

Розглядаються взаємозалежні процеси перевезення вантажів на магістральній транспортній мережі. Сформульована задача розподілу наявних транспортних засобів. Вхідні потоки замовлень є стохастичними, однак не мають ознак найпростіших. На заданій території замовлення на міжміські перевезення виникають і повторюються з випадковою періодичністю впродовж фіксованого періоду. Кожне замовлення має часові вікна. Автотранспортні засоби одного перевізника розташовані на транспортній мережі у випадковому порядку, відповідно до останньої виконаної їздки. Для виконання замовлень автопоїзди приймають вантаж у пункті розміщення, або, при відсутності завантажень, переміщуються у найближчий транспортний пункт, де таке замовлення виникає. Проаналізована типова ситуація, коли, навіть при наявності достатньої кількості автомобілів, клієнтам відмовляють у перевезенні, або автомобілі змушені простоювати, чи здійснювати порожній пробіг.

Розроблено методику імітаційного моделювання. З допомогою генератора випадкових чисел отримується множина координат пунктів відправлення і доставки вантажів випадкових замовлень, та пунктів, де першочергово розташовані автомобілі, а також часові вікна, обсяги перевезення, періодичність замовлень. Обслуговування здійснюється за однією з трьох стратегій: без порожнього пробігу та з очікуванням, з порожнім пробігом, з повним прогнозом про майбутній процес. Обчислено кількість відмов внаслідок відсутності транспорту або його зайнятості. Оцінювались параметри за декілька циклів. Стратегія обслуговування замовлень реалізується на основі корегування рішень суб'єктів процесу перевезень при отриманні додаткової інформації про попередні ітерації. Рішення суб'єктів обмежені намірами перевізника. Методика застосована для дослідження діяльності транспортного підприємства на південно-східній території України при перевезенні сільськогосподарських вантажів у період жив. Виявлено, що показники обслуговування вхідного потоку мають коливний характер. Здійснено порівняння трьох стратегій. Виявлено переваги і недоліки застосування порожнього пробігу, очікування, прогнозування, розподілу автомобілів за обсягом наявних робіт

Ключові слова: імітаційне моделювання, потік замовлень, вантажні перевезення, магістральна мережа, агентний підхід

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DEVELOPMENT OF THE PROCEDURE FOR SIMULATION MODELING OF INTERRELATED TRANSPORT PROCESSES ON THE MAIN ROAD NETWORK

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1. Introduction

Because of socio-economic changes and under the influence of the phenomena of economy globalization, logistic chains (LC) of goods and raw materials supply at enterprises are changing. The chains become longer and more complex in structure. Under the influence of information technologies accompanying material and financial flows, the integration of separate supply chains, which are independent economic units, is intensified. It also expands the geography of movement of material flows, which is manifested, in particular, in the increasing cargo turnover in the international and intercity connection in road transport. All these trends amid increased competition among transportation companies (TC) force to look for new methods for the LC control, to develop cooperation in production activities and increase

the efficiency of using own fleets of automotive transport vehicles (ATV).

The most successful control of transport processes (TP) can be realized in establishing the patterns of emergence and transformation of material flows. The receipt of orders for cargo transportation, which are considered as sources of cargo flows, is a stochastic process. In most cases the execution of transport cycles in intercity combination also has stochastic content. That is why one of the most common methods for researching material flows in transport systems are the methods of queuing theory (QT). The processes of emergence and handling of the transportation orders, which have the properties of the simplest Poisson flows are well-studied. In practice, the assumption about the simplest flows is not true due to several reasons. Firstly, there is no condition of ordinariness of random events. The period of

the formation of transportation orders at most enterprises is one day. During this time, the carrier receives several orders at the same point of departure, which arrive simultaneously. Secondly, the arrival of vehicles at an unloading point is also a non-ordinary process as vehicles arrive from different routes and are unloaded mainly at different terminals. The intensity of emergence of orders, especially for the transportation of seasonal goods and agricultural raw materials and (products, timber, construction materials, etc.) varies throughout the planning period. That is why the stationarity for intercity transportation is not a characteristic feature.

The main feature of the modern organization of servicing enterprises by the carrier is that refusals appear in case of non-compliance with the service rendering terms or non-adhering to the guaranteed parameters of the process. In the wide scale of the country, such events result in inefficient use of rolling stock and to delays in intercity cargo delivery. It is known, in particular, that the average coefficient of release of the fleet of main road ARV is 0.62...0.66 [1], and the average speed of cargo delivery in the intercity communication, depending on the type of cargo, is 26...34 km/h. That is why refusals, on the one hand, may be caused by the carrier, which does not keep the delivery deadlines and quality of transportation. On the other hand, the carrier may refuse to execute the order through the lack of the practical benefits. Under conditions of tough competition of the TC, refusals are perceived by clients as a reason to cancel further cooperation with the carrier. Consequently, the number of obtained subsequent orders for transportation decreases. In fact, this means that the incoming flow according to the QT has the effect of post-action of random events. Due to such circumstances, it is impossible to use the QT as the only procedure for the analytical representation of a transport system (TS). In addition, the TS, which cover incoming flows of random orders and stochastic processes of their implementation are complex and do not have a suitable analytical apparatus to display them in dynamics. That is why the application of simulation modeling (SM) is relevant in this case.

2. Literature review and problem statement

At present, many specialized and universal software tools for the creation and implementation of TP simulation modeling are known. Rather full reviews and analysis of simulation modeling models were made in papers [2, 3]. A common disadvantage of all the analyzed methods is that any SM is inaccurate and it is difficult to establish the measure of this inaccuracy immediately, but it is possible only after a considerable number of simulation modeling cycles. In addition, actual TP are reproduced in the simulation modeling time according to the uniformly established rules. Implementation of the model does not take into consideration that at a certain stage, agents (the elements that create events) can obtain additional information to make a better decision. That is why all subsequent progress may be different.

Nevertheless, the SM is now the main set of the most suitable means to research TP. However, the changes at the market of transportation-forwarding services resulted in the fact that models use the agent-oriented approach [4]. Its essence is related to the fact that a set of agents, which are able to independently make decisions for solving the set task under conditions of staying in the environment, is determined. On the one hand, this expands the area of values to search

for the optimum variant of the LC structure, on the other hand, adds additional uncertainty to the model. This greatly complicates the use of the known optimization methods. The object of the study is characterized by a wide range of input arbitrary data and a whole range of criteria of quality of the final system. The environment, in which the object exists, is characterized by a high degree of uncertainty.

The stochastic nature of incoming flows (orders) brings significant difficulties to the optimization of the LC set. In particular, in study [5], it was accepted that incoming flows are independent. It is difficult to agree with this assumption, taking into consideration the integration processes existing in the field of cargo transportation. Availability of information flows, integration of TC leads to the fact that decision making in the queuing systems, to which transport and logistic service of cargo turnover of several adjacent regions belongs, is a complex problem with a high level of uncertainty. In papers [6, 7], the authors managed to solve partially the problem of uncertainty in the rules of processes simulation modeling by means of decomposition of a general problem into simpler ones, using information technologies, including the methods of parallel computations. However, it is known that the more input data are applied, the more accurate the SM is. The proposed procedures increase only computation efficiency, but are limited to the array of input data.

Quite often the problems of the TP organization are of exponential complexity. An increase in the size of the source data (number of transport points, routes, vehicles, etc.) per unit leads to an e -multiple increase in the time required for the search for an optimum; doubling the data size squares the necessary time. Article [8] shows examples of these problems, but the dimensionality problem was not solved.

Different classes of deterministic models of the environment are used to solve this problem. Within each class, the incoming flow of orders can be described parametrically. The properties of repeatability and stochasticity are characteristic of most random flows that are found in nature and in the technical activity of humans. Using an approach that is based on periodic correlated random processes to analysis and simulation modeling of the incoming stochastic flows makes it possible to describe the TS properties that cause them. At the same time, regular, deterministic laws, as well as accidental interferences and disturbances that can carry both useful and parasitic information about the system are taken into account [9]. Periodic flows deserve a great deal of attention in solving the problem of simulation modeling of the QT of this class. Their main advantage is that stochastic periods that are reproduced with certain tact are sources of information to correct the rules of the subsequent simulation modeling steps. However, the theory of stochastic periodic flows has been little developed so far. Therefore, it is first necessary to detect the influence of the parameters of periodic flow on the TP process.

The importance of SM at solving a wide range of transport problems, as well as the historical development of simulation modeling methods, was emphasized in article [10]. The obvious advantages of these methods were indicated. However, the authors overlook the known shortcomings, in particular, inaccuracy of representation of the research object. The article does not present exact results, which would give grounds to the successful application of simulation modeling. Specifically, there is no solution to the problem of loading the service system at the stochastic input flow

in orders under conditions of an increase in the number of subjects of the market of services.

SM is most often used in the study of multimodal TC. Significant results of simulation modeling can be noted in the area of multimodal transportations, showing the interaction of vehicles in the network nodes [11, 12]. In particular, paper [12] provides an overview of the methods for simulating material flows in logistics systems. The QT methods and the Petri networks are considered most significant. The authors of article [11] emphasize that the most essential disadvantage of both methodologies is the lack of description in the explicit form of behavior, namely, the dynamics of a change of the TP states. The performed analysis of the methods gave grounds to argue that they must be chosen flexibly, taking into consideration the properties of a particular logistic system.

Modern methods for solving the problems of simulation modeling are substantially facilitated by the application of universal computer programs. The known packages of simulation modeling include Simulink (The MathWorks, USA), VisSim (PTV Planung Transport Verkehr AG, Germany), Model Vision (MicroSoft Corporation), IBM Statemate HyTech (IBM Corporation), AnyLogic (The AnyLogic Company, Russia). However, it is necessary to create specialized procedures and functions for deeper analysis. For example, in the presented results, the universal Python programming language was used in order to create new software products. Specialized algorithms and software were used in paper [5]. The time of turning the modeled system to compliance with the set change-daily task was selected as the criterion of successful operation of algorithms in research [4, 5]. Based on the developed SM, the experiments on a few simple simulated test structures of the LC were carried out. Simulation modeling experiments revealed the efficiency of the developed algorithms in their application to dispatching. However, despite its flexibility, the applied algorithm based on the used scenarios for converting material flows cannot solve the problem of the efficient use of the information that is already available or to apply prediction based on a priori information. That is why it is not suitable to achieve the set goal.

SM turned out to be a valuable method for experimenting and studying scenarios in different spheres of development of the strategy and tactics of the carrier. Paper [13] outlines the use of SM in the analysis of the TC strategies in the transportation market. Unfortunately, SM is not widely used for strategic planning in transportation. Because of this, it is difficult to verify the adequacy of their results. The reason for this is the lack of effective techniques that cannot only minimize the risk of the carrier, but also analyze and process incoming information displayed from the order flow.

Analysis of the advantages and disadvantages of the existing methods of TP simulation modeling is shown in article [14]. The presented results prove that the combination of SM and mathematical programming in one research process is especially effective. However, the main purpose of the presented results was to substantiate scientifically the methods, models and tools of the TP management informatization. Very little attention in the article was paid to the study of the incoming flows and the choice of strategy and methods for the TP control.

To research freight traffic, scientific institutions widely use SM, and in recent years – micro simulation [15]. Scientists assume that the volume of goods transportation will subsequently grow. Micro simulation modeling of cargo ac-

tivity of the TC is called the only way when it is possible to display the increasing demand for transportation in a wide scale. Activity-based approaches imply place, time, duration, way and route of transportation and other characteristics. Usually, an expert on the micro simulation modeling of the transport process creates the foundation for the development of more behavioral-realistic and reliable model for freight demand, capable to analyze various TC policies. The main motivation of the study was to choose the behavior of freight transportation companies in the U.S.A., that is why the nationwide micro simulation modeling was carried out. The main disadvantage of this kind of research is their aggregate character, which prevents the development of micro simulation modeling based on an individual agent. This is a key drawback, which seriously challenged the practicality of models in modern freight markets, where growing globalization increasingly encourages the companies to apply the LC management concepts. This study developed a large-scale behavioral structure called FAME. It was not taken into consideration that the use of new principles for processing the input flows and input information, based on the well-known regularities gives a significantly higher effect than the justification of the decision on the choice of the LC configuration.

A characteristic feature of long-distance and international road freight transportation is a long run of the ATV on the routes. To improve the effectiveness of this type of transportation, it is necessary to pay special attention to the process of search and selection of return loads. The task of selecting cargoes in the passing or reverse directions is partially resolved, which is due to the development of transport and information portals on the Internet. However, the problem of choosing a rational transportation variant from the set of alternative loads remains relevant. The decision on receiving a certain cargo for transportation is now taken by managers of carriers based on intuitive decisions, based on personal practical experience. As a rule, such strategies of making decisions on the choice of rational return transportation are reduced to the fact that a vehicle carries that load and the waiting time is minimal. Article [16] offers new strategies of making decision on the choice of the rational return run based on processing statistical information. However, statistical modeling was chosen as the technique, which enabled the author to adopt one of the alternative strategies of the construction of a transport cycle. This is a non-detailed technique that does not make it possible to develop a flexible strategy under conditions where there is an opportunity to use accessible information.

The proposed method for assessing the demand for freight transportation-forwarding services is presented in article [17]. This method makes it possible to determine the order flow parameters as random variable characteristics of the incoming flow. The possibility to estimate the intensity flow and the law of orders distribution around geographic regions based on generally acceptable data was also obtained. The numerical parameters, obtained in this study, can be used as a basis for modeling the orders flow in solving problems of enhancing the efficiency of freight forwarding services. However, the proposed studies do not reveal the reasons for low efficiency of the operation of the ATV fleet of one carrier. There is no display of temporal tolerances for order execution. It is impossible to reflect the interaction of separate vehicles in the proposed technique, which is, in fact, an important resource for improving their use.

The issue of the interaction between the ATV fleet was partially revealed in publication [1]. The authors consider the organization of execution of random orders. One of the reasons for the wide popularity of using such form of conclusion of contracts as a “single order” by cargo owners is powerful development of information technologies that caused the emergence and successful functioning of specialized logistic sites. The applicant applies the QT to plan the totality of such orders and SM to verify them. However, the author’s assumptions about the simplest flow of such orders seem doubtful, especially when it comes to specialized cargoes, servicing a small region, or the use of a small ATV fleet. In addition, it was not taken into consideration that the orders have permissible deadlines, so-called time windows, within which they can be executed, otherwise the order is transferred to a competitor. As a result, three strategies of the carrier’s operation are proposed in the work. Nevertheless, it is not considered that the cargo transportation market can have a situational prevalence of the offer over the demand, or vice versa.

The practice of analytic and SM of complex systems, including the LC, were considered in detail in paper [18]. It is emphasized that the presented data and conducted research are most widely used in researching the TS. However, the main approach to modeling is object-oriented. The disadvantage of it is the lack of the possibility of self-development of the used objects, because the set of the used methods is limited. Thus, SM itself quickly becomes obsolete at an increase in the requirements for it. At present, the object-oriented approach is inferior to the agent approach.

Simulation modeling of the processes of physical transition in time and space of different kinds of material objects belongs to “classic” discrete event simulation modeling, as was done in the article [19]. The purpose of this work is to present the individual experience in constructing conceptual logistic systems models. The collective ideas about the shares of some well-known scientific and engineering ideas regarding actual LC were verified and stated. However, it is impossible to agree that only professional institutions with profound knowledge of the relevant methods should be engaged in the creation of SM. After all, under conditions when it is possible to explore the general regularities of incoming flows, the expertise in the physical essence of the processes is more necessary than in the methods of processing the input information. Thus, specifically, the scientists discovered the potential of stochastic periodic (cyclic) processes, based on the experience and observation of actual processes of similar phenomena [20]. The main advantage of cyclic systems is the possibility of their development and self-development, adaptation based on the obtained information, which is also periodic in nature. To automate and simplify the analysis of processes with a variable period, as well as to increase the level of objectivity and reliability of analysis of such processes, it is important to have high information technologies. Coincidence of circumstances and the possibility of using this information in incoming flows of cargo orders open up the means to achieve the higher level of efficiency while handling a stochastic flow of orders.

If the most effective states of the control object (the carrier’s fleet) is known based on the cyclic flow of the process of the past, the apparatus of the death and reproduction theory can be applied to them with high efficiency [22].

However, such reasonable approaches in the field of TP have not been used so far.

In article [13], it is proposed to separate the following groups of elements in order to consider the model of the forwarding services market as a logistic problem of cargo delivery: cargo owners, carriers, cargo terminals (3PL-operators) and freight forwarders (4PL-operators). The proposed division brings more certainty in the study of incoming flows. However, in terms of integration of the objects of this market, this division is quite conditional, because logistic functions of enterprises were not distributed. The results of the research conducted by the author make it possible to argue that the interval of arrival of orders for service of cargo owners is distributed exponentially. The volume of the cargo batch and the delivery distance are distributed according to the gamma-law, if the forwarder serves more than 8 clients. In this case, the distribution of outgoing flows of orders of cargo owners is unknown. Under conditions of cooperation of cargo owners (dependence of incoming flows), these studies partially lose sense.

The review of the research presented in article [22] revealed the characteristics of the choice of the transportation mode made by cargo shippers and carriers with the introduction of a new system of cargo transportation. Using individual behavioral patterns, the authors established that they the SM, classified by delivery distances and other parameters, have statistical significance. However, given that the duration of the ATV run used in SM is a posteriori random magnitude, further studies are required to apply a new value of travel time, which will reflect a priori characteristics of the new TC in the future. A significant drawback of the approach applied in the paper is that the models of behavior are, most often, non-objective and do not reflect the interests of most TP participants.

The study of the flows in their general form is predominantly theoretical in nature. In applied research, the attention of specialists is attracted to separate classes of the flows, which are given certain features. Among such classes, the simplest, that is, those that meet the conditions of stationarity, ordinarity, and absence of the after-effect, are most studied [5]. The model of the simplest flow is a stationary Poisson process (flow). Analytical and statistical methods of their research were developed based on this model. However, as practice shows, the above conditions are met not for flows, that is, not all flows can be reduced to stationary [23]. It is easy to give examples when one or even two of these conditions are not met. An overview of literary sources shows that unlike Poisson stationary flows, most of the problems of studying periodic flows remain unresolved, and this is especially true for the estimation of flow intensity. To detect the patterns of the formation of the flows of orders for long distance transportation and their service, the known SM methods are not sufficiently effective. The agent approaches that are promising at this stage of research development can be used to display the transport processes in the network, since in this way it is possible to simulate their interdependence.

3. The aim and objectives of the study

The aim of this study is to determine the dependence of parameters of using the fleet of main road motor-vehicle trains on the parameters of incoming flows and the method for their reproduction.

To achieve the aim, the following tasks were set:

- to develop a totality of rules, by which the same carrier uses its resources to service a priori known set of orders, which are generated randomly;
- to create the simulation modeling algorithm;
- to explore the influence of different ways of generation of incoming flow for the operation of the ATV fleet of one carrier and prove the adequacy of the simulation modeling model;
- to justify the criteria for assessing the effectiveness of the operation of a carrier and to find the dependences of a numerical value of criteria on the parameters of incoming flows.

4. Rules of orders servicing by a carrier

The abstraction of the carrier’s activities from the influence of the competitive environment was applied. It was assumed that the object of the model, that is one carrier, has the exclusive right to choose orders, among those that were received in the assigned period, if they are sufficient. The refusal is received by a cargo owner only when all of the ATV have already been assigned to such transport tasks, for which the number of cargo runs, the average duration of one of the cargo run is greater. In this case, the operational indicators of the ATV fleet will be better. It was also taken into consideration that the individual intercity cargo transportations require the time exceeding the duration of a driver/crew shift of one motor-vehicle train. Then the accepted order reduces the number of available ATV for the next modeling cycle (planned period). Thus, the model circuit is: one carrier – several customers. The maximum number of customers is limited. Hence, the number of cyclic temporal series of incoming flows corresponds to this number.

Cargo transportations can be multi-cycle, that is, those that need several runs. They can be performed for several changes one by one by a single ATV, or simultaneously by some free ATV.

The model of transportation cycles with discrete time was applied. The smallest indivisible duration of a cycle is one working day. The ATV are loaded without a perspective plan for subsequent periods. The same ATV cannot be used to perform two different orders at the same time, even if they can be performed in one shift according to duration.

5. Algorithm of SM of incoming flows of orders for cargo transportation

The algorithm is cyclic. It consists of 16 steps that are repeated during $j=0, \dots, M_{\max}$ cycles.

Step 1. Start of the algorithm.

Step 2. The source data are entered from the external files:

1) parameters of the transport network (TN) with node points and distances between them, which are displayed in the form of the square matrix of temporal relations $|A_{yw}|$ of the size of $q \times q$, $y=1, \dots, q$ is the designation of the transport point-load shipper, $w=1, \dots, q$ are the designations of the transport point, cargo consumer. Each element a_{yw} of the matrix is the average time of the run of ATV between any two points y, w of the TN. Cargoes are loaded and shipped at point y , unloaded at point w . Since the network is represent-

ed by a strongly related graph, this time can be calculated between its any two points using the intermediate points. Matrix $|A_{yw}|$ is symmetric relative to the main diagonal, that is, for y, w : $a_{yw}=a_{wy}$ is true. Magnitudes a_{yw} for transport cycles of vehicles are known and constant. Similar characteristics of the TN are represented, specifically, in article [23];

2) maximum number of orders P_{\max} , which can occur at one point (magnitude that limits the size of matrices of source data); maximum number of orders Z_{\max} , which occur in the network in one simulation modeling cycle;

3) general number of automobile fleet, N_{\max} of motor-vehicle trains of one type, which at the initial step of SM are randomly located in the TN;

4) maximum duration of shift T_{\max} according to the requirements for the mode of drivers’ work and rest.

Step 3. Simulation modeling cycle $j=0$. Initialization of original values of variables, including quality indicators of the TP. The parameters are calculated for the total number of cycles M_{\max} , and their initialization is performed one time during the performance of the simulation modeling algorithm:

- $Z_{r\Sigma}$ is the number of refusals to execute the orders;
- Z_{Σ} is the number of actual orders that were received;
- T_{um} is the duration of useless mileage.
- ZW_{zj} is the “time window” of the z -th order, that is, the order number, that is the number of cycles beginning with the zero, until the execution of an order can be delayed;
- τ_z is the periodicity (tact), at which the z -th order appears, beginning with the zero step of SM; random magnitude, is measured by the number of cycles, in the general case, it is determined by permissible interval of values:

$$1 \leq \tau_z \leq \tau_{z\max}, \tau_z \geq ZW_z, \tag{1}$$

where $\tau_{z\max}=M_{\max}$ simulation modeling time is integer. Time of SM is measured by the number of cycles, physical magnitudes of which depend on the period of planning the orders of TC. As a rule, the time of formation of the transportation time at enterprises is one day.

The parameters that are initialized in each cycle:

- K_{2zj} is the number of runs during the execution of the z -th order which are in fact accepted for execution;
- F_{zj} is the integer variable, $F_{zj}=0$, if the z -th order was not accepted to be executed by any vehicle; $F_{zj}=1, \dots, K_{1z}$ is the order is accepted to be executed $K_{2zj} < K_{1z}$ times (cycles).

Step 4. Orders for cargo transportation are set as the coordinates of the starting and finishing points. Using a random number generator, the following magnitudes, which characterize random orders and the ability to execute them, are established:

- Y_{zj} is the vector of initial coordinates of the points, where the execution of each order $z=1, \dots, Z_{\max}$ (cargo shipment points) must start;
- W_{zj} is the vector of final points, where the execution of each z -th order must finish (cargo destination points);
- K_{1z} is the number of runs, which are necessary to execute the z -th order (cargo volume); the order that consists of some runs, that is $K_{1z} > 1$, can be executed simultaneously with the involvement of some ATV or sequentially by one or some ATV. In this case the duration of execution of all cargo runs should not exceed time window ZW_{zj} of the given order.

Assigning numeric values to separate random magnitudes is conditional. For example, numerical values $y_{zj}=w_{zj}$

are not permissible. In addition, the following conditions must be satisfied:

$$\text{if } Y_{zj} = 0, \text{ then } ZW_z = 0, \text{ and } K_{1z}. \quad (2)$$

Step 5. For each point, it is necessary to sort out existing and permissible orders by two features:

- a) duration of execution (the longer ones are preferred);
- b) the number of cargo runs (the greater number is preferred).

Such features of sorting are selected from the fact that modern carriers face considerable competition. In its activity, TC prefer sustainable long-term relations with customers to single orders [1]. Although, in the presence of sufficient information on the Internet, single orders have lately also occupied a considerable market segment. Because of this, executions of orders with multiple runs that are longer, as well as those that have constant routes are the desired strategy of most large and medium-sized carriers.

Step 6. For each transport point q , to form the set of orders Z_q and ready to use motor vehicles N_q , which are placed in it, as well as the ratio of the number of automobiles and orders. To perform the account of the ATV that are available to execute orders and free at these points. This procedure is performed as follows. In the zero cycle, the set of ready ATV must meet the condition:

$$Y_{z0} = X_{i0}. \quad (3)$$

For cycles $j=1, \dots, M_{\max}$, the readiness of the i -th ATV is checked under the terms that

$$X_{ij+1} = W_{zj}, \quad (4)$$

$$X_{i1} \neq 0. \quad (5)$$

To determine the ratio of these numbers. The number of orders that can be accepted for execution in the j -th cycle of SM will be determined from ratio:

$$Z_{ajj} = \min \left\{ Z_q, N_q \right\}. \quad (6)$$

If at point q the number of automobiles N_q is smaller than the number of orders Z_q , the available vehicles are assigned to perform available orders. The number of working shifts K_{dzj} , which are necessary to use in order to execute the z -th order, are determined:

$$K_{dzj} = \left\lceil K_{1z} \cdot \frac{a_{yw}}{T_{wh}} \right\rceil, \quad (7)$$

where square brackets mean rounding towards larger part; a_{yw} is the duration of cargo delivery from point y to point w ; T_{wh} is the shift duration working hours, which were accepted as 9, or maximum 10 hours.

Proceed to 7.

Step 7. Compare the number of orders that are placed at the q -th point with the number of vehicles available at this point and ready to use. Based on the comparison, the next step is selected. If there are more vehicles, then proceed to distribution procedure 12. If the number of vehicles is smaller, then proceed to the procedure of comparison of the number of runs.

Step 8. If the number of runs that is assigned randomly, $K_1 > 1$, proceed to compare the number of changes in step 9, otherwise proceed to step 10.

Step 9. Check if the number of shifts of order execution exceeds 1 cycle. If the order can be executed in one shift (the same is a cycle), the ATV is assigned at step 11. If the execution exceeds one cycle, the distribution of all free ATV is performed at step 12.

Step 10. Assign loading and unloading points for vehicles, that is:

$$X_{ij} := Y_{zj}, \quad X_{ij+1} := W_{zj}, \quad (8)$$

$$F_{zj} := 1, \quad (9)$$

for all i -th vehicles that are free in the TN and for all z orders that were not executed or accepted by this time.

The orders are selected from the sorted arrays. Condition (8) means that the i -th vehicle is assigned to execute the z -th order, while at the next $j+1$ -th simulation modeling step the i -th vehicle will receive the initial coordinate of the destination point in the form of the final coordinate of the point of the order which was executed. The logical variable F_{zj} acquires the value of the number of completed order-related runs, in this case $F_{zj}=1$.

Step 11. It is performed in the case where the number of orders exceeds the ATV, however it will take more than one run to execute some orders. The distribution of the vehicles differs from step 10 because the vehicles are distributed for K_1 cycles ahead. In this case, each distributed vehicle executes all the runs required sequentially by the z -th orders. That is why the ATV will be assigned for all these runs, using the expression:

$$X_{ij+K_{1z}} := W_{zj+K_{1z}}. \quad (10)$$

Expression (10) means that the vehicle gets to the destination point at the end of each transport cycle, if all K_1 runs are completed. In this case the ATV moves along the pendulum route $Y-W$, staying at its final point at the end of the cycle.

Step 12. Distribution of vehicles at this step differs by the fact that all orders without exception are accepted. There is no priority for the ATV distribution.

Step 13. Regardless of the procedure of distribution of free ATV between available orders, the indicators of quality of order flow service is calculated: the number of refusals to execute order N_{Σ} , the number of executed orders N_{ord} , the duration of the service process T_{um} . After each distribution, the following simulation modeling indicators are determined:

- the number of new orders received within the cycle;
- the number of free vehicles at the beginning of the cycle;
- the orders that can be accepted to execution that are determined by the availability of free transport (if an order remained unaccepted at the given simulation modeling step, it can be completed at the next step if it is permissible by the time window);
- the number of involved vehicles that takes into account the number of vehicles distributed at the previous steps;
- the number of orders that are being performed at the given step taking into account their duration (the required number of shifts) of multiplicity of runs;

- the number of performed runs at the given simulation modeling step;
- the number of rejected orders;
- the duration of load runs, h;
- the downtime, h;
- idle run of vehicles taking into account the motion between neighboring transportation points, h.

Step 14. The initial and final points of the z -th order Y_{zj} , W_{zj} are generated randomly only in zero cycle of SM. It is assumed that the list of all possible orders is known a priori, but the time of its occurrence is a random, periodic magnitude. The size of time window ZW_{zj} is generated at j -th simulation modeling step, if $Y_{zj} \neq 0$. The periodicity of incoming orders is generated depending on the chosen simulation modeling tactics as a random or constant magnitude. The number of runs that form the execution

of order K_1 is generated randomly only at the first step of simulation modeling.

Step 15. Check if the maximum assigned number of simulation modeling cycles is reached. If the condition of the step is not met, start a new cycle. Otherwise, complete the algorithm.

Step 16. End of the algorithm.

The block diagram of the described algorithm is shown in Fig. 1.

To perform the algorithm, we developed software in the programming language Delphi 7.

The algorithm can be changed depending on the order service strategy applicable in a particular TN. That is why SM and the corresponding computer program include a number of rules that are used in converting initial values. 3 strategies were applied.

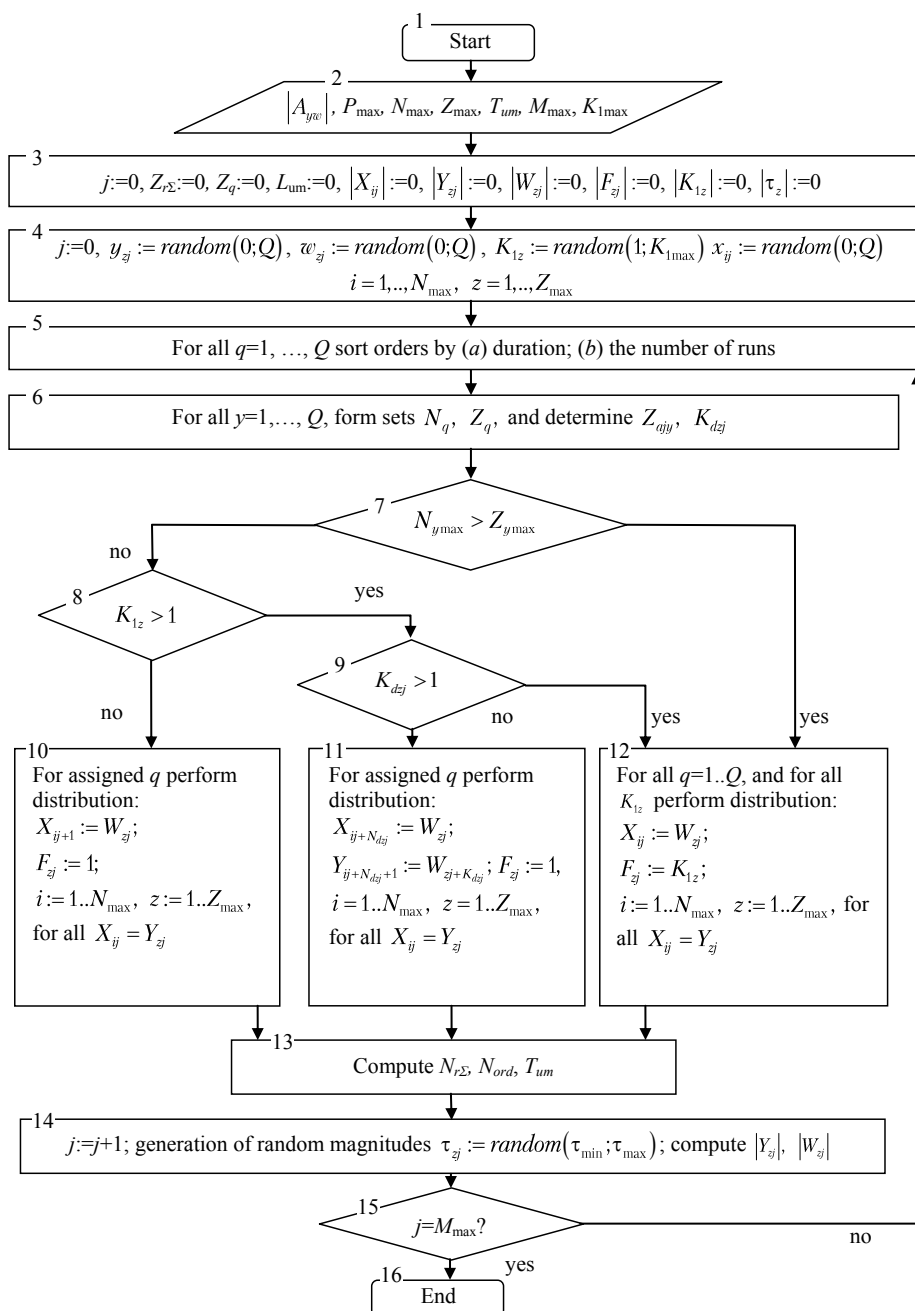


Fig. 1. Block-diagram of the simulation modeling algorithm at random periodicity of arrival of orders for cargo transportation

Strategy I. The algorithm of this strategy is shown completely in Fig. 1. The peculiarities of the strategy are the following. All available orders that are generated randomly at zero step and are repeated with random periodicity at the following steps are accepted for execution. Random order sequence is generated according to the following scheme. When the input data are initialized, the initial and final coordinates of all orders are equal to zero. At the zero step, random magnitudes are determined:

$$Y_{z0} = \text{random}(0; Y_{\max}),$$

$$W_{z0} = \text{random}(0; W_{\max}), \quad Y_{z0} \neq W_{z0}, \quad (11)$$

where Y_{\max} , W_{\max} are the boundary ordinal numbers of transport points in the explored transport network.

If it is established by expression (11) that $Y_{zj}=0$, or $W_{zj}=0$, it formally means that the z -th order is missing. If the z -th order does not appear within the following simulation modeling steps, the order exists during the time allowed by its time window ZW_{zj} , that is:

$$Y_{zj} = Y_{zj+\delta}, \quad \delta = 1, 2, \dots, ZW_{zj}. \quad (12)$$

If order z is completed or its time window (permissible time of execution) was over, the same order will be received by the carrier again through random period τ_{zj} and will have a random value of time window. The coordinates of the points of such orders will be equal to:

$$Y_{zj} = Y_{zj+\tau_{zj}}, \quad W_{zj} = W_{zj+\tau_{zj}}, \quad (13)$$

$$\tau_{zj} = \text{random}(\tau_{\min}; \tau_{\max}), \quad (14)$$

where τ_{\min} , τ_{\max} are the minimum and maximum values of periodicity of arrival of orders, which are restricted by magnitudes:

$$\tau_{\min} \geq ZW_{z,j}, \quad \tau_{\max} \leq M_{\max}, \quad (15)$$

where M_{\max} is the maximum number of simulation modeling cycles.

The number of simulation modeling steps is the constant magnitude.

Strategy II differs from strategy I by the fact that when there is no available order for a free vehicle at the Y_j -th point in the j -th cycle, the ATV does not remain at this point in the $j+1$ -th cycle. The ATV moves to the nearest transport point where there is an unexecuted order z , the time window of which is $ZW_{zj} > 1$. That is, in this variant the no-load run is permissible. The no-load run can compensate probable downtime of the ATV through the absence of orders.

Strategy III implies that the order is random in terms of content, volume (number of runs) and time windows. However, orders appear at approximately predicted moments of time (with accuracy of up to one cycle) through the predicted periodicity, that is $\tau_{zj} = \text{const}$. Periodicity of different orders is different. However, there are possible options when there are several groups of orders in the flow that have the same periodicity. The orders arising at different points are independent, not related by mutual time restrictions. Like in strategy II, the no-load run is allowed.

The SM algorithm for each of the three strategies consists of steps 1–15 until the assigned number of cycles is

achieved (Fig. 1). Each variant of the strategy differs from strategy I by the fact that the generation of new orders is carried out with the help of magnitude τ_z , which, depending on the chosen modeling strategy, can be random or constant. In addition, the difference between the algorithms is that at the beginning of each simulation modeling step the location of vehicles is no longer random, but depends on the pre-implemented distribution. All the other procedures and functions remain constant.

6. Verification of adequacy of the simulation model for incoming flows

SM is applied for the analysis of incoming flow of orders for the transportation of bulk cargoes by Ukrainian company-carrier, Ltd. "Trans-Service-1" on the territory of Ukraine. The cargoes transported by the enterprise include grain crops and wastes of their processing (cake, meal), construction materials, raw materials for metallurgical industry, industrial and household waste. For such transportation, the company uses freight road trains composed of the tractor car MAN with the platform for self-unloading+trailer-dump trailer. A volume of cargo in such a motor-vehicle train is 92 m³. The period of active use of dump trailer is May through September. The observation data regarding the transportation of bulk cargoes in the south-eastern and central regions of Ukraine during the harvest period were used. Transportation is performed from elevators to the port, between different elevators and processing enterprises. The TC has three anchor points in these regions: Haisyn, Dnipro, and Odesa. The data were collected for June–July of the current year 2019. The route map shows the main load-generating and load-absorbing points and the average time of movement between them (Fig. 2). The anchor points of the enterprise are marked on the scheme with black circles (there are three of them in scheme 3), all the transport points are numbered (there are 17 of them in the scheme).

The average time of travel was determined for the average summer intensity of transport flows in the period from 10 a.m. to 5 p.m. along existing highways of this region of Ukraine as of June–July 2019 using the Google Map router. Based on the distances between each two transport items, as well as when using Google Map, a matrix of duration of motion $A_{y,w}$ was constructed.

The size of car fleet that carries out the transportation of bulk cargoes on the territory is 28. All are serviceable, with the run from the start of operation of not more than 50 thousand km. The duration of vehicle loading and unloading per one cycle is 2.0 hours, taking into consideration the time of maneuvers. The working shift duration is 10 hours. A 2-month period of transportation execution, that is 60 simulation modeling cycles, was considered.

Orders for transportation arrive at the head office of the enterprise and form the incoming flow within one working day. Thereafter, the orders are distributed between free ATV. The average daily number of orders is 24. RMS is 6. Maximum number of orders per day is 30. At the enterprise, the orders are processed both by the logistics department and by the commercial-financial department. As a result, some orders are cut off as disadvantageous for TC or as those that cannot be performed. The results of simulation modeling of orders execution were presented with the assumption that all orders are financially beneficial for the enterprise.

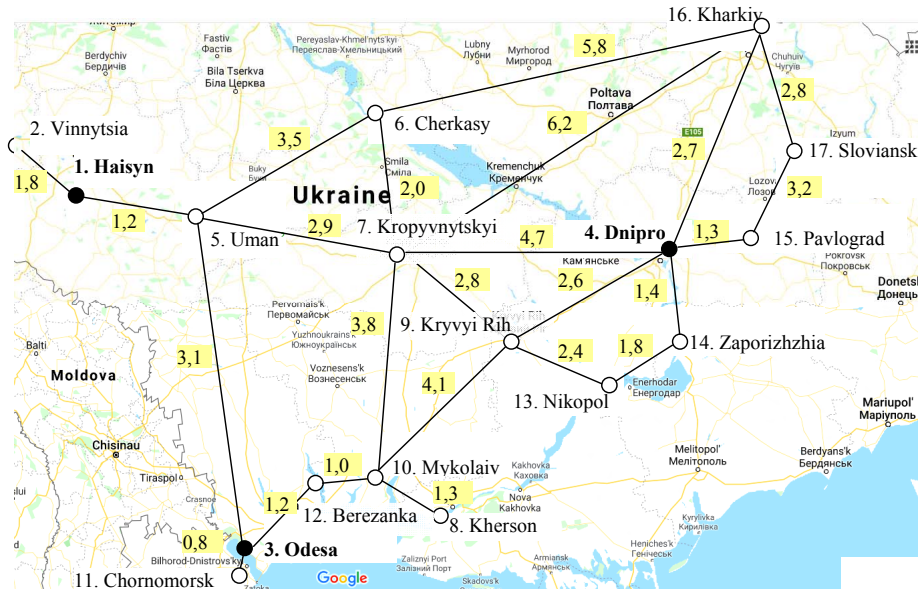


Fig. 2. The scheme of location of points of bulk cargo transportation by vehicles of the enterprise: average time of travel between assigned points, hours, is highlighted in yellow

As a result of simulation modeling, for example, the following incoming flow of orders was obtained by service strategy II:

Initial and final points of an order:

- order No. 8 start – 14 finish – 8
- order No. 9 start – 1 finish – 12
- order No. 10 start – 7 finish – 10
- order No. 11 start – 1 finish – 2
- order No. 12 start – 6 finish – 13
- order No. 13 start – 11 finish – 13
- order No. 14 start – 4 finish – 8
- order No. 15 start – 12 finish – 6
- order No. 1 start – 5 finish – 3
- order No. 2 start – 3 finish – 16
- order No. 3 start – 3 finish – 16
- order No. 4 start – 15 finish – 1
- order No. 5 start – 4 finish – 13
- order No. 6 start – 10 finish – 3
- order No. 7 start – 7 finish – 13
- order No. 16 start – 5 finish – 14
- order No. 17 start – 4 finish – 13
- order No. 18 start – 13 finish – 9
- order No. 19 – missing
- order No. 20 start – 15 finish – 10
- order No. 21 start – 10 finish – 9
- order No. 22 start – 14 finish – 15
- order No. 23 start – 7 finish – 14
- order No. 24 start – 9 finish – 14
- order No. 25 start – 8 finish – 11
- order No. 26 start – 7 finish – 9
- order No. 27 start – 12 finish – 11
- order No. 28 start – 12 finish – 13
- order No. 29 start – 13 finish – 6
- order No. 30 start – 13 finish – 4

A random number was established for each order, which is the number of runs, which ranges from 1 to 3 (Table 1).

Table 1

Distribution of the number of runs by orders

No. of orders	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Number of runs	3	1	3	3	3	3	1	1	3	2	3	3	2	2	2
No. of orders	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Number of runs	2	1	1	–	1	3	1	2	2	1	3	3	1	3	1

As a result of the initial distribution of orders at zero step, we obtain the following representation:

Distribution of orders among points:

- Point 1) 11, 9;
- Point 2) –;
- Point 3) 3;
- Point 4) 14, 5;
- Point 5) 16, 1;
- Point 6) 12;
- Point 7) 23, 7, 10, 26;
- Point 8) 25;
- Point 9) 24;
- Point 10) 21, 6;
- Point 11) 13;
- Point 12) 28, 15, 27;
- Point 13) 29, 18;
- Point 14) 8, 22;
- Point 15) 4, 20;
- Point 16) –;
- Point 17) –.

As one can see, there are no orders at some points: 2, 16, 17. In others, there are up to 4 orders, which were sorted programmatically in order of decreasing the priority of execution. For example, at point 7 (Kropyvnytskyi), there are 4 orders from No. 23, 7, 10, 26. The longest orders and those that require the largest number of runs are distributed first. It is also evident that some orders from the

30 maximum possible are missing, as the randomization procedure zeroed their initial points. Thus, it was assigned that the number of orders that come to the carrier: $Z_{\min} \leq Z \leq Z_{\max}$, where $Z_{\min}=18$, $Z_{\max}=30$ – these are, respectively, the lower and upper boundaries of the number of orders. Randomization assumes fewer number of orders due to the uniform distribution of their arrivals. In the example, in particular, there is no order number 19. The readiness of vehicles to execute orders is displayed in the following representation:

at point 1 ATV – 2 orders – 2 ATV not more;
 at point 2 ATV – 2 orders – 0 ATV more;
 at point 3 ATV – 1 order – 2 ATV not more;
 at point 4 ATV – 3 orders – 3 ATV not more;
 at point 5 ATV – 3 orders – 2 ATV more;
 at point 6 ATV – 1 order – 1 ATV not more;
 at point 7 ATV – 0 orders – 4 ATV missing;
 at point 8 ATV – 2 orders – 1 ATV more;
 at point 9 ATV – 1 order – 1 ATV not more;
 at point 10 ATV – 2 orders – 2 ATV not more;
 at point 11 ATV – 0 orders – 1 ATV missing;
 at point 12 ATV – 3 orders – 3 ATV not more;
 at point 13 ATV – 0 orders – 3 ATV missing;
 at point 14 ATV – 3 orders – 2 ATV more;
 at point 15 ATV – 4 orders – 2 ATV more;
 at point 16 ATV – 1 order – 0 ATV more;
 at point 17 ATV – 0 orders – 0 ATV not more;
 Number of new orders that arrived – 29;
 Number of free ATV at the beginning of the cycle – 28;
 Orders that can be accepted for execution – 20.

Thus, as a result, we have the following initial data of the zero cycle of SM:

- maximally possible number of orders – 30;
- new orders that arrived – 29;
- number of free vehicles at the beginning of the cycle – 28;
- orders that can be immediately accepted for execution – 20.

Taking into consideration the duration of execution of each order and the number of runs that need to be performed to do it, the distribution of vehicles turned out to be not corresponding to the initial data:

Number of engaged vehicles	– 13;
Number of orders being performed	– 14;
Number of performed runs	– 14;
Number of rejected orders	– 15;
Duration of load runs	– 100.7 h;
Downtime	– 179.3 h;
Duration of no-load run of vehicles	– 65.1 h.

The indicator of refusal to execute orders deserves particular attention. Its numeric value 15 for the following example means that 14 orders out of 29 actual orders are executed. At this, it would be possible to take 20 orders for execution if vehicles are available at corresponding points. However, based on the above described strategy of the carrier, only 14 orders were chosen because such orders consist of several runs. As there were more vehicles than orders at some points, instead of a no-load run to the neighboring point, the possibility to perform all runs of actual orders was chosen. Such decision influences the carrier's business. In practice,

the existence of refusals leads to the loss of a potential customer by the carrier because of the loss of confidence, which is not reflected in this simulation modeling model.

The constructed algorithm and the IM program are different from the well-known ones also by the fact that it gives a clear schedule of execution of orders. For the above example, at the zero step:

Order No. 11; shifts – 4; performed runs – 1;
 Route **ATV 14** should be – 2-1-2-1;
 Order No. 11; shifts – 1; performed runs – 1;
 Route **ATV 16** should be – 2-1;
 Order No. 3; shifts – 7; performed runs – 1;
 Route **ATV 8** should be – 16-3-16-3;
 Order No. 14; shifts – 3; performed runs – 1;
 Route **ATV 9** should be – 8-4-8;
 Order No. 14; shifts – 3; performed runs – 1;
 Route **ATV 19** should be – 8-4-8;
 Order No. 14; shifts – 3; performed runs – 1;
 Route **ATV 20** should be – 8-4-8;
 Order No. 12; shifts – 4; performed runs – 1;
 Route **ATV 10** should be – 13-6-13-6;
 Order No. 24; shifts – 2; performed runs – 1;
 Route **ATV 12** should be – 14-9-14;
 Order No. 21; shifts – 1; performed runs – 1;
 Route **ATV 1** should be 10-9;
 Order No. 21; shifts – 1; performed runs – 1;
 Route **ATV 3** should be – 9-10;
 Order No. 28; shifts – 1; performed runs – 1;
 Route **ATV 7** should be 12-13;
 Order No. 28; shifts – 1; performed runs – 1;
 Route **ATV 11** should be – 13-12;
 Order No. 28; shifts – 1; performed runs – 1;
 Route **ATV 28** should be – 13-12;
 Order No. 16; shifts – 10; performed runs – 2;
 Route **ATV 4** should be 5-14;
 Order No. 1; shifts – 2; performed runs – 3;
 Route **ATV 5** should be 5-3;
 Order No. 25; shifts – 1; possible runs – 1;
 Route **ATV 2** should be 8-11;
 Order No. 8; shifts – 1; possible runs – 1;
 Route **ATV 4** should be 14-8;
 Order No. 22; shifts – 2; possible runs – 3;
 Route **ATV 22** should be 14-15;
 Order No. 4; shifts – 6; possible runs – 3;
 Route **ATV 6** should be 15-1;
 Order No. 20; shifts – 5; possible runs – 3;
 Route **ATV 13** should be 15-10.

The resulting schedule fragment shows that vehicles No. 1, 3, 2, 4 are assigned to execute orders for one run. Vehicles No. 14, 16 – for parallel performance in 2 runs of order No. 11 by vehicle No. 14 and in one run – by vehicle No. 16. Likewise, vehicles No. 9, 19 execute order No. 14; other vehicles are assigned for the sequential execution of orders that are executed in not more than one run. Some orders that are executed in more than one run, are provided with one vehicle, which consistently executes them. This is, for example, order No. 12, which must be executed by vehicle No. 10 on the route: points 13-6-13-6. Since the duration of one load run 13-6 and return run 6-13 takes 2 shifts, the total engagement of vehicle No. 10 for this order will be 4 shifts. In this regard, the significant indicators of the process are the duration of load run (paid service) and

downtime of the ATV (unpaid time). These indicators were derived as a numeric estimation of simulation modeling.

7. Use of simulation modeling to assess the operation of ATV fleet depending on incoming flows

The initial data from the TC “Trans-Service-1” were used in SM. Simulation modeling of servicing of evenly distributed flow of incoming orders for the transportation of bulk cargoes by each of the three strategies was performed. The strategies were considered: without no-load run with waiting at the arrival point, with no-load run to nearest loading; with fixed periods of repetition of the orders known beforehand.

The main parameter of SM, specifically, the number of refusals, along with its derivative characteristics, is shown in Fig. 3, 4. Each diagram shows four time series.

The first series is the number of orders received in the form of requests to the company. This is the largest numeric value among all time series, which depends only on the random number generator.

The second series is the number of orders that can be accepted for execution, which is determined from expression (9). This number is maximum at the beginning of simulation modeling. However, when the ATV have already been distributed among the routes, their final points, as a rule, do not coincide with the initial points of new orders. That is why this magnitude Z_a on the subsequent cycles fluctuates.

The third series – the number of refusals is the difference between the number of orders received and those that were accepted for the execution at the current step. The orders that are still in progress Z_a were not taken into account. The TC cannot influence the total volume of orders by direct methods. That is why it is necessary to consider the methods of organization so that the routes should be rational and take into consideration the available forecast of the input flow. The number of refusals at the following simulation modeling steps starting with $j=1$ also depends on the amount of work to implement the orders at step $j-1$.

The number of orders being performed depends on how the vehicles were allocated in the past and on the number of available orders at the present moment.

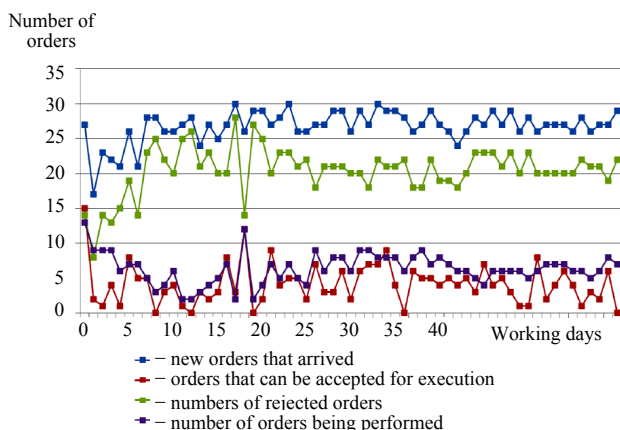


Fig. 3. Step-by-step change of incoming flow of orders and its servicing at the absence of no-load run with waiting for an order at the point of final unloading (strategy I)

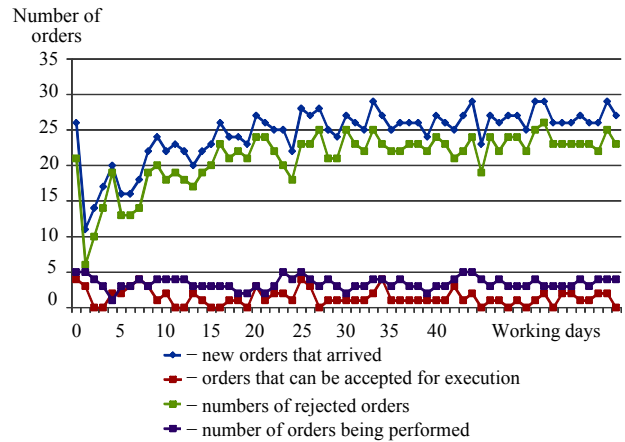


Fig. 4. Step-by-step change of the incoming flow and its servicing with no-load run and without waiting for next order at the point of final unloading (strategy II)

If a no-load run of the ATV is prohibited (strategy I), the discrepancy between the number of orders received and those that are performed is very large (Fig. 3). After all, the ATV is limited to use even if there is information about non-executed and available orders. However, it should be noted that by the end of the last cycle, the number of refusals and the number of orders that are performed for the given service strategy are stabilized and their time series acquire stochastic-periodic character.

The total number of refusals at strategy II decreases slightly. It is not possible to speak about the improvement of use of ATV fleet. After all, even if a vehicle is moving to the neighboring nearest point, where there is load for transportation from the previous uncompleted order, this does not mean that this vehicle will be used. The same run can be performed by other vehicles. However, in strategy II, the number of orders being performed is almost a stationary process that has little fluctuation. The main reason for this phenomenon is the number of orders that are received in previous cycles and are usually higher than the number of new ones that were taken in the current cycle. Thus, it can be concluded that strategy II is aimed at performing large (many cargo runs) and long-term (many shifts in vehicle engagement) orders. Strategy 2 brings stability but does not decrease downtime of vehicles of one fleet.

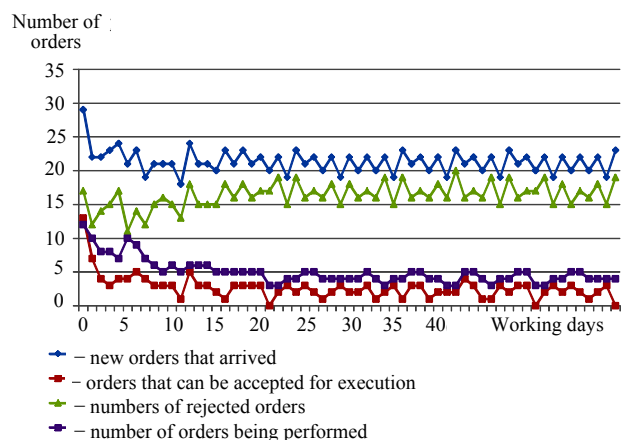


Fig. 5. Step-by-step change of the incoming flow and its servicing with no-load run and without waiting for the next order at the point of final unloading at fixed periodicity of order arrival (strategy 3)

The number of refusals decreases if one uses the available prediction data on the periodicity of arrival of orders and their varieties. For example, if the periodicity of arrival of orders is known and does not exceed 12 days, the incoming flow can be characterized by approximately constant intensity. However, it does not reduce significantly the number of rejected orders, although the process of their execution gets stabilized. This is reflected by time series of strategy 3 (Fig. 5).

8. Comparison of strategies of a carrier in the simulation model

If we compare total and average per cycle parameters of SM, which are configured for each of the three strategies, it is possible to identify (Table 2) their following features. Table 2 shows the simulation modeling results at the fixed value of maximum (30 days) and minimum (12 days) periodicity of order placement.

Table 2

Indicators of simulation modeling brought together for 60 steps at three strategies of servicing the incoming flow of orders for cargo transportation

Indicator	Strategy No. 1	Strategy No. 2	Strategy No. 3
Average duration of load runs per cycle, h	31.4	56.1	35.7
Total duration of load runs per cycle, h	1,882.7	3,368.8	2,139.0
Average duration of transport downtime per cycle, h	253.3	228.5	249.0
Total duration of downtime per cycle, h	15,197.3	13,711.2	14,940.8
Total number of refusals	1,512	1,250	1,132
Total number of orders	1,712	1,735	1,461
Average duration of no-load run per cycle, h	0.0	41.8	1.02

The characteristic features of the proposed strategies are:
 – for strategy 1 – absence of no-load run, but the highest number of refusals and downtime;
 – for strategy 2 – great number of load runs, however, to do this, the ATV have to perform long no-load runs, transport downtime is the shortest;
 – for strategy 3 – the smallest number of refusals, but short time of load run.

To prove the revealed features of incoming flows and their servicing, we conducted simulation modeling with variable periodicity of order placement (Fig. 6–8). The dependences of the number of refusals to execute cargo transportation orders on random periodicity of their arrival, which is assigned by the interval. For example, periodicity interval of 4 days means that all orders are single at minimum periodicity of 4. If minimum periodicity of order placement is 4 days and the periodicity interval is 28 days, it means that the order appears within the period, which makes up interval [4...32] days. Distribution of order placement in each of the intervals is uniform.

For strategy 3, periodicity of order placement is a deterministic magnitude. For some orders periodicity may be the same. That is why Fig. 8 shows the dependence of the number

of refusals to execute orders in the interval of periodicity provided that the number of the same intervals of periodicity that do not intersect is 3. This multiplicity was chosen for the purity of the experiment: the average number of orders received per day should be equal to 24. At the number of the same periodicities is 3 and at total interval is 8 days, all orders can be divided into two three. The first group of orders occurs at periodicity of 4, the second group – 6 days, and the third one – 8 days. Otherwise, when maximum periodicity is 28 days, and the number of groups of orders of the same periodicity is 5, all of them can be divided as follows: 12, 16, 20, 24, and 28 days. In general, this affects the number of new orders that a carrier receives.

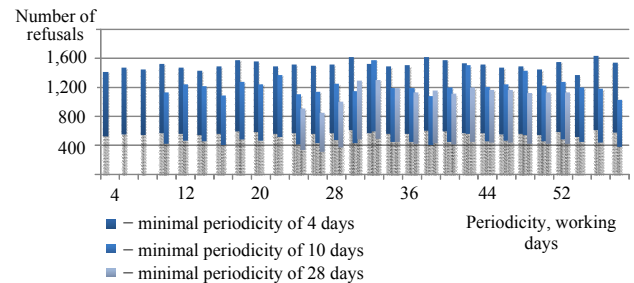


Fig. 6. Change in the number of refusals at a change in the periodicity of order placement for service strategy No. 1

Due to the fact that periodicity is assigned by the difference between magnitudes $\tau_{max}-\tau_{min}$, the minimum periodicity is decisive for the orders' flow, that is why in Fig. 6, 7 the corresponding histograms begin with the values of the accepted magnitude τ_{min} .

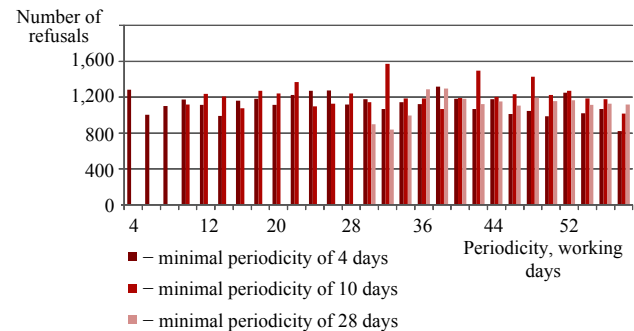


Fig. 7. Change in the number of refusals at a change in the periodicity of order placement for service strategy No. 2

The periodicity of order placement for strategy No. 3 was accepted from the statistical data about such observations in the previous 2018 in the same company, Ltd. "Trans-Service-1". In particular, it was found that periodicity of order's arrival is the magnitude that is directly proportional to the duration of its execution. That is why each order was matched with the periodicity interval corresponding to its duration. It is also known that some orders appear with the same periodicity. That is why simulation modeling of strategy No. 3 was conducted at a variable interval of periodicity of orders (Fig. 8).

The presented histograms show that the periodicity interval at the uniform distribution of the incoming flow of orders is not a significant factor that affects the number of refusals for strategies No. 1 and No. 2. For strategy No. 3, the main thing is not the periodicity interval, but rather the

correlation between the duration of the transport cycle and the periodicity of its performance.

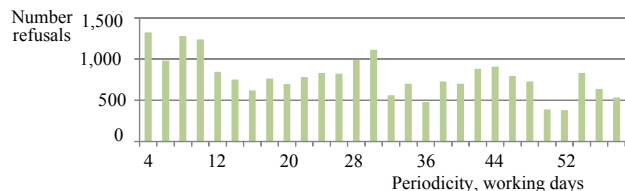


Fig. 8. Change in the number of refusals at a change in the periodicity of order placement for service strategy No. 3

9. Discussion of results from applying simulation modeling of transport processes on the main road network

The obtained results of simulation modeling show a rather large share of refusals to execute cargo transportation orders. The ratio of the total number of rejected orders to the total number of orders that the TC could potentially execute is not less than 0.72 for all cycles, regardless of the service strategy. At the beginning of simulation modeling, the number of refusals is small. However, in the process of performing transportations, the ATV insufficiently interact in terms of redistribution of transport tasks. In this regard, vehicles loading becomes non-uniform. The cargoes that do not meet a high priority of execution are accumulated at shipment points. That is why the number of refusals to cargo shippers increases. However, Fig. 6–8 show that in the further course of transport cycles, the number of rejected orders fluctuates with respect to some stationary value. This phenomenon is especially noticeable when a carrier gets to know the forecast and the patterns of the order flow (strategy 3 – Fig. 8). This means that the ATV flows of the assigned TC in the network are periodically harmonized with the incoming flows. However, transport cycles of the motor-vehicle fleet are still not sufficiently coordinated. It is not included in the possibilities of the developed simulation modeling technique.

On the other hand, comparing the obtained results with those that can be obtained using the QT models, one can specify the obvious merits of the proposed SM. The main advantage is the obtained opportunity to establish the regularities of appearance, acceptance, and execution of transport tasks. Most of known methods are devoid of this possibility. The known SM methods are based on a certain type of the QT models. The process of rendering services or appearance of refusals is considered in such SM without taking into consideration the peculiarities of location of the service object in space and time. The agent-oriented approach applied in the proposed procedure is the specific balance between subjective and objective factors in the decision-making process.

The second advantage of the presented SM is the simplified possibility to display different strategies of handling cargo transportation orders. The SM adequacy verification was performed for three strategies that exist in practice. Such strategies are logical under the terms of their use. However, there are other possible options for cargo flows control that can be displayed as a non-complicated change of the proposed algorithm. The computer program and the algorithm have a block structure that makes it possible to easily

make changes to it. This opens up the possibility to apply the procedure to study the system of managerial decisions of the TC, including research into conditions of interaction between different carriers in cooperation.

However, subsequent studies may face difficulties that relate to dimensionality of incoming flows and the complexity of preparation of initial data. Difficulties are related primarily to the construction of the duration matrix. The time matrix can be several times as large, and time elements of this matrix are dynamic. To eliminate such difficulties, it is necessary to additionally equip the SM with integrated routing algorithms and to provide with dynamic database. In this case, SM will more accurately display the processes of cargo flow handling and will be a highly effective practical tool for controlling transportation processes.

10. Conclusions

1. The set of rules that most accurately displays the content of the desired effects of transportation execution can be reduced to the fact that the operation of each ATV should include the cycles that are proportional to the cyclicity of an incoming flow. However, the size of the periodicity interval does not affect the accuracy of simulation modeling of the TP of intercity cargo transportation.

2. A carrier should not avoid completely no-load and zero runs in transport cycles, because due to their existence and stochastic nature of order placement, it is possible to avoid unproductive downtime of the ATV and significantly reduce the number of rejected orders. If periodicity of order placement is fixed and its interval is proportional to the duration of the order execution, the number of refusals to perform transportation and downtime at the same time is minimal, the ATV utilization rate also decreases.

3. Given the SM results, it can be argued that the indicator of the number of orders in the context of those received, rejected and fulfilled is the most significant for the successful operation of the TC on long-distance routes. For those variants of the ATV distribution between the available orders, where the number of refusals is minimal, all other operating indicators also acquire the optimum value.

4. While advancing our completed research, it is necessary to develop organizational and technological measures to ensure a more efficient level of operation of the ATV fleet. To do this, by means of the developed IM, it is necessary to perform the research into the process of servicing stochastic periodic incoming flows with the variable ATV fleet with the possibility to involve additional means for cooperation with other carriers. It is necessary to expand the opportunities of the model for the display of intercity processes of cargo transportation in the larger space-time volume.

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