it may also be ineffective. Delivery time of containers can increase greatly at this strategy due to the passage of alterations at switchyard stations, which can also cause an additional idle time for a ship at a port. Thus, a rational approach to the organization of a land part of intermodal transportation is the formation of a mixed strategy, which will determine the most advantageous option of sending containers to a port taking into account current and forecasted information.

One can consider information which station may receive freight forwarders as precise information. However, the accuracy of even such information is never close to 100 %, as there may be incorrect calculations, unforeseen delays due to failure of freight equipment and other reasons.

Thus, an adequate process model that will be suitable for use as a basis for the formation of the automated technology for the organization of container transportation by the railroad in the intermodal system should take into account its stochastic component.

4. 2. Selection of a mathematical apparatus

One should note that the aim of the classical probability theory is the modeling of the probability of an occurrence of single events or their combinations. Modeling of random processes that relate to sequences of events over time has many specific features. It is challenging, but there are several mathematical tools that seem to be applicable to solve it. For example, the Petri nets apparatus was designed specifically to model discrete random processes. However, its more detailed study reveals that this mathematical apparatus is a kind of "a thing in itself". It is almost impossible to apply it in the composition of other mathematical models, which contain traditional mathematical structures. There is also difficulty in obtaining some characteristics of the process. In addition, all the obtained numerical characteristics of the Petri model are purely empirical. However, it is also almost impossible to construct the necessary model using the Petri net only. There are no important mechanisms for modeling of such processes as, for example, the process of accumulation of elements, which are containers in this case, even in the most modern versions of this mathematical apparatus, such as color Petri nets. It is possible to model it only by the introduction of artificial structures into the model. According to the authors, the reason is a need to preserve the simplicity of the semantics of this popular mathematical apparatus.

Another option for the solution of this problem is a mathematical apparatus of the theory of Markovian processes. But a detailed study makes us conclude that their focus is a theoretical study. However, it is also inconvenient apparatus for practical application, as it is almost impossible to calculate and apply such values as, for example, multidimensional densities and correlations. Another mathematical apparatus, which preserves all completeness and accuracy of a mathematical description of random processes and aims at practical application at the same time, is a mathematical apparatus of the theory of point processes. Its advantages are the ability to describe numerical characteristics of random sequences of events, which relate not only to a class of Markovian processes, and which imply the possibility of simultaneous occurrence of several events and a change in probabilistic characteristics over time. Thus, the theory of point processes is the most adequate mathematical apparatus for the representation of flows of container arrivals at terminal railroad stations.

4. 3. Formation of a mathematical model

The key to solving the problem of the organization of container transportation is the determination of the optimal time to complete the accumulation of a container batch. The time must correspond to the maximum or acceptable value of the probability that the accumulated already batch of containers will come to a port on time and there will be no shipping delay. At the same time, the model should ensure that a number of containers, which arrive at a port on time, are maximal.

Studies prove that arrival flows have independent patterns of container arrival times at different time intervals, so one can consider them as flows without an aftereffect, that is the Poisson flows. One should note that these flows are also extraordinary, as containers can arrive in groups, that is several event flows can occur at one time. It is advisable to use a Poisson flow of grouped points to model such flows. One should also take into account that the intensity of actual flows of arrivals of containers at a station changes over time.

The most important value, which characterizes such flow in the context of the solution of the problem, is the probability function of the occurrence of at least *k* events at a time interval. One can represent it as follows for flows of such type taking into account information on generating probability and multiplicity functions [9]:

$$P\left(k,\left[t_0,\tau\right]\right)=1-\exp\left(-\int\limits_{t_0}^{\tau}\Lambda(t)\,\mathrm{d}t\right)\times$$
$$\times\sum_{i=1}^{x(s,k)}\prod_{\substack{j=1,\\ \Sigma jq_{ij}<k,q_{ij}\in\mathbb{N}}}^{s}\frac{\left(\int\limits_{t_0}^{\tau}\lambda_j(t)\,\mathrm{d}t\right)^{q_{ij}}}{q_{ij}\,!},\qquad(1)$$

where k is the number of containers, which will arrive at a station; t_0, τ are the beginning and end moments of a planning period, respectively; $\lambda_j(t)$ is the intensity of a flow of containers of *j* multiplicity as a function of time; q_{ij} is the number of events of a flow of *j* multiplicity in $[t_0,\tau]$ time interval in *i*-th case of events; *s* is the maximum multiplicity of a flow considered at a given terminal; $x(s,k)$ is the power of a set of probabilistic events for given values of *s* and *k* variables, when we understand a case as one of the possible realizations of a flow characterized by $\{q_{i1},q_{i2},q_{i3}\ldots q_{is}\}$; flow set considered at a given terminal; $\Lambda(t)$ is the "leading flow function" [9], that is a total flow intensity of all multiples as a function of time defined as

$$\Lambda(t)=\sum_{j=1}^{s}\lambda_j(t).$$

The formula indicates that in calculations for each *i*-th case, it is necessary to take into account all q_{ij}, which satisfy the ratio

$$q_{i1}+2q_{i2}+3q_{i3}+\ldots+sq_{is}<k,$$

that is, those, which provide that a total number of events of flows of all multiplicities does not exceed a number of k.

Thus, let us define $W(P,\tau,\Lambda(t))$, the functional, which returns the maximum value of a number of containers with a *P* probability that they can be accumulated at a station over *t* time interval taking into account $\Lambda(t)$ intensity, which is variable over time.

One should also note that not only container flows from freight forwarders to terminal points are random in the intermodal transportation system. The randomness factor is fully present in such parameters as, for example, time for the reorganization of trains at switchyard stations, time of movement of a train from a port railroad station to a port dock, and many other parameters. Studies proved [10] that the listed parameters are subject to normal or close to distribution laws. The actual values of these parameters may differ from average ones or normal ones by several times. Therefore, one can state that planning of transport processes without taking into account various types of uncertainty can reduce the quality of management significantly. The probabilistic nature of processes is critically important in decision making in operational planning taking into account high density and coherence of the processes in intermodal transportations.

In view of the above, it becomes possible to state the problem of the rational organization of container transportation to a seaport by the railroad in the intermodal transportation in the form of a stochastic optimization problem.

The main management factor under such conditions is the determination of times of completion of containers accumulation and the start of their transportation to a seaport. A method and a corresponding cost of their transportation: as a part of a direct route, as part of a non-scheduled direct train, as a part of other trains, with subsequent reorganization at switchyard stations along a route, depend on the amount and quantity of containers accumulated.

One should note that such formulation of the problem makes it possible to have some variations in the cost of transportation of containers both on different railroad lines and within the same direction. However, the main objective is to minimize the cumulative expenses of an intermodal operator for delivering containers by railroad to a seaport. In such circumstances, it is advisable to choose a specific value of expenses for transportation of one container as a criterion. Therefore, one can define the objective function as follows:

$$C(\tau,P)=\frac{1}{\sum\limits_{i=1}^{z}\left(N_i(P,\tau_i)+N_i^0\right)}\times$$
$$\times\sum_{i=1}^{z}\left(\begin{array}{l} e_{c\cdot h}\int\limits_{t_0}^{\tau_i}W_i\left(P,\tau_i,\Lambda_i(t)\right)\mathrm{d}t+e_{w\cdot km}\cdot l_i+ \\ +\left(\left(e_{c\cdot h}+e_{w\cdot h}\right)\left(N_i(P,\tau_i)+N_i^0\right)+e_{t\cdot h}\right)\times \\ \times\left(\begin{array}{l} \tau_i+\dfrac{l_i}{v_i^{\text{ave}}}+H\left(\left(m_i-\delta_i\right)-\left(N_i(P,\tau_i)+N_i^0\right)\right)\times \\ \times\sum\limits_{j=1}^{S_i}\left(\mu_{ij}^{\text{proc}}+\sigma_{ij}^{\text{proc}}\sqrt{2}erf^{-1}(2P-1)\right)+ \\ +\left(\mu_i^{\text{pass}}+\sigma_i^{\text{pass}}\sqrt{2}erf^{-1}(2P-1)\right) \end{array}\right)+ \\ +e_{s\cdot h}\left(\left(T_i(\tau_i)+\left(N_i(P,\tau_i)+N_i^0\right)t_c\right)-t_{el}\right)\times \\ \times H\left(\left(T_i(\tau_i)+\left(N_i(P,\tau_i)+N_i^0\right)\right)-t_{el}\right) \end{array}\right)\to\min, \quad (2)$$

where P is the current level of probability; z is the number of routs of container delivery to a port; τ is the variable vector of $\tau=(\tau_1,\tau_2\ldots\tau_z)$ time of completion of accumulation of container batches at terminal stations of routes; $e_{c\cdot h}$ is the cost of a container-hour; $e_{w\cdot h}$ is the cost of a wagon-hour; $e_{t\cdot h}$ is the cost of a train-hour; $e_{w\cdot km}$ is the cost of a wagon-kilometer; $e_{s\cdot h}$ is the cost of a ship-hour; t_0 is the moment of beginning of a planning period; $\Lambda_i(t)$ is the general function of intensity of arrival of containers at a terminal (initial) station of i-th route taking into account multiplicity of events; $W_i\left(P,\tau_i,\Lambda_i(t)\right)$ is the functional, which returns a minimum value of a number of containers that will be accumulated at the terminal station of i-th route at a time according to the intensity function with P probability; $N_i(P,\tau_i)$ is the minimum number of containers that will accumulate at a terminal station of i-th route with P probability, which is returned by $W_i\left(P,\tau_i,\Lambda_i(t)\right)$; functional; N_i^0 is the number of containers at a terminal station of i-th route at t_0; beginning of a planning period; l_i is the length of i-th route from a terminal station to a port; m_i is the norm of a number of wagons in a train on i-th route taking into account that one fitting platform transports one 40-foot container; δ_i is the maximum deviation of a number of wagons in the direction of reduction when forming a direct container train on i-th route; v_i^{ave} is the average train speed on i-th route; S_i is the number of switchyard stations on a section of passage on i-th route; μ_{ij}^{proc}, $\sigma_{ij}^{\text{proc}}$ are the values of a mathematical expectation and standard deviation, respectively, for calculation of

$$Q_{ij}^{\text{proc}}(P)=\mu_{ij}^{\text{proc}}+\sigma_{ij}^{\text{proc}}\sqrt{2}erf^{-1}(2P-1),$$

quantiles of the normal distribution of time for processing of train at j-th switchyard station of i-th route, which contains wagons with containers; μ_i^{pass}, σ_i^{pass} are the values of a mathematical expectation and standard deviation, respectively, for calculation of

$$Q_i^{\text{pass}}(P)=\mu_i^{\text{pass}}+\sigma_i^{\text{pass}}\sqrt{2}erf^{-1}(2P-1),$$

quantile of the normal distribution for time of train passage from a port station to a port on i-th route, which contains wagons with containers; $erf^{-1}(x)$ is the inverse function of Laplace deviations; $T_i(\tau_i)$ is the current time of arrival of containers on i-th route to a port; t_c is the average loading time of a container to a ship; t_{el} is the moment of an end of loading of a ship according to a schedule; H is the Heaviside function defined as follows:

$$H(x)=\begin{cases}1, & \text{if } x>0,\\ 0, & \text{if } x\le 0.\end{cases}$$

One should also note that we take into account expenses due to a possible delay of a ship in the objective function just to improve the quality of planning of operation of railroad transport in interaction with a seaport and not to optimize operational expenses of the railroad and maritime transport enterprises.

It is necessary to optimize the model taking into consideration the following limitations:

$$\begin{cases}\tau_i\ge 0, \forall i=1,2\ldots q,\\ P\ge P_{\min},\\ N_i^0+N_i(P,\tau_i)\le m_i^{\max}, \forall i=1,2\ldots q,\\ \sum\limits_{i=1}^{q}\int\limits_{\tau_0}^{\tau_i}W_i\left(P,\tau_i,\Lambda_i(t)\right)\mathrm{d}t\le N\ ,\end{cases} \quad (3)$$

where $P_{\min}$ is the minimum acceptable level of probability in planning, that is, a minimum level of certainty about the possibility of implementation of the obtained plan; $m_i^{\max}$ is the maximum acceptable number of wagons in a train on i-th route; N_c is the number of available places for loading of containers to a ship.

The first limitation is necessary to ensure the condition inexistence of times of the end of accumulation of container batches. The second limitation provides the required level of realization of the plan. The third limitation prevents the accumulation of containers in a number, which exceeds the maximum acceptable train composition. The fourth limitation prevents the accumulation and transportation of containers at all terminals in a number, which exceeds the number of available slots in a ship.

Thus, the optimization of the developed mathematical model is a problem of stochastic programming.

4. 4. Modeling and analysis of its results

We developed a software product in the MATLAB environment based on the constructed model. The test site consisted of 2 routes for container delivery to one ship (Fig. 1). There was a terminal freight station and a switchyard station on each route, both routes passed through one port station and ended at the territory of a seaport. We used the mathematical apparatus of genetic algorithms as a mechanism for stochastic model optimization. Fig. 2 shows the dependence of a value of the objective function on times of the end of accumulation of containers at two terminal stations.

The minimum of the objective function was USD 3,993.86, which corresponded to the average specific cost of transportation of one container from a terminal station to a seaport. The objective function reaches the minimum when the value of times of an end of accumulation of containers at two terminal stations is 5.52 and 8.05 hours, respectively. As we can see from the obtained dependence (Fig. 2), these time values correspond to the minimum of expenses and are separated from the critical time by time intervals of considerable duration. The critical accumulation time is approximately

15 hours from the beginning of the planning period at both terminal stations, because of the start of "storage on water" mode of a ship.

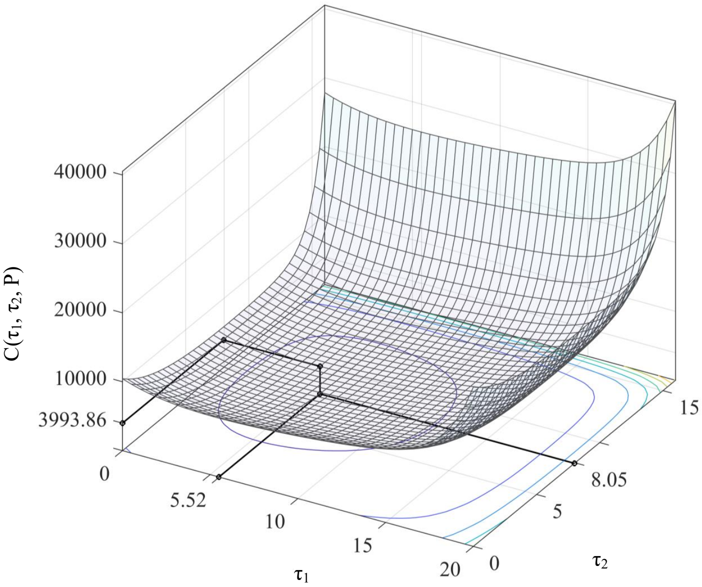

Fig. 2. Dependence of the specific expenses for transportation of one container by railroad to a seaport on times of an end of accumulation of batches of containers at two terminal stations

The simultaneous application of the mathematical apparatus of the point process theory and classical approaches to the probability theory is a new approach to the construction of stochastic models. Work [11] proved theoretically that the approach gives the possibility to obtain at least a 10 % improvement in model accuracy. Application of such model as a basis for formation of technology for the organization of delivery of containers to a port in the intermodal transportation provides the basis for implementation of reserves to reduce a cost of such transportation, implementation of a system effect in interaction of railroad carriers and seaports and improvement of the reliability of the system as a whole. One can consider the constructed model as the basis for further automation of the technological process of container transportation within the intermodal transportation system.

5. Discussion of results of studying the technology of the organization of transportation of container trains in the implementation of intermodal transportation

The obtained dependence (Fig. 2) demonstrates the existence of an extremum of the objective function, which is reached at the values of control variables that lie within the planning horizon. The obtained value of the minimum of the objective function (Fig. 2) is also consistent with the cost of transportation of containers. Therefore, the proposed model is adequate.

Construction of this mathematical model (2), (3) was possible due to the obtained dependence (1) used to determine the number of containers accumulated at a terminal station at a certain time interval and with a probability, which exceeded a certain set level. Obtaining correct numerical characteristics of the random process of accumulation of containers became possible due to the application of the mathematical apparatus of the theory of point processes in the determination of the dependence (1). Thus, we increased the accuracy of the model (2), (3) by at least 10 %. The possibility of simultaneous decision-making in the form of times of an end of accumulation of container batches within a single model demonstrates the effective application of the system effect.

The formalization of the model optimization process in the form of a stochastic programming problem enables numerical characteristics of container flows to fluctuate according to a certain probability interval. Such model flexibility makes it possible to obtain higher quality solutions compared to deterministic models, which can use probabilistic parameters of random processes in the form of constant values only.

Optimization results, which represent times of an end of accumulation of container batches, have a direct impact not only on the determination of a way of containers transportation (as part of a full, direct incomplete or collective train) but also they ensure timely delivery of container batches to a port. Thus, the use of this model will reduce idle time for containers and rolling stock at terminal stations and minimize the possibility of idle time for container carriers in ports, which in turn will lead to cheaper and faster delivery of goods internationally.

The proposed model represents container flows in the form of extraordinary and non-stationary Poisson flows, which corresponds to the mode of operation of terminal stations when they receive containers from many independent freight forwarders. This places some restrictions on its application in cases when terminal stations accept containers from a few freight forwarders only and there is a pronounced after-effect of flows. The model (2) is universal, but it will require the application of probabilistic dependencies corresponding to other types of flows, such as the Erlang flow, in this case. However, obtaining such dependences explicitly is not an easy task for some practically important types of flows. It is a challenge for further studies. Another area for further studies is the improvement of the technology of operation of switchyard and port stations to speed up processing and moving of container trains.

6. Conclusions

1. Our analysis of the technology of the organization of container transportation on a land section of a route under conditions of intermodal transportation has revealed problems. The problems are the presence of significant additional idle time for containers at loading, switchyards and port stations, the occurrence of delays in the loading of ships. The problems lead to an increase in the cost of transportation, failure to meet delivery times and other negative phenomena. One of the important reasons for the problems is the imperfection of the existing technology of container transportation. Its reason is the absence of effective mechanisms to take into account the probabilistic nature of container flows and the processes of moving of container trains on railroad routes. Improvement of the state of the problems is possible due to the introduction of the automated technology for the organization of container transportation by railroad under conditions of intermodal transportation. The technology should not only take into account the random nature of traffic flows but also the co-

ordinate operation of terminal stations and ports based on a systematic approach.

2. The actual process of accumulation of containers at freight railroad stations used as terminal points in intermodal transport systems may be presented as a non-stationary non-ordinary Poisson flow. This makes it possible to apply the dependencies obtained in the theory of point processes, to abandon the detailed forecasting of events of the process of accumulation of container batches to obtain its probabilistic characteristics, making only a forecast of the dynamics of its probabilistic characteristics – the intensity of a flow.

3. We formalized the process of the organization of transportation of containers by railroad under conditions of intermodal transportation in the form of an optimization model of stochastic programming. The objective function of the model is the criterion for the total operating expenses, which takes into account expenses due to idle time for containers and railroad rolling stock at stations, additional idle time for ships in ports, expenses for movement of trains on railroad sections.

4. The obtained modeling results testify to the adequacy of the developed model. They are also helpful in making decisions for railroad operational staff in forming and moving trains that carry containers to a seaport. The application of the model as a part of the automated technology of the organization of the process of delivery of containers by the railroad in intermodal transportation makes it possible to use a systemic effect in the interaction of terminal railroad stations and seaports. The introduction of this technology opens the possibility to reduce, by larger than 10 %, the cost of land transportation of containers in international traffic.

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