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Abstract. The article presents the methodology of the logistic system simulation in the Petri Nets environment on the example of agro-products delivery from Ukraine to the Netherlands, as well as a set of case-studies that can be used as didactic means for course "The modeling of transport processes" to teach the future transport industry specialists.

The content, features and capabilities of the Petri Nets in the logistics systems simulation have been analyzed. A structural logistic system model of agro-products delivery, which takes into account the operation sequence, the combination peculiarities and the use resources in each subsystem, has been constructed into the Petri Nets. A time criterion has been proposed to determine the effective option for agro-products delivery.

According to the results of the logistics system simulation in the Petri Nets environment, a statistical analysis of the parameters has been carried out. It has been made a choice of a suitable option of the delivery scheme allowing for the time spent and the magnitude of the possible costs associated with the use of certain transport modes.

It has been made conclusion about feasibility of creating the case-study set, which is based on real facts and being solved into the Petri Nets environment, in order to organize the future transport industry specialists' study and research activities.

Keywords: simulation, logistic system of cargo delivery, Petri Nets, vocational training of future specialists for transport industry.

1   Introduction

Today, in fact, Ukraine is one of the world's leading exporters of agricultural products. The agro-industrial complex is the most priority sector of the Ukrainian economy. In the near future the strategy of its entry into the European Union market is essential for the development of Ukraine. In line with this viewpoint, along with the economic and technical aspects, it becomes significant the content and directions of the transport industry specialists' vocational training. Such specialists should know the general patterns of logistic systems development, the features and trends of management and material

flows optimization; they need orient and apply modern computer-based methods of logistic systems simulation.

We would like be show the most indicative data describing the facts of increasing the volume of agricultural products transportation. In the period January-September 2019, agricultural products were exported to the EU at 4.76 billion USD, which is 106.9% more than in previous year, and it constitutes 30% of Ukraine total exports [20]. According to *IMF group Ukraine* estimates, the total potential agricultural demand for rail transportation by 2022 may increase from 52.4 (2018) to 70 or 95 million tons of annual freight. For its part, a rise in grain production causes a corresponding growth in the consumption of chemical and mineral fertilizers. By 2022, this figure can increase by 22.8% [29].

By results of 2019, the seaports of Ukraine had raised the volume of cargo transshipment by 18.4% and reached record high performances in the whole history of their existence. For the first time, the volume of transshipment of 13 Ukrainian active ports exceeded 160 million tons [10]. The maximum indicators of transshipment of grain cargoes and ore were recorded. Container transportation overcame a 10-year high of 1 million TEU. In total for 2019 Ukrainian seaports handled 11,850 vessels, which is 196 ones (1.7%) more than last year. Grain loads and oil accounted for more than a third (37.7%) of the total cargo flow. Four ports of Ukraine became the leaders in terms of transshipment in 2019. They were the Port Yuzhny – 53.9 million tons (+ 26.1% to the last year), Mykolayiv – 33,4 million tons (+ 14.5%), Chernomorsk – 26.2 million tons (+ 21.4%), and Odessa – 25.3 million tons (+ 16.8%).

Along with the increasing volume of transportation, there are difficulties associated with the efficient management and construction of a supply logistics "rigid schedule" from the production location to the consumer. These difficulties are due to the fact that the logistic system of agricultural products delivery has many links, including informative ones, and involves a large number of elements [33]. Yet another problem is the unjustified additional costs for the agricultural products delivery. In Ukraine grain freight, e.g., costs an additional 8 US$ per ton compared to France and Germany. Transportation value includes the cost of pure transportation, ware-housing, storage, cleaning, drying of goods, handling operations, processing documents, packaging, security, as well as the payment of any commissions, tariffs and fees because of the grain export. On account to increased logistics costs, Ukrainian agricultural producers receive less profit in contrast to world market prices. They have to bear the costs caused by the inefficiency of the logistic system [31].

The active ICTs development in the previous years has allowed to accelerate the process of presentation, processing and use of information in the logistic system for the delivery of various cargo types [22]. But here too, there are troubles and problems in creating effective information systems in enterprises. One of the first things is deficit of prompt collection of reliable information in companies. Mostly companies suffer losses as a result of untimely or incorrect data on the operational situation at each stage of the logistics supply chain [5]. Therefore, today attention is increasingly drawn to the information flow through which the movement of material resources is planned, managed and controlled [34]. There is a need to model and study the behavior of the logistic transport system in order to obtain information and forecast its most important

characteristics. The systems of parallel processing information and parallel objects operating allow to solve the problem with effective interaction of individual elements of this delivery frame. The best of these are models based on the Petri Nets Theory.

In light of these facts, the implementation in the content of the future transport industry specialists vocational training the case-studies based on simulation into the Petri Nets environment will be able to prepare them for work in real conditions of the transport process organizing.

The purpose of the paper is to present the methodology of the logistic system simulation into the Petri Nets environment at the example of agro-products delivery, as well as a set of case-studies that can be used as didactic means for course "The modeling of transport processes" to teach the future transport industry specialists.

2   Materials and Methods

Nowadays, freight delivery management in Ukraine during the execution of applications uses techniques based on heuristic methods; on own managerial experience and on degree of responsibility. In practice, this means the occurrence of real losses associated with the increase in the cargos delivery time, downtime of wagons at the approaches to ports, at border crossings and at warehouses of enterprises (elevators), as well as it caused by arrhythmia in the operation of transport subsystems in general. A selective analysis of the cargo delivery time, conducted by A. I. Kirichenko, shows that the violation of the term occurs in transportation for all types of dispatch at 5%, container – 32%, rail wagon – 17% and group shipments – 8% [14]. Therefore, the logistics delivery system, e.g. of the agro-products, should cover the consideration of the transportation organizing both by motor-cars and railroad wagon, and with the use of containers [32].

It's generally recognized the effective supply tracking is critical for global trade and logistics management [21]. To cope with the growing complexity of customer requirements, supply chain organization and management systems are constantly moving towards the area of collaboration, intellectuality, and service orientation. This fact has been emphasized by R. Giustia, D. Manerbaa [7], D. Kopytkov, O. Pavlenko [16], S. Pan, R. Y. Zhong [21] and others. Majority logistic companies in the world have made cargo tracking a must in the delivery chain [15]. However, flow management is still a challenge for supply participants. This fact confirms the feasibility of the idea of a smart system for monitoring the promotion of cargos in containers in the multimodal transportations context [32]. A number of papers (V. Aulin, O. Lyashuk, O. Pavlenko, D. Velykodnyi, N. Shramenko, D. Muzylyov) also reveal a complex multifactor system to track cargos movement on the grounds of computer-based simulation [2; 19; 26].

Undoubtedly the technology of transport systems computer simulation is a very sophisticated professional technology. It provides a system for information gathering with use of data collection card, which is too much costly and not always an effective process. In so far years, thanks to widespread implementation of ICTs, the simulation technologies have been developing rapidly. Based on the model of activities of organization, researchers (H. Hasan, E. AlHadhrami, A. AlDhaheri, K. Salah, and R. Jayaraman)

reveal the content, concepts and methodology of simulation technologies, methods of simulation modeling and simulation experiment, as well as typical algorithms for simulation of various processes. In [8] the authors also proved the relevance of simulation of events occurring in the pragmatist processes. General issues about computer-aided students' simulation training have been covered by R. Horbatiuk, O. Lavrentieva, I. Petrytsyn, S. Semerikov, V. Soloviev, I. Teplytskyi and others [9; 17; 28].

It has been found that the most promising for describing the process of cargos delivered by transport technological schemes is the use of simulation modeling. Unfortunately, there are some complexities while designing and creating new models. They are cased not so much by number of projected system elements, but by the complication of causation in the complex of components which are interacting, interconnected and interdependent. To solve the problems of optimizing the functioning of logistic systems separately and as a whole, C. F. Jin, H. M. Yang, L. L. Wang [11], N. Shramenko, D. Muzylyov [27] developed the neural networks. At the same time, it is the Petri Nets that can be more effectively used to simulate the systems with parallel processing of information and objects.

The Petri Nets, as it has been pointed out by W. Z. Zhong, X. Q. Fu [36], N. Shramenko, O. Pavlenko, D. Muzylyov [25], G.X. Zhang, S. He, Z.Y. Zhang [35], M. Gaied, A. M'halla, D. Lefebvre and others [6], are much more commonly exploited to investigate an object behavior in real time and to evaluate the performance of the transport system. The Petri Net Theory is a mathematical apparatus designed to work with parallel and asynchronous systems. It first described in 1962 by the German mathematician Carl Petrie. Now the theory is being considerable used virtually in every field of research [3]. In the following we consider the potential of the Petri Nets environment in transportation system simulation, as well as its benefits for organizing vocational training for future specialists for transport industry.

3 Theoretical background

First of all, to simulate the transportation system an object-oriented model should be constructed. This type of simulation is a simple and concise method of modeling and competent mathematical analysis for all spheres of activity, including logistic systems. An object-oriented model describes the structure of system objects, their attributes, operations, links with other objects [12]. Such simulation reflects those concepts and objects of the reality that are principal for the system development. It is object-oriented technology that is combined with Petri Networks for studying logistic processes [18].

The Petri Net is a clear and well-formalized simulator for the behavior of parallel systems with asynchronous interactions. It reflects in a compact form the links structure between the system elements and dynamics of changing its states under given initial conditions [4]. The model abstraction level is very high. It corresponds to the description of interactions in the system in terms of only two concepts – events and conditions. The Petri Nets are integration of a graph and a discrete dynamic system. Thus, they can serve as a static and dynamic object model, which in turn makes it possible to solve a fairly wide class of tasks [4]. Petri Nets allow modeling the assembly lines, simulation and analysis of technological processes and resource allocation of the enterprise.

Graphically, the Petri Net is interpreted as a bipartite oriented graph with a given initial state, called the initial marking (or token) – M_o [4]. The graph consists of nodes (vertices) of two types – places (positions) P (i.e. conditions) and transitions T (i.e. events that may occur); they are connected by arcs. The same type nodes can't be tied together. The marking can be put within the position and may move by network. At the Petri Net diagram, positions are represented by circles, transitions – by bold bars, and arcs are signified by arrows. The directed arcs describe which places are pre- and/or postconditions for which transitions. The arcs are denoted by the weight factors (integers). It's accepted that the arcs with equal weights k are equivalent to parallel arcs. Marking (state) attributes to each position regard as an integer non-negative number M (P) equal to the number of chips in position P [1]. So, a formal presentation Petri Net is following:

$$PN = (P, T, F, W, Mo), \qquad (1)$$

where $P = (p1, p2, ..., p_m)$ – is a finite set of positions; $T = (t_1, t_2, ..., t_n)$ is the finite set of transitions; F – set of arcs (flow relationships)

$$F \subseteq (P \times T) \bigcup (T \times P), \qquad (2)$$

where $W: F \rightarrow (1, 2, 3, ...)$ is a weight function; $M_0: P \rightarrow (0, 1, 2, 3, ...,)$ is the initial marking.

In modeling tasks, where the concepts of conditions (states) and events are applied, positions comply conditions and transitions are events. Each transition (event) is associated with a certain number of input and output positions-analog according to the pre- and postconditions of this event. The presence of a chip in some position is interpreted as the truth of the condition corresponding to that position, and also indicates the availability in the position k of data elements or an appropriate amount of resources [1].

Models based on Petri Nets allow to analyze two types of properties defined by the original M_o marking and independent from it. The first-kind properties are called behavioral ones. Reach, limited, and energy are main for them. The second kind properties are called structural ones. They are characterized, as a rule, by the matrix of incidents C and related equations and inequalities. These include structural limitation and activity, safety, repeatability, and etc. The safety and repeatability properties enable to respectively determine the positional and transient invariants into the Petri Nets environment.

Known methods for analyzing the properties of Petri Nets are divided into three groups: 1) methods based on building multiple reach; 2) ones using matrix equations and network invariants; 3) ones allowing decomposition of the network to the subnet. The main areas of applied the Petri Net Theory are synthesis, analysis and modeling. The purpose of the Petri Nets simulation is to investigate the dynamics of studied system functioning and its behavior for different initial conditions. However, the popularity of Petri Nets is caused not only because of their high modeling possibility, but also thanks to a well-developed formal apparatus for analyzing the properties of a constructed model [24].

Next, we will consider the capability of the Petri Nets to solve the problems of logistic systems simulation. By way of example we will analyze the agricultural products delivery from Ukraine to the Netherlands. The choice of this country is caused by the fact that the largest volume of Ukrainian agricultural products export accounts for the

Netherlands – 1.06 billion US\$. Furthermore, of the 16 commodity items of cargo shipment to this country, grain crops are of the highest importance; their part is 43.6% of the total volume of transportations [31]. To accomplish the construction task of efficient logistics system, it is necessary to develop a model of agro-products transportation from a manufacturer in Ukraine to a destination seaport in the Netherlands, to perform simulations to determine the estimation parameter – the time, as well as to clarify the conditions for the effective functioning of the entire delivery process.

4 Technique for using Petri Nets to simulate the logistic systems

4.1 General overview of the logistic system for agricultural products delivery from Ukraine to the Netherlands

In general, the logistic system of agricultural products delivery in Ukraine has a structure based on the interaction of such participants as: traders – organizers of products export, manufacturers, storage systems, transport companies, as well as the existing infrastructure of ports, railways and highways. The traders are a centralized system of the required technological level, aimed at organizing the interaction between participants, and besides, on receiving and analyzing input and output data, and to ensure greater transparency of the delivery process [30]. The logistic system can be interpreted as a holistic perspective, built in real time for all its participants allowing traders to make appropriate short-term and long-term decisions directed at the process development.

The system is built from the following subsystems: harvesting, transportation to the departure port, shipping by sea. The macro-level structural model reflects it in a comprehensive manner (see Fig. 1). To determine the effective delivery option, the main investigated parameter we defined the delivery time of agricultural products. Clearly, the time minimization process is affected by intensities of the receipt of orders and technical means – I_V, the volume of the order – Q_V, and time of execution of the main operations in the corresponding subsystem – t_V. It means following:

$$T = \{I_V \; ; \; Q_V \; ; \; t_V \} \qquad (3)$$

Each of the time minimization parameters consists of a number of components. Presumably, duration of technological operations and time of work technological intervals determine the variables that could be managed. The main system parameters change under the influence of load on the simulation model and during its management. These model parameters act as phase variables that can vary depending on the load on the system.
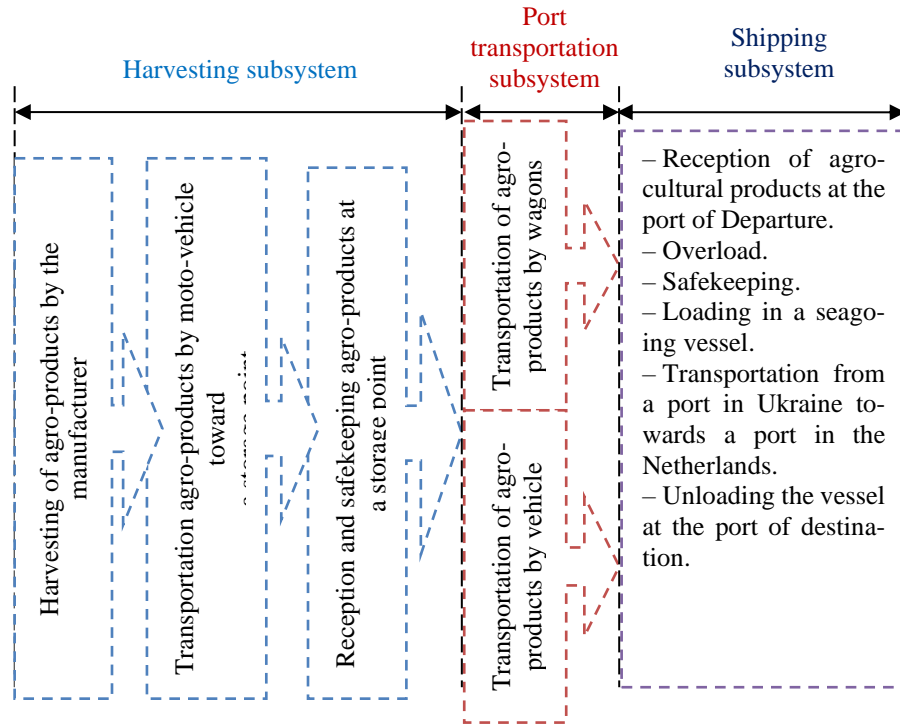
Fig. 1. The structural model of the agricultural products delivery system from Ukraine to the Netherlands

To construct a transport system model, it is advisable to employ a stochastic estimation of the Petri Nets, where the vertices of the places have an integer number of marks and are used to quantify some parameters of the system functioning like reliability and performance. In such networks each transition is attributed to a probability of its activation over time [24].

Considering the functional connections between the elements, it's possible to construct an enlarged model into the Petri Nets environment (Fig. 2). The model will be to describe the logistics system functioning – the process of promotion of agro-products from the sender (Ukraine) to the destination seaport (the Netherlands).

The presented scheme depicts the process with the established elements. As for transitions, these determine following ones: T_1, T_2 –intensity of applications receipt from the trader and the farmer; T_3, T_5, T_3, T_{10} –time of cargo moving respectively by cars, wagons, sea vessels; T_4, T_7, T_8, T_9, T_{11} – the corresponding distribution of cargo, information, technical means. The positions are represented by: P_1, P_2 – the presence of agro-products from the farmer and demands (technical means) from trader; P_1–P_{13} – cargo position at each operation stage.
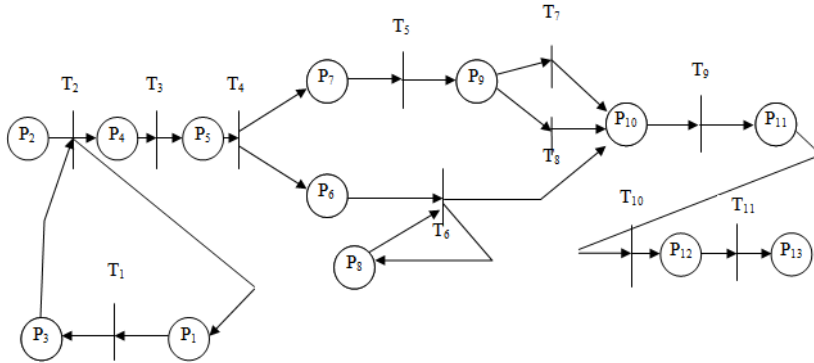
Fig. 2. The model of agro-products movement from the sender to the destination seaport

As can be seen, movements and positions are key points to the model presented. Therefore, in the future in modeling process, it should be paid maximum attention to these aspects.

4.2 General description of the Petri Nets application

As mentioned above the Petri Net modeling technique can be used for qualitative and quantitative analysis of workflow and workflow system in general. Apps market proposes a lot of offers that are founded on general modeling methodology into Petri Net environment [23].

"*Petri Net Integrated Simulator*" is aimed at the research and development of complex systems in various subject areas, including road transport. It provides following: 1) automation in construction of complex objects models; 2) simulation in step-by-step modes for tuning models, and statistics collection; 3) the formal analysis of systems represented by Petri Nets in terms of their structural and behavioral properties [23].

The Petri Nets graphic editor is aimed at creation and edition of Petri Nets and their modifications (F-networks, temporary networks, etc.) presented in graphical form. The editor is based on the general ideology of the multi-window interface and is functionally divided into two parts. The first part is the basic; it ensures the construction and edition of the Petri network overall structure. The second part is parametric; it provides the change of parameters of the network basic elements such as position (P) and transitions (T). The parametric part, in turn, also consists of two parts where each one processes either "position" or "transitions". The work of parametric part is ensured by changing the parameters of the network elements via directly interacting with the main objects of the general data structure like "position" and "transition".

The simulation process consists of two main parts. First one is the window-user interface (presented on Fig. 3) and second one is the Petri network operation procedure. The simulation process in part of window-user interface is founded on the widespread ideology of software complex organizing and uses the functions of the multi-window interface created within it. By virtue of this fact, the process interacts with external devices (and through them with the user) and messaging with other complex processes.
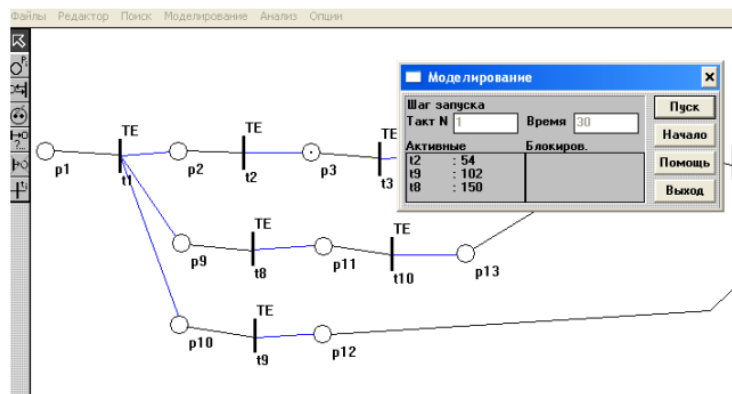
Fig. 3. Window fragment of the simulation process

The operation procedure applies for its work a special structure data created for storing, modifying and processing the Petri Net description. The operation procedure is started by the command of window-user interface and sequentially executes the simulation algorithm until it is interrupted by the user or by the command window according to the specified simulation mode. This mode sets in the Mode menu item.

An integrated system of modeling and formal analysis based on Petri Nets can be applied in the future transport industry specialists vocational training process. In particular, in order to create the content and didactical tools of the course "The modeling of transport processes" and for students' study and research work.

4.3 A case-studies set for the analysis and statistical evaluation of logistic models

In order to simulate the functioning of the logistic system of agro-products delivery, it is necessary to carry out a statistical analysis of parameters that are used to set initial values by transitions and positions in the Petri Net environment.

Case-study 1. You need, based on the data presented on the volume of cargo and the number of wagons for *Kernel Trade* – a large vertically integrated agricultural holding of Ukraine and information in [13], determine the time of grain delivery from senders (farmers) to the port station Odessa-Port with overload on the Odessa port grain terminal, and further – to the Netherlands. It should be considered that the cargo is delivered from the Odessa port to the Netherlands ports by means of vessels (Fig. 3). You must find out the most appropriate type of transport for each operation stage.

Some solution ways. For statistical estimation of the values of the used parameters given in the model transitions – T_i, they are expediently divided into groups by characteristic feature (Table 1). The initial values in the positions (P_i) can be determined by the availability of statistical information of Ukrzaliznytsia, as well as by data of delivery information services.

Fig. 3. Scheme of agro-products transportation from the Odessa-seaport to the Netherlands-port

<div align="center">Table 1. The model parameters statistical estimation</div>

Parameter group name	Sample volume, units	Limits of the parameter's mathematical expectation values	Distribution law
Intensity of receiving orders, units / h.	68	0,2-6	Exponential
Intensity of agro-products receipting from collection and storage sites, t / h.	83	10-42	Exponential
Intensity of cars arrival, units / h.	49	1-5	Exponential
Intensity of wagons and locomotives arrival, units / h.	152	0,4-32	Exponential
Arrivals and departures of trains, units / h.	91	0,1-2	Exponential
Intensity of arrival or departure of vessel, units / h.	47	0,1-1	Exponential
Time for performance of harvesting technological operations, h.	72	8-53	Exponential
Time for performance of technological operations at storage in specialized places – in the warehouses, elevators, h.	59	0,5-28	Normal
Time for performance of technological operations on car, h.	63	0,2-34	Normal
Time for performance of technological operations on railway transport, h.	82	0,7-77	Normal
Time of carrying out technological operations on sea transport – into the ports, h.	51	1,3-164	Normal
Time for performance of technological operations during moving between ports, h.	37	320-384	Lognormal

The complex system analysis based on the Petri Nets environment can be performed with the use of simulation model. In line with this strategy, it is evidently needed to specify the input flows of demands and determine the system response. The initial parameters will be able to calculate processing the statistical material accumulated during the simulation.

Apparently, if it has a good chance to use both a road and a rail transport, then there are three variants of cargo flow distribution in the appropriate logistic systems of agro-products delivery. They are:

Option 1 – 100% of cargo is transported by rail across Ukraine.

Option 2 – cargo is transported equally for each mode of transport (rail and road).

Option 3 – 100% of the cargo is transported by road.

For all of those options, the models can be built in the Petri Nets environment. As a modeling result, the data distributed over the duration of execution of basic technological operations throughout the logistic system were obtained (see Fig. 4).

Case-study 2. You should analyze the behavior of the model depending on the volume of the order of the agricultural products delivery (Fig. 4) and determine the best variant of the grain cargo delivery chain from the sender toward the recipient (destination port). The number of values is 54 units, it is determined by the level of confidence probability, error and number of observations. The value of transport volume varies from 20 to 3240 tons [13].
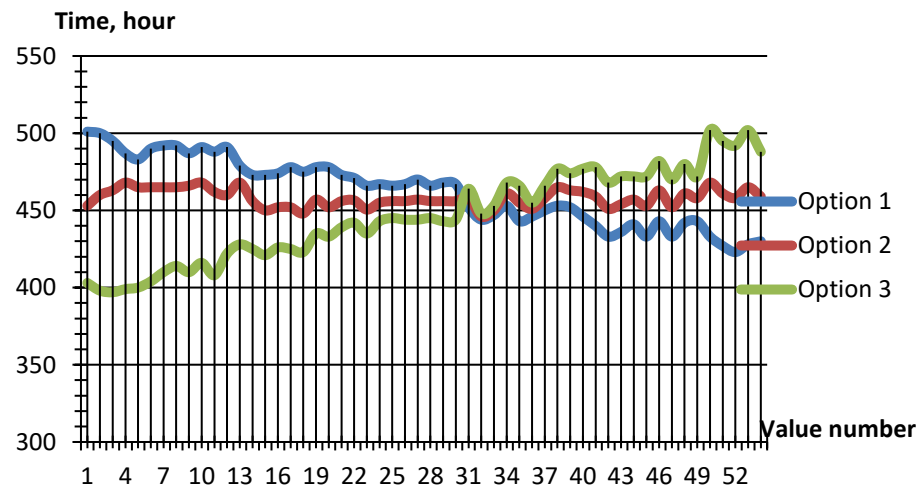

Fig. 4. The logistic system modeling results for three options of agro-products delivery with usage of Petri Nets app

Some solution ways. From the histogram (Fig. 4) the best option of the delivery model can be chosen. The choice should be made according to the criterion of minimum time for agro-products delivery. Meanwhile, it is possible to clearly trace the trend concerning parameter at position "32", which corresponds to a cargo volume about 1470 tons. Under these terms, transportation by road is more advantageous. For larger volumes, it is advisable to deliver cargo to the port by rail only. In this case the usage of trucks is unacceptable alternative since this is due to the need to have a significant number of

trucks, which for Ukrainian transport operators is inefficient.

The presented above approach allows to decide not only the timing scheme, but also to estimate directly the possible costs associated with determining the cost of delivery in terms of existing resources.

These, and simpler, case-study that are created on fact data and solved into the Petri Nets environment can be used as a basis for organizing future transport industry specialists' study and research activities. In next time students will be able to independently look at the current important information about cargo delivery and use it to estimate various logistical models with the help of simulation into the Petri Net environment.

5 Conclusions

It is established, in the context of increasing the intensity of transport flows and the widespread of ICT, the approaches to the modeling of logistic transport systems need to be qualitatively updated. From one part, globalization and information processes do affect the content and methods of vocational training of future specialists for transport industry.

It is found out that in Ukraine the logistic system of the agricultural products delivery has a structure based on the principles of alternative subsystem construction. The operation of each subsystem individually, as well as in the interaction is most effectively described with exploitation of the Petri Nets, which are used to investigate the behavior of an object in real time.

The paper presents an analysis of the theoretical foundations of the Petri Nets and the adequacy of their application for the transport processes simulation. It is shown that the Petri Nets allow to study in depth the behavior of a simulated system and to obtain information about its most important characteristics. It also takes into account that the logistic systems for the agricultural products delivery should be considered as systems for parallel processing of information and parallel operation of facilities. Modeling via the Petri Nets enables to track and analyze the results, the same way as to predict and control the forwarding cargo process (e.g. agricultural products) in various logistic systems.

The advantages of the Petri Nets app are the low complexity of model development and the possibility to simulate adequately, even with a small amount of source information. During the simulation it was found that this tool allowed to analyze and to forecast the work for all system participants, to calculate quickly the parameter values for each specific control object in logistic system.

As an example, it's provided the case-study set concerning simulation in three options agro-products delivery from Ukraine to the Netherlands with the use of the Petri Nets environment. The set can be applied in the system of students' study and research activities in transport area of expertise.

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