Досліджено процес переміщення рухомого складу на напрямку, що враховує можливі ризики при перевезенні вантажу. Виявлено основні причини, що ведуть до виникнення ефекту першої та останньої милі. А саме, відсутність необхідної кількості технічно справного рухомого складу у встановлені терміни та істотні труднощі із пропуском поїздів, зокрема через припортові та прикордонні станції.

Формалізовано технологічний процес перевезення вантажу на напрямку у вигляді оптимізаційної математичної моделі процесу просування вантажних вагонів. Цільова функція моделі представляє сукупні експлуатаційні витрати та заснована на використанні інтеграла Лебега-Стілтʼєса, що враховує ефект першої та останньої милі. Модель також враховує можливі ризики, що виникають у процесі експлуатації вагонів. Сформовану оптимізаційну модель доцільно віднести до задач стохастичного програмування.

Аналіз статистичних даних виявив, що час просування вагонів від початкової станції маршруту до припортової станції, а також час переміщення вагонів від припортової станції безпосередньо до порту підпорядковані нормальному розподілу. Наявність позитивної кореляції між цими двома величинами дає підстави розглянути відповідні параметри в межах єдиного імовірнісного поля. Такий підхід дає можливість більш точно визначити імовірність несвоєчасного прибуття вагонів до порту і відповідно величину фінансового ризику.

В результаті моделювання доведено, що існує екстремум цільової функції типу мінімум, що дозволяє сформувати процедуру оптимального управління параметрами перевезення. Таким чином, сформована модель носить універсальний характер та в умовах наявності зворотнього зв'язку дозволяє управляти перевізним процесом з найменшими експлуатаційними витратами залізниці. Проведені розрахунки показали зменшення витрат залізниці приблизно на 10 % у порівнянні з витратами, що розраховуються за існуючою методикою визначення фактичної собівартості перевезень вантажів. Оптимізаційна модель є основою формування автоматизованої технології управління вантажними перевезеннями, яку пропонується реалізувати у вигляді системи підтримки прийняття рішень диспетчерського апарату

Ключові слова: залізничний транспорт, перша та остання милі, експлуатаційні витрати, функція ризику

UDC 656.222.6
DOI: 10.15587/1729-4061.2019.156098

FORMING AN AUTOMATED TECHNOLOGY TO MANAGE FREIGHT TRANSPORTATION ALONG A DIRECTION

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1. Introduction

Railway transport is a large and complex system. The form of resource management on the railroad is outdated. It does not correspond to actual trends in the global transportation market. A lack of measures for rational management of infrastructure and railway transport objects, a low level of implementation of modern technologies and implementation of innovation policy in the transport industry leads to a decrease in the competitiveness of the railway.

We observe a tendency towards reduction in the volume of rail transportations and its attractiveness over the past 5 years. The turnover of a wagon increases, a number of wagons in expectation of locomotives increases also. One of the main problems of railway transport is the condition of freight moving and traction stock. In connection with this, a volume of freight traffic decreases due to delayed delivery times of freight, which leads to an increase in financial losses both by the railway and shippers. It is necessary to increase efficiency of operation of the existing resources of the railway to maximize the use of transport potential.

The modern rail freight market requires improved traffic management, increased flexibility and speed of decision making by dispatcher staff, reduced operation costs and increased operational efficiency of operational workers. The Strategy implies fulfillment of delivery terms of freight and improvement of turnover of wagons, transition from regional principles of management of the transport process to organization of train movement on areas of a significant length [1].

Thus, the actual task is formation of automated control technology for wagon traffic on the main directions. It will eliminate delays in traffic with minimal operation costs. Such technology will give dispatcher staff of the railway possibility to make quick rational decisions on organization of transportation process on a certain direction in the automated mode under conditions of uncertainty. It is necessary to examine the process of transportation of freight from a consignor to a consignee and to identify main difficulties that arise during planning, organization and management of wagons for reliability of conditions for wagons movement.

2. Literature review and problem statement

Article [2] considers the formulation and algorithm of implementation of a mathematical model of distribution of empty wagons for loading at a railway transport junction. The model takes into consideration requirements of wagon owners at their operation and a level of loading of railway stations of a junction under operational mode. The proposed technology determines possibility of inclusion of groups of empty wagons into transferring or moving out trains at connection of trains, which circulate according to a contact graph. At the same time, authors ignore risks that may arise in the process of wagon movement and, thus, reduce traffic capacity of a junction.

The main purpose of work [3] is to achieve high productivity of the railway infrastructure at the lowest cost. Authors propose a multicriteria approach to railway system modeling based on the theory of reliability taking into consideration functional and operational properties of the infrastructure. It is possible to apply the method to determine a level of influence on the industry operation in case of failure of railway transport objects, namely in case of absence of a corresponding freight or traction rolling stock.

Authors of publication [4] present a simulation model that studies, optimizes and evaluates performance of a rail network at changes in processes in the infrastructure, in moving units and traffic management. The simulation process leads to improvement of operation of a railway line due to introduction of innovative computer technologies. This gives possibility to monitor operation of subsystems of the railway in real time.

The methods of forecasting of transportation volumes of freight given in paper [5] make it possible to determine traffic load of a railway network. The proposed optimization model of management of freight rolling stock takes into consideration non-uniformity of transportations and offers an optimal plan for distribution of wagons on a site. Paper [6] considers combined integral programming for resolution of the problem of distribution of freight wagons by directions. The purpose of the paper is to develop a mathematical model, which can offer an optimal plan for operation of the railway network. But the paper does not take into consideration peculiarities of operation of border points and port stations.

Work [7] uses a method of genetic algorithm. It gives possibility to resolve the problem of calculation of formation of a train plan for the whole landfill of Ukraine's railways based on preliminary data on volumes of freight transportation. The method provides possibility to take into consideration restrictions on throughput and processing capacity of railway infrastructure objects, but it does not take into consideration risks associated with traction rolling stock.

Paper [8] studies the problem of highway traffic on roads to the port [8]. Authors indicate that difficulties arise at the last mile towards the port. It leads to traffic jams and lengthens time to get to the port and in the opposite direction. Such obstacles arise at the delivery of freight to the port by rail. Authors note that construction of a new highway will resolve the problem. But the construction requires large investments. It is possible to avoid the effect of the last mile by rational co-ordination of a number and time of moving units. Study [9] presents innovative strategies for last mile's logistics aimed at reducing of effects of external factors on urban traffic. Innovation is an important tool for transition from existing logistics systems to more sustainable and intelligent systems in this context. It is possible to use the proposed concept of cooperative urban logistics for railway transport also taking into consideration the specifics of its operation.

The objective of scientific studies [2–9] is improvement of a certain part of the transportation process. However, there are no sufficient studies on the full cycle of movement of wagon traffic. Therefore, it is expedient to study the process of supply of an empty freight wagons to a consignor, loading of wagons, transportation of freight, unloading and returning of empty rolling stock to a dislocation station. The study should take into consideration possible delays at movement of wagons along a direction to a port or a border transshipment station and idle time for wagons in the absence of a traction rolling stock. It is necessary to take into consideration the experience of both the railway and automobile transport industry to formalize the general situation in case of possible obstacles to transportation of freight.

3. The aim and objectives of the study

The objective of the study is to form an effective technology for organization and management of freight trains. Such technology will enable the dispatcher staff of all levels to make informed decisions on the rational use of railway transport objects on main directions under the operational mode. It will also help to eliminate delays in the transportation process taking into consideration the first and last mile.

We set the following tasks to achieve the objective:

– to study the technological parameters, which affect the process of freight delivery by rail;

– to formalize the technological process of freight transportation along a direction taking into consideration the effect of the first and last mile in the form of an optimization mathematical model taking into consideration possible risks;

– to determine the expediency of application of the proposed technology for management of a transportation process.

4. Formalization of the transportation process in the form of a mathematical model

4. 1. Preconditions for improvement the process of freight delivery by rail

One of the most important conditions for the successful development of freight traffic on railways is continuous improvement of the technology of organization of wagon traffic. The organization of wagon traffic should establish a rational system for formation of trains and minimization of operational costs of the railway. It should meet needs of customers for transportation. Improvement of the organization of wagon traffic will accelerate delivery time of freight, eliminate obstacles in throughput capacity of the infrastructure and optimize operation of rail lines with low traffic.

The largest shippers of Ukraine are System Capital Management, OJSC Poltava GOK Corporation, PJSC ArcelorMittal Kryviy Rih, PJSC Ivano-Frankivsk Cement, PJSC

Kryvorizh Iron Ore Company [10]. The share of these shippers makes up about 37 % of the total freight flow of Ukraine. Their freight flows are the most stable and most massive. The bulk of their freight falls on export transportations, which follow in the direction of the port or the western border of Ukraine. These are the most loaded destinations. Therefore, there are difficulties with passage of trains, especially on these directions. Stations for the passage of export wagons do not cope with the "inflow" of wagons often. It leads to an increase in idle time of rolling stock in expectation of their processing by relevant stations. Therefore, it is expedient to investigate peculiarities of organization of wagon traffic on the example of large shippers on certain directions precisely.

Recent trends in Ukraine's freight sector performance reflect the poor state of operation of rail transport. There was the reduction in the volume of rail traffic by 4.5 % on average in 2018 as compared to 2017. But automobile transportations show an increase by 8 %. The main means, namely freight wagons, traction rolling stock and infrastructure, are worn out. The turnover of a wagon is increasing. It grew from 5.85 to 9.34 days in 2017 as compared to 2011. Table 1 gives data from the Department of Statistics [11] on the basic performance indicators for all freight wagons of JSC "Ukrzaliznytsya" over 2017.

Table 1

Basic performance indicators of freight wagons over 2017

Indicator name	Total for Regional branches of JSC «Ukrzaliznytsya»
Turnover of a freight wagon, day	9.34
Wagons idle time at one technical station, hour	11.59
Wagons idle time under one freight operation, hour	62.54
Percentage of empty run of wagons to total, %	40.4
Percentage of empty run of wagons to loaded one, %	67.8
Average daily capacity of a wagon, tkm net	3,753
Operational stock of freight wagons of various forms of ownership, wag. per day on average	135,792
Total number of wagons delayed in trains per year, number of train delays, among them are:	12,786
– delays at port stations and approaches to them	6,741
– delays at border stations and approaches to them	4,809
– other delays	1,236
Total time of wagons delay in trains, hour	3,536.3

The wear of freight wagons, which belong to JSC "Ukrzaliznytsya" (inventory wagons) is 90 %. The technical condition of these wagons poses a threat to safety of infrastructure facilities and safety of freight. The railway is not able to provide all customers with high-quality rolling stock in time and in the required quantity. Even if there are wagons with normal commercial suitability owned by private enterprises, there is no possibility of their transportation in time due to the lack of sufficient locomotives [12]. Absence of the required number of technically sound rolling stock in due time leads to an increase in time of stay of freight at the consignor and increases his financial losses. The effect of the first mile emerges due to untimely supply of technically sound wagons and locomotives to the load points. Investigation of idle time of a local wagon at a departure station according to theoretical data showed that this time has a probabilistic nature and, on average, exceeds the normative time.

An analysis of turnover elements of wagon based on the use of statistical data given by Branch of the Main Information and Computing Center of JSC "Ukrzaliznytsya" showed that they spend the greatest amount of spent time to find a rolling stock at an unloading station. There is an excess of the standard time of stay at the station of destination in almost 70 % of cases according to the results of the operation of "Chornomorsk-Port" station. On average, a simple local wagon makes 52.58 hours against the standard time of 30.1 hours by a daily schedule.

The obstacle to movement of export freight under condition of timely delivery is idle of wagons at port and border transshipment stations due to overloading of the infrastructure on these directions. Such indicators reflect inconsistency of the operation of the railway with the port and the customs. That is, there is the effect of the last mile.

The mentioned parameters, which lead to the effect of the first and last mile, affect timely delivery of freight to a consignor. That is, the delay of the normative term of delivery of freight arises, which leads to increased operation costs of the railways and losses of financial resources of shippers.

4. 2. Construction of an optimization mathematical model

The quality of the process of transportation depends on a set of issues, especially on rationalization of initial and final operations. The term of delivery of freight is one of the most significant parameters of the quality of customer service. The time of delivery of freight by rail depends on rational organization of the first and last mile. The terms "first mile" and "last mile" mean the concepts used in management of supply chains and transport planning to describe movement of moving units from the start of the wagon traffic to its redemption at the final point. Authors of article [9] note that last mile logistics is the least efficient stage in the supply chain. It makes up to 28 % of the total delivery cost. In this case, the logistics of the first and last mile is almost not applicable in transportation of freight by rail. Although the delivery cost varies sharply at these stages precisely, and it is necessary to conduct a detailed study of them.

Planning the first and last mile is critical. The new system of intelligent logistics for rail transport aims to find a competitive way of management of transport and making the best decisions on how to eliminate the effect of the first and last mile. We can achieve the maximum efficiency by taking into consideration a vector of control variables (1) and a vector of variables of the current state of the system (2).

$$X = \{N_a, t_1, t_2\}, \quad (1)$$

where X is the vector of control variables; N_a is the number of wagons of a certain a-th belonging, wag.; t_1 is the time needed for wagons to come from the initial station of a route to the final one, days; t_2 is the time of stay of local wagons on the first or last mile taking into consideration interruptions in operation of stations, days.

$$Y = \{m_{tr}, m_{sh}\}, \tag{2}$$

where Y is the vector of variables in the system's state; m_{tr}, m_{sh} is the number of main line and shunting locomotives, respectively.

Taking into consideration control variables and a current state of the system, we propose the following form of a mathematical model of freight transportation management technology along a direction taking into consideration possible delays at the first and last mile with the probability of obtaining financial risks:

$$\begin{aligned} C(N_a, t_1, t_2, m_{tr}, m_{sh}) &= N_a \cdot \frac{C_{\sup}}{n_{un}} \cdot \vartheta_1(m_{tr}) + \\ &+ \frac{1}{N_a} \cdot \left(\begin{aligned} &\frac{C_{st}^{dep} \cdot \vartheta_2^{dep}(m_{sh})}{\sigma\sqrt{2\pi}} \int_{t_{\min}}^{t_2} t_{st}^{dep} \cdot e^{-\frac{1}{2}\left(\frac{t_{st}^{dep} - \overline{t_{st}^{dep}}}{\sigma}\right)^2} dt_{st}^{dep} + \\ &+ \frac{C_{st}^{dest} \cdot \vartheta_2^{dest}(m_{sh})}{\sigma\sqrt{2\pi}} \int_{t_{\min}}^{t_2} t_{st}^{dest} \cdot e^{-\frac{1}{2}\left(\frac{t_{st}^{dest} - \overline{t_{st}^{dest}}}{\sigma}\right)^2} dt_{st}^{dest} \end{aligned} \right) + \\ &+ \frac{C_f(t_1) \cdot \vartheta_3(m_{tr})}{N_a} + N_a \cdot \frac{C_r}{\overline{N}} \cdot \vartheta_4(m_{tr}) + \\ &+ \frac{N_a \cdot R(t_1, t_2)}{k_{fil} \cdot n_p} \to \min, \end{aligned} \tag{3}$$

where $C_{\sup}$ are the specific costs associated with the passage of freight wagons through a district and technical stations on the given direction, respectively, s.u./wag.; n_{un} is the unified number of wagons in a train on the planning ground (that is, brought to a loading station), wag.; $\vartheta_\gamma(m_\varsigma)$ is the Heaviside function, which takes into consideration the presence or absence of main or shunting locomotives in a given technological process in the form of:

$$\vartheta_\gamma(m_\varsigma) = \begin{cases} 0, & m_\varsigma \le 0, \\ 1, & m_\varsigma > 0, \end{cases} \tag{4}$$

where m_ς is the number of locomotives of ς-type (main or shunting), which corresponds to a certain technological process; γ is the index, which corresponds to each element of the technological process of operation of the railway system; C_{st}^{dep}, C_{st}^{dest} are the expenses on departure and destination stations, respectively, USD/hour; σ is the standard deviation of idle time of local wagons at a station; $t_{\min}$ is the minimum time of local wagons stay at a station, day; t_{st}^{dep}, t_{st}^{dest} is the actual time of idle of local wagons at departure and destination stations, respectively; C_f are the expenses on a route, USD; C_r are the expenses for return of own empty wagons to a station of the registry or a foreign wagon to an interstate unit, USD/wag.; $\overline{N}$ is the average power of a flow of wagon traffic on a given direction, wag.; $R(t_1, t_2)$ is the function of financial risk related to possibility of money losses of the railway in case of payment of a fine for delayed delivery of freight or untimely return of own empty wagons to a station of dislocation and a use of foreign wagons in the emergency return, USD/wag.; k_{fil} is the coefficient of filling of capacity of a railway line; n_p is the power of an existing technical state on a given direction, wag.

$f(C_u)$, (u=1,..., 5) functional has an additive character. It consists of five elements, and C_u value defines expenses for each element of the supply chain depending on a number of wagons of a certain belonging.

The first summand of the objective function reflects expenses of the railway for supply of the required number of technically sound wagons within the prescribed time period to the station in accordance with the requests of a sender. When planning the supply of rolling stock for loading, the dispatching staff of the railway should take into consideration existence of three types of wagons in the network. They are: wagons, which belong to the railway; own wagons, which belong to private enterprises; wagons, which belong to foreign states. We should take into consideration possibility of their use on a certain direction and availability of the corresponding locomotive. The effect of the first mile shows itself at this stage of transportation.

The second summand represents expenses for finding of wagons at loading and unloading stations. Formalization of the component of the second summand of the objective function at departure and destination stations, where the effect of the last mile arises, is of particular interest. It is expedient to use the Lebesgue-Stieltjes integral to calculate the mathematical expectation in the presence of a probability density function expressed in analytical terms. It has a significant number of applications not only in the theory of probability, but also in many other sections of mathematics [13]. The Lebesgue-Stieltjes integral with a variable upper boundary of time of wagons stay at the first and last mile reproduces the nature of uncertainty at these stages of the transport process. Studies showed that time of wagons stay at stations is stochastic. Using the application of the Lebesgue-Stieltjes integral, which reproduces the stochastic nature of the process, we can determine possible time of finding of wagons at the first and last mile. That is, time is a variable value. We can control it based on the Lebesgue-Stieltjes integral. Thus, we obtain a model of stochastic programming.

The third summand of the objective function reflects expenses of railways on the route of wagons, depending on time of wagons for a route, presence of a locomotive, a type of traction, capacity of stations and points along a direction and a type of connection.

The fourth summand corresponds to possibility of freight transportation in own or foreign wagons in formula (3). So, it is necessary to take into consideration expenses for the need to return own empty wagons to a station of registry or a foreign wagon to an interstate station. There is no need to calculate such costs at transportation of freight using wagons, which belong to the railway.

The last component of the objective function reflects possible financial losses of the railway in case of the effect of the first and last mile in the form of a fine for delayed delivery of freight. Rejections of terms of delivery of freight arise frequently at transportation export freight along a direction to a port. The reason for non-compliance with the delivery deadline may be a delay from a departure station to t_1 near-port station, a delay at the first at the last mile t_2, as well as both delays at the same time. Let us consider a risk of fines for the railway at freight transportation along a direction to the port in more detail.

The time of passage of wagons from an initial station to a port station, as well as the time spent by local wagons on the first and last mile are subject to normal distribution. There is also a correlation dependence between these values, as evidenced by the value of the linear correlation coefficient ρ=+0.2429. The correlation dependence of these two values exists due to the fact that port stations operate under high loading conditions most of the time, which causes trains' delays both in approach to a station and during delays at the first and last mile.

The presence of a positive correlation between these two values gives grounds for consideration of them within a single probabilistic field. It is advisable to construct a linear regression model in the form of a bivariational normal distribution law. The approach will provide an opportunity to determine more accurately probability of untimely arrival of wagons to a port and, accordingly, a value of the financial risk associated with possibility of financial losses of the railway in case of a fine.

Accordingly, the probability of realization of the risk does not depend on possible ranges, within the limits of which values of the data on probability variables fall, but on a value that can make up their amount. In this case, it is necessary to calculate a volume of a figure, which is a part of a dome-shaped Gaussian surface, to determine the probability. It is a density function of given bivariational normal distribution law [14]. However, to determine the probability in this case, it is necessary to calculate a volume of a figure, which has a base of a part of this figure cut off by a plane at a certain angle and not a rectangle with sides parallel to the coordinate axes. Thus, we record write the formula using the logical expression in the indicator function and using the Iverson's notation:

$$q=\int_0^\infty\int_0^\infty [t_1+t_2>t_r]\cdot f(t_1,t_2)\,\mathrm{d}t_1\mathrm{d}t_2, \quad (5)$$

where $f(t_1, t_2)$ is the density function of a bivariate normal distribution law; t_r is the term of realization of risk connected with t_n normative term of arrival of wagons by the following ratio: $t_r = t_n + 2$, days. The realization of risk, that is, the calculation of fines for delayed delivery, begins from 2 days of exceeding the standard time of delivery of freight [15].

We choose the normative term of delivery of freight to the port as 8 days for the calculation. Then, the term of the realization of risk is equal to 10 days. Fig. 1 is a graphical representation of the modeling of the probability of risk implementation. We built it based on the statistical data.

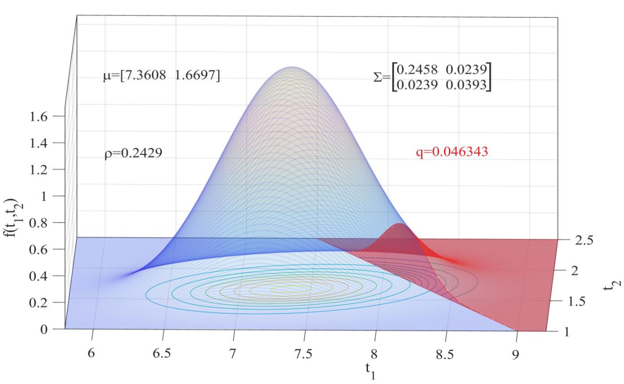

Fig. 1. Graphical scheme of the modeling of the probability of risk implementation based on bivariate normal distribution law

Thus, the risk function with the use of an expanded recording of the density function of a bivariate normal distribution law takes the following form

$$R(t_1,t_2)=\left(\bar{c}\cdot\bar{f}\right)\int_0^\infty\int_0^\infty\left([t_1+t_2>t_r]\frac{1}{2\pi\sigma_{t_1}\sigma_{t_2}\sqrt{1-\rho^2}}e^{-\frac{1}{2(1-\rho^2)}\left(\left(\frac{t_1-\mu_{t1}}{\sigma_{t1}}\right)^2-2\rho\left(\frac{t_1-\mu_{t1}}{\sigma_{t1}}\right)\left(\frac{t_2-\mu_{t2}}{\sigma_{t2}}\right)+\left(\frac{t_2-\mu_{t2}}{\sigma_{t2}}\right)^2\right)}\mathrm{d}t_1\mathrm{d}t_2\right), \quad (6)$$

where c is the average transportation fee for one wagon in a given train, UAH/wag.; f is the average proportion of the fine in relation to a transportation fee on this direction determined based on statistical data; μ_{t1}, σ_{t1}, μ_{t2}, σ_{t2} is the mathematical expectation and an average square deviation of t_1 and t_2 probability variables, respectively.

The presented technology of transportation is subject to optimization on a given direction with mandatory consideration of the following technological constraints:

$$\begin{cases} 1\le N_a\le\dfrac{a_y}{q_s} & \text{– arrival of the required number of wagons} \\ \text{to the loading points;} & \\ t_1+t_2\le T_d & \text{– fulfilment of the term to deliver a cargo;} \\ N_{j\,\mathrm{tr}}\le N_s & \text{– length of the freight train should} \\ \text{not exceed the length of the receiving – dispatching stations;} & \\ \sum\limits_s\sum\limits_d \Pi_{av}^{\mathrm{st/p}}\ge \Pi & \text{– a possibility for a train} \\ \text{to pass in a certain direction;} & \\ Q_{es\,l}\ge Q_{gr\,\mathrm{tr}} & \text{– capability of the locomotive} \\ \text{to carry the assigned train's mass;} & \\ t_{st}\le t_{rat} & \text{– the period the trains are at stations should} \\ \text{not exceed the normative time,} & \end{cases} \quad (7)$$

where a_y is the amount of freight at the loading point y, t; q_s is the average static loading of a wagon, t/wag.; T_d is the term of delivery of freight, day; $N_{j\,tr}$ is the length of the j-th train, wag.; N_s is the length of receiving and sending tracks on the s-th station, wag.; $P_{av}^{st/p}$ is the available capacity of s stations and d points in trains, respectively; Π is the number of trains involved in distribution of wagons by directions; $Q_{es\,l}$ is the estimated force of traction of a given locomotive, t; $Q_{gr\,tr}$ is the gross mass of a train, t; t_{rat} is the rated time of stay of local wagons at a station, h.

4. 3. Modeling of the technology to control the process of freight transportation

We developed software in the Matlab programming environment to solve the problem of optimal management of the transportation process based on the proposed mathematical model of the process of freight wagons movement. The total expenses for transportation, C, USD, depend on N number of carriages and t total time of wagons stay at the first and last t, h. Fig. 2 shows graphic interpretation of the simulation result

The presence of a minimum of objective function achieved at values of arguments within acceptable limits (Fig. 2) indicates a possibility to form an optimal control over parameters of transportation. Thus, the developed model is universal and it gives possibility to manage the transport process with the least operational costs of the railway in the presence of feedback. In addition, the model takes into consideration expenses associated with risks of freight transportation. Possible expenses associated with these risks make up several tens of percent of the full value of the cost. And even taking into consideration these expenses, the proposed technology of optimal transportation management reduces operating costs by approximately 10 % compared to the costs calculated by the existing Ukrzaliznytsya methodology for determination of the actual cost of freight transportation in the base period, which is shown in [16]. Such indicator depicts the economic feasibility of introduction of the proposed technology. We can achieve the best result under non-discriminatory access to the railroad infrastructure of all participants of transportation and provision of a "hard" thread schedule.

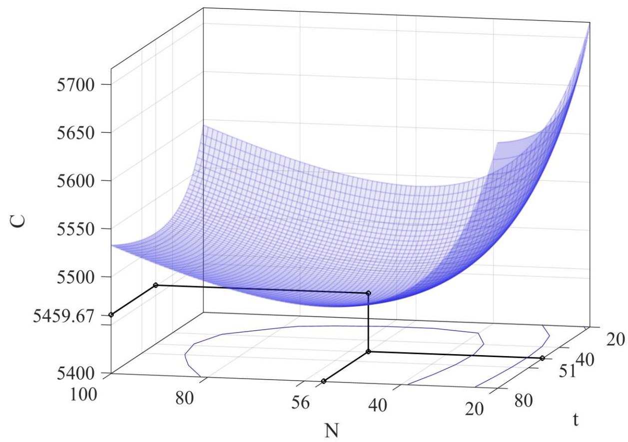

Fig. 2. Graphic interpretation of simulation results

The formed mathematical model takes into consideration the full cycle of the operation of a freight wagon taking into consideration the effect of the first and last mile. At the same time, it takes into consideration possible risks of charging fines for rail in case of a failure of freight and traction units and loading on the infrastructure.

The optimization model is the basis for formation of automated freight transportation management technology. We propose to implement it as a decision support system (DSS) for the dispatcher staff. We propose to integrate DSS into the automated workplace of the united controller (AWP UC) along a direction that is connected to the unified automated system of transportation control of Ukrzaliznytsya. In this case, the transport process is displayed in real time mode. Fig. 3 presents the improved structure of the automated DSS dispatcher, taking into consideration the effect of the first and last mile, probability of obtaining a financial risk and the result of modeling along a direction.

The current automated technology of the transport process control provides information and technological support to a dispatcher for rational formation of wagon traffic with reducing of expenses of railroad for transportation of freight.

5. Discussion of results of studying the technological process of freight transportation

Creation of the traffic management technology was possible due to the presence of the minimum of a objective function, which, in turn, is due to the existence of a set of competing factors that correspond to different groups of expenses. The application of the Lebesgue-Stieltjes integral and the bivariate normal distribution law gave us possibility to consider occurrence of delays that apply to all stages of the transport process within a single probability field of the probability. This made possible to calculate a value of risk more accurately.

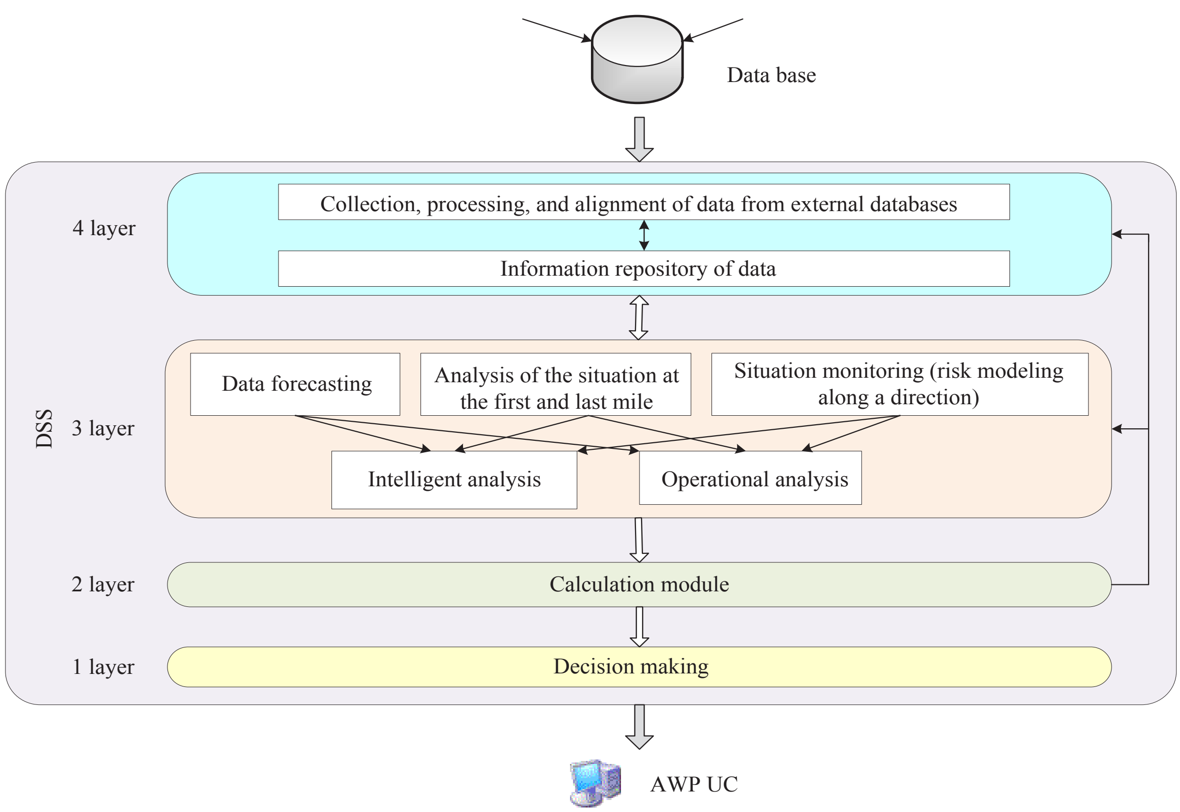

Fig. 3. Improved structure of the decision support system implemented at the automated workplace of the dispatcher along a direction

The positive difference between these studies is taking into consideration of risks, due to construction of the delay model based on the effect of the first and last mile. The proposed technology will make it possible to reduce idle time of wagons at stations and to satisfy the demand for transportation along a direction fully without additional capital expenditures on increasing of the capacity and expansion of rolling stock. However, there is a need for updated data on operation schedules of adjacent transport companies such as ports and customs to maximize the efficiency of application of the technology. The focus of the study is on export transportation of freight, but it is expedient to increase the proportion of statistics that correspond to other types of traffic for greater universality of the model.

The basis of the proposed model was data corresponding to shippers, who carry out mass transit transportation. For further research, it would be advisable to include data of shippers who carry out regular wagon shipments. For further development and increasing of accuracy of the model, there is a need for sufficient amounts of relevant data. However, the obstacle to obtaining of them is a high level of closure of the results of operating activities of enterprises and a lack of transparency in their management mechanisms.

6. Conclusions

1. We investigated the technological parameters, which affect the process of freight delivery. We found that both the number of trains delayed and the delay time caused by idle time of trains at the final stage of transportation increase considerably in the case of loaded transportation direction. The data obtained confirm the existence of the effect of the first and last mile.

2. We formalized the technological process of transa portation of cargo along a direction in the form of an optimization mathematical model of the process of movement of freight wagons for more precise organization of the transport process. The objective function of the model represents total operation costs. Its base is the use of the Lebesgue-Stieltjes integral taking into consideration the effect of the first and last mile. The formed mathematical model takes into consideration possible risks arising during operation of wagons also.

3. The results of modeling proved that there is an extremum of the objective function of the minimum type, which gives possibility to form a procedure for optimal control of transportation parameters. The proposed technology of optimal transportation management reduces operating costs by approximately 10 % compared with the costs calculated using the existing methodology for determination of the actual cost of freight traffic. The technology will provide opportunity to organize wagon traffic with minimal operation costs taking into consideration financial risks associated with possible delays in transportation through large areas of major directions in real time.

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UDC 330.322:658

DOI: 10.15587/1729-4061.2019.155779

AN ALGORITHM OF SELECTING THE PRICING MODEL FOR A CONSTRUCTION CONTRACT

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Розроблено алгоритм вибору цінової моделі контракту на будівництво. Це важливо, тому що ціна є одним з ключових параметрів контракту. Саме цей параметр визначає, яка частина створюваної в рамках контракту цінності у грошовій формі дістається підряднику (виконавцю, постачальнику), а яка залишається замовникові. В результаті дослідження встановлено, що контрактними драйверами ціноутворення виступають початкова ціна, контроль, стимули (моральний ризик) і фінальна ціна. Така трактовка збігається з основами Теорії контрактів і є передумовою фундаментальної достовірності розробленої системи. Базовими вхідними компонентами алгоритму прийняття рішення щодо найбільш доцільної цінової стратегії є матриця властивостей моделей ціни контракту і метрика питань з оцінювання відповідних пріоритетів Замовника по проекту. Система дозволяє обрати одну з п'яти ключових стратегій ціни: CRC, MC, TC, LS або GMP, які застосовуються міжнародною практикою. Використання системи вибору цінової моделі контракту спільно з системою обрання організаційного профілю виконання проекту дає можливість обрати найбільш доцільну стратегію з 130-ти парних альтернатив. Пропонований підхід кумулятивним чином сприяє успіху будівельних проектів і має уніфікований характер. Формалізований інструментарій порівняльного аналізу альтернатив є цифровим змістом Системи вибору цінової стратегії COMP (Contract Organizational Mechanisms: Pricing). Алгоритм побудований на розрахунку векторів пріоритетів факторів ціноутворення по проекту (на основі визначених множин рангів і рейтингів) з подальшою бальною оцінкою доцільності застосування у проекті кожної з альтернативних моделей ціни. Апробація системи COMP у проекті будівництва Льодової арени в м. Києві показала, що створена концептуальна модель (пропонований алгоритм) дозволяє дійти доцільного рішення щодо цінової стратегії контракту з математичною, високою теоретичною і практичною аргументованістю

Ключові слова: теорія контрактів, багатокритеріальний аналіз, цінові механізми, прийняття стратегічних рішень

1. Introduction

In capital construction, procurement can be considered as the backbone of the entire management structure [1]. In keeping with this figurative terminology, the decision to apply a particular price mechanism (payment profile) is its main vertebra.

Price is one of the key parameters of a contract. It is this parameter that determines what part of the value created by the contract in the form of money is due to the contractor (performer, supplier) and what remains to the client. Construction contracts deal with creating significant (capital) values, and therefore, pricing issues in this area are of particular importance. Acknowledging this challenge, international practice has created a range of pricing models for a construction contract, each of which has its advantages and disadvantages. As to the reverse side of this medal, in the framework of each capital construction project there is a problem of a reasonable choice of a price strategy.

The choice of a pricing structure for a construction contract is still based on acquired empirical experience, without the use of a systematic mathematically formalized procedure. Sometimes the choice is made intuitively and sometimes it is based on considering established traditions or business fashion. The solution to this problem used to be hampered by the lack of a recognized theory that would serve as the basis for creating an appropriate conceptual framework for making the appropriate decision. Fortunately, this hurdle is currently "officially" lifted – the founders of contract theory were awarded the Nobel Prize in 2016 [2]. Thus, now the peak of relevance is the task to develop a formalized apparatus (algorithm) for selecting a price model of a construction contract in the context of contract theory.

2. Literature review and problem statement

The subject of this study has three key projections that are disclosed in published sources, and one of them is the typology of contract price models with considering their characteristics. Capital construction projects are implemented using the following typical price mechanisms: