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APPROACH TO INTELLECTUALIZATION OF COMPLETE SUPPLY CHAIN MANAGEMENT PROCESSES USING FUZZY EXPERT SYSTEMS

Yuri Romanenkov, Yashar Rahimi, Danova Mariia, Feoktystova Olena, Shostak Igor "Approach to intellectualization of complete supply chain management processes using fuzzy expert systems". *It is shown that in order to increase the efficiency of the functioning of complete logistical supply chains (CLSC), it is* *necessary to develop special methodological tools, and, on their basis, software to facilitate decision-making on the timely formation of liquid consignments at the terminal sections of the chain of liquid goods. The article describes a fuzzy network of CLSC in the form of a hierarchical two-level nested Petri net (NPN), the upper level of which reproduces the process of functioning of the focal company as the central element of the CLSC, and each of the components of the lower level of the network model is an elementary Petri net reflecting the logistic processes at the terminal sections of the CLSC production of raw materials and sale of finished products. This article also gives a description of the procedure for creating a fuzzy network model for representing information about business processes that take place during the functioning of the CLSC, taking into account the existing time and resource constraints, in the form of a NPN, which is expanded by introducing fuzzy and temporal statements. Special methods of automated decision- making on the sustainable functioning of CLSCs are described and justified in terms of making a choice on the transport mode and optimal routing. Based on the developed methodological tools, the process of forming and providing the stable functioning of the CLSC for typical food products of the grocery group, namely dried fruits, is considered.*

Keywords: complete supply chain, transport logistics, focal company, retailers. Nested Petri net, temporal statement theory, fuzzy theory, expert system.

Романенков Юрій, Яшар Рахімі, Данова Марія, Феоктістова Олена, Шостак Ігор “Підхід до інтелектуалізації процесів управління повними ланцюгами поставок з використанням нечітких експертних систем”. *Показано, що для підвищення ефективності функціонування повних логістичних ланцюжків поставок (CLSC) необхідно розробити спеціальні методичні інструменти і на їх основі програмне забезпечення для полегшення прийняття рішень щодо своєчасного формування наливних партій вантажів. На кінцевих ділянках ланцюжка наливних вантажів. У статті описується нечітка мережа CLSC у вигляді ієрархічної дворівневої вкладеної мережі Петрі (NPN), верхній рівень якої показує процес функціонування фокальної компанії як центрального елементу CLSC, а кожен з компонентів нижнього рівня мережевої моделі є елементарна мережа Петрі, яка відображатиме логістичні процеси на термінальних ділянках CLSC з виробництва сировини та реалізації готової продукції. У цій статті також дається опис процедури створення нечіткої мережної моделі для представлення інформації про бізнес-процеси, що відбуваються під час функціонування CLSC, з урахуванням існуючих тимчасових і ресурсних обмежень, в формі NPN, яка є розширенням за рахунок введення нечітких і тимчасових тверджень. Описані та обгрунтовані спеціальні методи автоматизованого прийняття рішень про стійке функціонування CLSC з точки зору вибору виду транспорту та оптимального маршруту. На основі розробленого методичного інструментарію розглядається процес формування та забезпечення стабільного функціонування CLSC для типових харчових продуктів продуктової групи - сухофруктів.*

Ключові слова: повний ланцюжок поставок, транспортна логістика, головна компанія, роздрібні торговці, вкладена мережа Петрі, теорія часових рядів, нечітка теорія, експертна система.

Романенков Юрий, Яшар Рахими, Данова Мария, Феоктистова Елена, Шостак Игорь “Подход к интеллектуализации процессов управления полными цепями поставок с использованием нечетких экспертных систем". *Показано, что для повышения эффективности функционирования полных логистических цепочек поставок (CLSC) необходимо разработать специальные методические инструменты и на их основе программное обеспечение для облегчения принятия решений по своевременному формированию наливных партий грузов. На конечных участках цепочки наливных грузов. В статье описывается нечеткая сеть CLSC в виде иерархической двухуровневой вложенной сети Петри (NPN), верхний уровень которой показывает процесс функционирования фокальной компании как центрального элемента CLSC, а каждый из Компонентов нижнего уровня сетевой модели представляет собой элементарную сеть Петри, отражающую логистические процессы на терминальных участках CLSC по производству сырья и реализации готовой продукции. В этой статье также дается описание процедуры создания нечеткой сетевой модели для представления информации о бизнес-процессах, происходящих во время функционирования CLSC, с учетом существующих временных и ресурсных ограничений, в* *форме NPN, которая является расширением за счет введения нечетких и временных утверждений. Описаны и обоснованы специальные методы автоматизированного принятия решений об устойчивом функционировании CLSC с точки зрения выбора вида транспорта и оптимального маршрута. На основе разработанного методического инструментария рассматривается процесс формирования и обеспечения стабильного функционирования CLSC для типичных пищевых продуктов продуктовой группы - сухофруктов.*

Ключевые слова: полная цепочка поставок, транспортная логистика, координационная компания, розничные торговцы, вложенная сеть Петри, теория временных рядов, нечеткая теория, экспертная система.

Introduction. In the modern world, the efficiency of business processes at the regional, national and global levels largely depends on the quality of the of logistical systems development. The typical object here is the complete food supply chain (CLCS), which is a complex socio-economic system consisting of a large number of raw material suppliers, a focal company (processing and packaging), warehouse terminals, distributors, customs brokers, 3PL and 4PL providers, retailers. The interaction between the participants of the CLCS is reflected by a multitude of continuous material, financial, and information flows and services from sources of raw materials to the end consumer. The variety of regions of the world from which supplies are made, a wide range of goods, yields, fluctuations in exchange rates, customs tariffs, seasonality, cause a high level of uncertainty in the processes of formation and decision-making by the participants of the CLCS. By its nature, CLCS is a complex stochastic system which functioning is characterized by the following features: a relatively large number of independent participants in business processes; difficulty to formalize the nature of the interactionы among the CLCS participants who are often competitors; high dynamics of changes within the system; non-stationarity of the majority of processes that take place during the functioning of the CLCS.

These circumstances determine the insufficient effectiveness of the existing means of information support for the CLCS, and necessitate their modernization, by expanding the concept of SCM (supply chain management), by supplementing knowledge with oriented methods, to achieve a conjunctive consensus between the participants of the CLCS.

A significant contribution to the development of issues related to the information technologies and systems use for the CLCS life cycle managing was made by such national and foreign scientists as: A.K. Pokrovsky, A.N. Kotlubay, V.A. Zubenko, R.S. Bespalov, L. Brodetsky, M. Christopher, J. Stock, J. Kloss, D. Bowersox, M. Wagner and others. Outstanding results in this direction have been obtained by several research centers such as Dassault Systemes (France), Siemens PLM Software (Germany), Unigraphics (USA), etc. Along with this, the specifics of the CLCS functioning does not allow the direct using of the corresponding standard means of automating the processes of interaction among the participants in the chain, since these developments do not provide an effective solution to the entire complex of tasks of information support of processes within the entire chain. In addition, the presence of a theoretical basis in the form of elements of the theory of Petri nets, the theory of temporal statements and fuzzy mathematics makes it possible, through theoretical generalization, to create a methodological basis for organizing transportation between the elements of the CLCS in the "just-in-time" mode. Based on this, there is a need for further development of methods and means of information support for CLCS management processes, in terms of ensuring transportation, in order to create a special applied information technology. Thus, increasing the efficiency of PCP functioning by ensuring the timeliness of deliveries within the chain, through the development and implementation of information support technology for the transportation of goods in terms of ensuring the "just-in-time" mode, is an urgent scientific task to be solve for achieving a par5ticular benefit in application.

The purpose of the article is to outline an approach to the rational organization of business processes associated with the most important aspect in the life cycle management of the CLCS - namely ensuring efficient transportation of goods within the entire supply chain.

Problem Statement. Improving the efficiency of cargo transportation within the framework of the CLCS based on the methods and means of artificial intelligence is a complicated and complex problem. One of the options for solving this problem is to implement a set of the following particular tasks consistently.

1. Develop a network model of the complete supply chain that would adequately reflect the hierarchy of the chain, namely its upper level (a focal company for the processing of raw materials) and lower levels reflecting the activities of suppliers of raw materials and finished products distributors.
2. Develop a method for representing time dependencies between business processes in the complete supply chain, which would provide an opportunity to identify deviations in the functioning of the chain and assess the extreme values of these deviations in order to comply with the principle of "just- in- time".
3. Synthesize a method for making decisions on the choice of a optimal transportation route within a complete logistical chain, which would provide an opportunity to reduce the level of uncertainty on time and financial costs in the supply chain operation.

The solution of the above tasks will make it possible to develop an intelligent technology of information support for the functioning of the complete logistics supply chain in terms of organizing cargo transportation.

Basic material and results. Effective supply chain management is not possible without analyzing them at various levels - strategic, tactical and operational [1].

At the strategic level, the tasks of designing the CLCS and determining the size of service facilities are solved, taking into account international, national and regional features of the development of transport systems. As part of the CLCS, the main terminals, distribution centers, consolidation warehouses are determined, between which regular transportation of raw materials and finished products is carried out (main routes). Other objects in the CLCS are served using a variety of secondary transportation routes.

Based on demand forecasting, the tasks of purchasing and distributing within the service network are solved, taking into account the urgency of supplies, the range of supplied raw materials and the distribution of finished products, the seasonality of production and sale of food products, and the level of transport costs in the supply chains. Based on the amount of transport costs, the problem of determining tariffs for transport services is solved, taking into account the "price / quality" ratio and the dynamics of the use of rolling stock.

At the tactical level of providing transport and logistical services, the plans for the transportation of goods are adjusted taking into account the Bullwhip effect, uneven demand, the presence of rolling stock at the nodes of supply chains. At this stage, based on the chosen strategy for distributing products through sales channels, the scheduling of product delivery by main and subordinate routes is carried out, taking into account the frequency of service, the capacity of warehouses and terminals, and the compatibility of the transported products.

Network management methods can be used while developing models of supply chains, [2-4].

Figure 1 shows the structure of a typical CLCS. The focal company (node # 8) receives material resources from three suppliers (nodes # 1, 3, 7). The first supplier works through intermediaries, the third supplier works through intermediaries and directly, the seventh supplier carries out direct deliveries. The focal company (node # 8) uses both direct and indirect channels to market finished products. Nodes ## 9, 10, 11 and 14 represent sales resellers, and Nodes ## 12, 13 and 15 represent retailers.

When analyzing the functioning of the CLCS using network models, the concepts of "central node" of the network and "subnet" form the foundation. The central node of the network is the focal company. A subnet is a part of a network, a collection of connected links. The left and right subnets in the network are selected. The left subnet is formed by the central link and all the links that are involved in the supply of raw materials (primarily fresh fruit) to the focal company. The right subnet is formed by the central link, sales intermediaries and retailers.

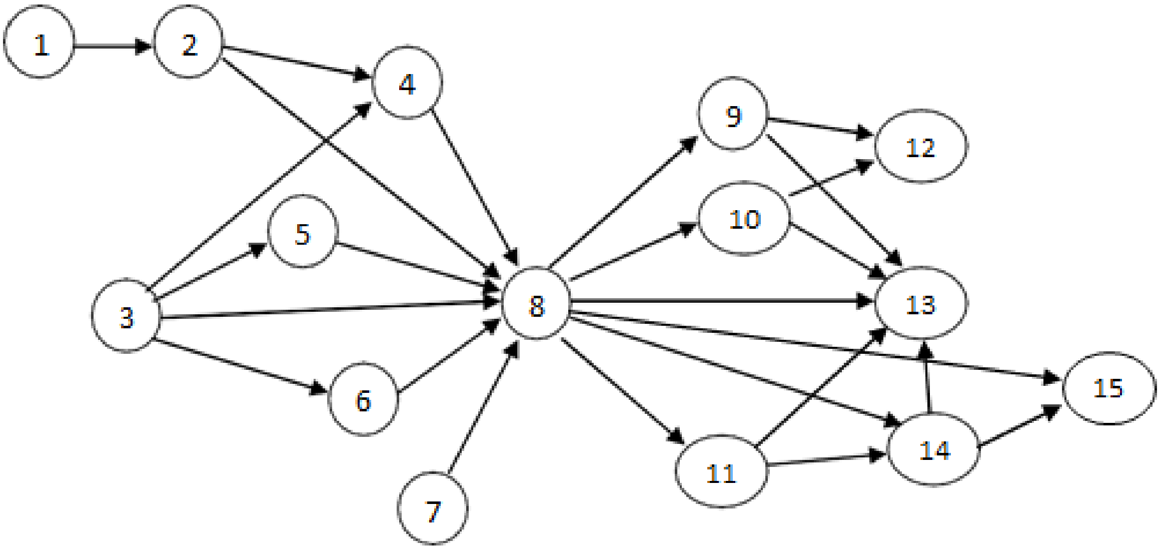


Figure 1 –Network model of a typical CLCS

Unlike the classical network model of management, the network model of the CLCS has a number of the specific features: the main elements of the supply chain are nodes and material flows; the goals of the subnets in the CLCS are different; the CLCS network model always has the central node and subnets; there is no concept of "critical path" for the CLCS network model; the supplies of one subnet within the CLCS are relatively independent of the supplies of the other subnet.

The development of an effective CLCS involves solving a set of tasks related to minimizing logistical costs for both the focal company and other participants in the chain. To formalize the problem under consideration, we will separately consider the planned indicators of purchases, sales, and costs for the left and for the right subnets of the CLCS. Let the size of the production program of the focus company be equal to the plan for selling products by retailers. Assume that the prices on the purchased raw materials and sold finished products are stable [5].

The planned demand of the focal company for the raw materials is:

$$M_l = \sum_{i=1}^{m} R_{li} \times Q_i,$$

where R_{li} – consumption rate of l-th type of raw material for production of the i-th type of the product; m – product range of the focal company moved within the logistical chain; Q_i – product volume required to fulfil the production plan of the focal company.

The planned volume of products manufactured by the focus company is determined based on the production (sales) plan, taking into account a set of factors that determine the current and future demand for products:

$$Q_i = \sum_{j=1}^{n} P_j \times k_{ij},$$

where Pj – production plan (sales) of the j-th product ; kij – volume of the i-th type of raw material used in production of the j-th type of product; n – number of items in the range of sold products. Logistic costs associated with the procurement of raw materials (costs of the left subnet of the supply chain):

$$Z_1 = \sum_{p=1}^{u} \sum_{l=1}^{t} Z_{lp},$$

where Z_{lp} – delivery costs of the l-th type of raw materials from the p-th supplier; u – number of suppliers; t – range of supplied raw materials.

The sales plan is determined based on research of target market segments:

$$P_j = \sum_{k=1}^{s} P_{jk},$$

where P_{jk} – sales plan of the j-th type of product for the k-th segment; s – the number of segments.

Delivery costs associated with the sales of finished products (costs in the right subnet):

$$Z_2 = \sum_{k=1}^{s} \sum_{j=1}^{n} Z_{jk},$$

where Z_{jk} – delivery costs on the j-th type of product in the k-th segment.

The objective function, which assumes minimization of the total logistical costs of the focal company related to procurement and sales, is:

$$Z = Z_1 + Z_2 \rightarrow min.$$

The solution to this problem is the selection of suppliers of raw materials and the volumes of these supplies, as well as the selection of links in the distribution network and the distribution of batches of finished products among them.

The process of creating, deploying and supporting the functioning of a CLCS can be adequately represented in the form of a hierarchical two-level nested Petri net framework (NPN) [6]:

$$IPN =< SN^{(1)}, EN_1^{(2)},..., EN_m^{(2)} >$$

where $\mathrm{SN}^{(1)}$ – system network simulating the process of functioning of a focal company; $\mathrm{EN}_1^{(2)}, \ldots, \mathrm{EN}_\mathrm{m}^{(2)}$ – a set of elementary Petri nets each of which simulates the processes of raw material procurement, production and packaging of finished products.

In this case, the network model of the CLCS is a tuple:

$$\mathrm{IPN} =< \mathrm{N}, \mathrm{C}, \mathrm{W}, \mathrm{G}, \Omega, \mathrm{M}_0 >$$

where $\mathrm{N} = (\mathrm{P}, \mathrm{T}, \mathrm{F})$ – finite network with multiple positions P, the set of transitions $\mathrm{T_i}$ by the incidence relation F; $\mathrm{C} : \mathrm{P} \rightarrow \Omega$ - position coloring function that maps each position of $\mathrm{p} \in \mathrm{P}$ its color $\mathrm{C(p)}$; W- a function that assigns to the arrows of network N the expressions of the type

$$((\mathrm{p},\mathrm{t}),(\mathrm{t}',\mathrm{p}')) \in \mathrm{F} : (\mathrm{Type}(\mathrm{W}(\mathrm{p},\mathrm{t})) = \mathrm{M}(\mathrm{C}(\mathrm{p}))) \vee$$
$$\vee(\mathrm{Type}(\mathrm{W}(\mathrm{t}',\mathrm{p}')) = \mathrm{M}(\mathrm{C}(\mathrm{p}')));$$

where $\mathrm{G} : \mathrm{T} \rightarrow \mathrm{L}$ - the function which matches every transition $\mathrm{t} \in \mathrm{T}$ and some expressions of Boolean logics which reflect the corresponding event; M_0 – the function which matches every position of $\mathrm{p} \in \mathrm{P}$ the following expression:

$$\forall \mathrm{p} \in \mathrm{P} : (\mathrm{Type}(\mathrm{M}_0(\mathrm{p}) = \mathrm{M}(\mathrm{C}(\mathrm{p}))))$$

The function M_0 determines the initial markup of the NPN that includes the determination of the color of the markers and reflects a specific production situation because the focal company has the finished products in the warehouse.

The NPN class gives an opportunity to reflect the hierarchical structure of the CLC in an adequate manner. At the same time, there is no mechanism for reflecting time in this kind of Petri nets. Based on this, in order to comply with the 'just-in-time' principle, it is critically important to expand the model presented in the form of NPN in the aspect of taking into account time dependences.

To build a model for the explicit representation of time during the functioning of the CSC, it is necessary to implement the following steps [7]:

1. Select base primitives of time and define base relationships between them
2. Introduce the necessary elementary functions for transforming primitives and relations.
3. Represent the properties of the structure of time using axioms that determine the basic properties of time and the properties of basic relations.
4. Describe a way to represent time dependencies.
5. Choose a method to associate logical statements with time.
6. Synthesize the theory of temporary statements.

At the first stage of the knowledge model synthesis, taking into account time dependencies, moments and / or time intervals are used as basic primitives. If necessary, time constants are used to indicate the moments of time and intervals (seconds, minutes, hours, days, dates, time, etc.), besides, the primitive "Duration" is used, with the help of which the distance between the moments of time is set up.

The second stage: some of the functions are built on the basic relations and are their functional version; the functions allow converting between temporary primitives.

At the third stage of the model synthesis, it is necessary to specify the connection among several primitives of time in the form of the corresponding axioms, taking into account the properties (discreteness / continuity) of time, characteristics of individual elements of the CLSC; at the fourth stage, a method for describing time dependences (time model) is chosen.

The fifth stage of the synthesis of the model of time dependencies involves the use of approaches that have good expressiveness.

At the last, sixth stage, it is necessary to define the basic temporary statements, and set up their properties using a set of axioms.

The information about the current state of tasks scheduled for execution is updated in the model $\mathrm{SN}^{(1)}$ based on data from the lower-level models $\mathrm{EN}_1^{(2)}, \ldots, \mathrm{EN}_m^{(2)}$. According to the rules for the functioning of the CSC, the tasks are checked in order to determine the facts of deviations and the magnitude of the task delays.

The set of all planned tasks will be denoted by Z. In this case, there is a mapping $ZP\colon\ Z \rightarrow\ P$, which specifies the correspondence of the state of production tasks to the network positions $\mathrm{SN}^{(1)}$. The current status of a task $z_i \in Z$ has the *Status* attribute, which determines whether it belongs to the set of started Φ^n, in the process of execution of Φ^w, or completed Φ^r tasks.

The timeliness of the implementation of tasks is characterized by the attribute *Timeliness*, which determines task affiliation of z_i to $\overline{W}$ or $\widetilde{W}$, where $\overline{W}$ is a set of issued or completed assignments within the predetermined delivery schedule, and $\widetilde{W}$ is a set of tasks which execution or delivery time was delayed due to the influence of various kinds of external or parametric disturbances, moreover $\overline{W} \cap \widetilde{W} = \varnothing$ and there is a reflection such that $ZW : Z \rightarrow (\overline{W} \cup \widetilde{W})$. Tasks are divided into procurement-related Z^k (procurement of raw materials, production and packaging) and transportation-related Z^a, $Z = \left\{Z^k \cup Z^a\right\}$, where $Z^k \cap Z^a = \varnothing$. There are such bijective mappings $Z^k \to B$ and $Z^a \to ((P \setminus B) \setminus R)$.

In order to activate the $\mathrm{SN}^{(1)}$ set of events, which are the results of the tasks' performance in the process of their functioning of CLSC, is reflected by the elements of the set of all the events $E^a = \left\{E^{p\phi} \cup E^d\right\}$, where $E^{p\phi}$ are the events of actual and planned start/|end of a task while $E^{p\phi} \to E$, where E^d are job status check events at the beginning of each monitoring cycle. The events from the set E^a change the features of tasks at the time moments from the set $T = \left\{T^p \cup T^f\right\}$, $T^p \cap T^f = \varnothing$, where T^p is a set of the check time moments at the beginning of every monitoring cycle which have taken place since the CLSC started, and T^f is a set of check time moments at the beginning of every monitoring cycle of the current state of the CLCS.

The purpose of the developed method is to identify deviations from the schedule when performing tasks during the functioning of the CLCS and to formulate instructions for stabilizing the current state of the chain.

The first stage of the method (steps 1-4) is carried out in parallel, asynchronously and cyclically during each cycle of monitoring the links of the logistics chain, this makes it possible to take into account the current state of its individual links in the process of supporting decision-making on the implementation of CLCS.

The second stage of the method (steps 5-7), in the case of time delays, makes it possible to form solutions to stabilize the CLCS functioning.

The initial state (CLCS start) is assigned as follows: $\forall z_i \in \overline{W} \wedge \forall z_i \in \Phi^n$, $\exists Z^p : Z^k \to Z^a$.

1. In case of the events $e_{\mathrm{j}}^{\phi} \in E^{p\phi}$ of actual tasks changes state, where $j \in \left\{\text{нач}, \text{оконч}\right\}$, *нач* is a task's start and *оконч* is the task's end:

- if $e_{\text{нач}_{z_i}}^{\phi}$ is the change of Φ^n and Φ^w sets' content occurs through: $\Phi_k^n = \Phi_{k-1}^n - \varphi_{z_i}^{\Phi^n} \quad \wedge \quad \Phi_k^w = \Phi_{k-1}^w + \varphi_{z_i}^{\Phi^n}$, where k is the next cycle of monitoring the current state of CLCS;
- if none of these events occurs for any task, go to step 2.

2. In case of events $e_{\mathrm{j}}^{pl} \in E^{p\phi}$ of the planned changes of tasks' state, where $j \in \left\{\text{нач}, \text{оконч}\right\}$, *нач* – the start of task's performance and *оконч* – the end of a task's performance:

- if $e_{\text{нач}_{z_i}}^{pl}$ for $\forall z_i \middle| z_i \in \overline{W} \wedge z_i \in \Phi^n \wedge t_{\text{нач}_{z_i}}^{pl} \in$ $\in T^p \wedge t_{\text{нач}_{z_i}}^{\phi} \in T^f$ the change in the composition of the sets $\overline{W}$ and $\widetilde{W}$ occurs through: $\overline{W}_k = \overline{W}_{k-1} - \omega_{z_i}^{\overline{W}} \;\wedge\; \widetilde{W}_k = \widetilde{W}_{k-1} + \omega_{z_i}^{\overline{W}}$
- if $e_{\text{оконч}_{z_i}}^{pl}$ for $\forall z_i \middle| z_i \in \overline{W} \wedge \forall z_i \in \Phi^w \wedge$ $\wedge\, t_{\text{оконч}_{z_i}}^{pl} \in T^p \wedge t_{\text{оконч}_{z_i}}^{\phi} \in T^f$ the change in the composition of the sets $\overline{W}$ and $\widetilde{W}$ occurs through: $\overline{W}_k = \overline{W}_{k-1} - \omega_{z_i}^{\overline{W}} \quad \wedge$ $\widetilde{W}_k = \widetilde{W}_{k-1} + \omega_{z_i}^{\overline{W}}$;
- if $e_{\text{оконч}_{z_i}}^{pl}$ for $\forall z_i \middle| z_i \in \widetilde{W} \wedge z_i \in \Phi^r \wedge$ $\wedge\, (t_{\text{оконч}_{z_i}}^{\phi} \le t_{\text{оконч}_{z_i}}^{pl})$ – the change in the composition of the sets $\overline{W}$ and $\widetilde{W}$ occurs through: $\widetilde{W}_k = \widetilde{W}_{k-1} - \omega_{z_i}^{\widetilde{W}} \wedge \overline{W}_k = \overline{W}_{k-1} + \omega_{z_i}^{\widetilde{W}}$
- if none of these events occurs for any task, go to step 3.

3. In case of events' initiation of $e_{\mathrm{K}_j}^{ch} \in E^d$ task's status check, where K is a set of indices, $\mathrm{K} = \left\{\varphi\varphi, \omega\omega, bb\right\}$, $\varphi\varphi$ – task's status check, $\omega\omega$ – task's timeliness check, bb - task's delay check: '

- if $e^{ch}_{\varphi\varphi_{z_i}}$ for $\forall z_i | z_i \in \Phi^w \wedge t^{pl}_{\text{оконч}_{z_i}} \in T^f \wedge \wedge t^{\phi}_{\text{оконч}_{z_i}} \in T^f \wedge t_{\text{проверки}_{z_i}}$ calculating the current duration of the task goes as $dur^w_{z_i} = t_{\text{проверки}_{z_i}} - t^{\phi}_{\text{нач}_{z_i}}$;

- if $e^{ch}_{\omega\omega_{z_i}}$ for $\forall z_i | z_i \in \Phi^w \wedge z_i \in \widetilde{W} \wedge \wedge t_{\text{проверки}_{z_i}}$ calculating the current duration of the task with delay goes as $dur^r_{z_i} = t_{\text{проверки}_{z_i}} - t^{pl}_{\text{оконч}_{z_i}}$;

- if $e^{ch}_{bb_{z_i}}$ for $\forall z_i | z_i \in \Phi^r \wedge z_i \in \widetilde{W} \wedge \wedge (t^{pl}_{\text{оконч}_{z_i}} \le t^{\phi}_{\text{оконч}_{z_i}})$ the change in the composition of the sets $\overline{W}$ and $\widetilde{W}$ occurs through: $\widetilde{W}_k = \widetilde{W}_{k-1} - \omega^{\widetilde{W}}_{z_i} \wedge \overline{W}_k = \overline{W}_{k-1} + \omega^{\widetilde{W}}_{z_i}$.

- if none of these events occurs for any task, go to step 4.

4. For every task $z_i \in Z^a$, which must be performed during the functioning of the CLCS, the execution lag is checked through $dur^r_{z_i}$ of the tasks which compose it, the delay value is calculated as $dur_{max} = \max_i (dur^r_{z_i})$ and determined that dur_{max} will constitute the overall delay within the complete supply chain (CSC).

5. Defining a consumer for a task $z_i \in Z^a$, by analyzing the delivery route and transmitting information about the fluctuations during the CSC functioning to the decision-maker.

6. Determining the presence of a critical situation by comparing the duration of the delay dur_{max} of the task $z_i \in Z$ with the critical values of the task's slack.

7. Enabling the rules of the critical node in the network diagram $\mathrm{SN}^{(1)}$ and developing decisions on the stabilization of the CSC status.

8. The execution of the method will end under the conditions if the current state of all tasks has the status "Completed", that is, the functioning of the CSC is completed.

To determine the mode of transport for the dried fruits delivery, it is necessary to take into account the six main factors influencing decision-making process: delivery time; transportation costs; compliance with the delivery schedule; frequency of departures; variety of good to be shipped, and the ability to deliver cargo anywhere. In the process of purchasing and delivering material resources within the CSC, as well as distributing finished products to consumers, a focal company can use various types of transport, various logistical partners and various transportation options [6].

The selection of the optimal mode of transport for the formation of the CSC will be carried out while considering that the delivery time and costs are the optimization criteria. The choice of the type of transport will be carried out using artificial intelligence methods, namely fuzzy modeling.

Let us make a choice of the mode of transport for the supply of raw materials and supplies from raw material suppliers to the focal company (the left side of the network). For this purpose, we construct a fuzzy model [8] based on two binary fuzzy relations S and T. The first of these fuzzy relations is built on two basic sets X and Y, and the second - on two basic sets Y and Z. Here X describes the set of modes of transport by which the transportation can be carried out, Y - the set of transport options, and Z - transport characteristics. The fuzzy relation S meaningfully describes the relationship between the mode of transport and the transportation option, and T describes the assessment of various transportation options for each of the factors.

Specifically:

a) $X = \{x_1, x_2, x_3, x_4, x_5, x_6\}$;

b) $Y = \{y_1, y_2, y_3, y_4, y_5, y_6\}$;

c) $Z = \{z_1, z_2, z_3, z_4, z_5, z_6\}$.

The elements of the universes have the following meaning:

a) x_1 – «railway transport», x_2 – «roadway transportation», x_3 – «waterway transportation», x_4 – «pipeline transportation», x_5 – «air transportation», x_6 – «maritime transportation»;

b) y_1 – «unimodal», y_2 – «mixed», y_3 – «combined», y_4 – «intermodal», y_5 – «terminal», y_6 – «multimodal»;

b) z_1 – «delivery time», z_2 – «delivery frequency», z_3 – «schedule reliability», z_4 – «handling variety of cargo», z_5 – «ability to deliver goods in any geographical point», z_6 – «delivery costs».

Specific values of membership functions $\mu_S(<x_i, y_j>)$ and $\mu_T(<y_j, z_k>)$ of the considered fuzzy relations are presented in matrices (1) and (2).

The matrices of these fuzzy relations are as follows:

$$M_S = \begin{bmatrix} 0{,}5 & 0{,}7 & 0{,}3 & 0{,}2 & 0{,}3 & 0{,}3 \\ 0{,}1 & 0{,}8 & 0{,}8 & 0{,}3 & 0{,}7 & 0{,}5 \\ 0{,}8 & 0{,}7 & 0{,}8 & 0{,}3 & 0{,}3 & 0{,}3 \\ 0{,}3 & 0{,}3 & 0{,}2 & 0{,}2 & 0{,}2 & 0{,}2 \\ 0{,}8 & 0{,}3 & 0{,}4 & 0{,}3 & 0{,}3 & 0{,}3 \\ 0{,}1 & 0{,}8 & 0{,}9 & 0{,}4 & 0{,}7 & 0{,}5 \end{bmatrix}, \qquad (1)$$

$$M_T = \begin{bmatrix} 0{,}8 & 0{,}6 & 0{,}4 & 0{,}3 & 0{,}3 & 0{,}3 \\ 0{,}4 & 0{,}6 & 0{,}5 & 0{,}7 & 0{,}3 & 0{,}5 \\ 0{,}3 & 0{,}7 & 0{,}7 & 0{,}9 & 0{,}3 & 0{,}6 \\ 0{,}4 & 0{,}5 & 0{,}6 & 0{,}8 & 0{,}9 & 0{,}7 \\ 0{,}4 & 0{,}5 & 0{,}6 & 0{,}8 & 0{,}9 & 0{,}8 \\ 0{,}4 & 0{,}5 & 0{,}6 & 0{,}8 & 0{,}9 & 0{,}7 \end{bmatrix} \qquad (2)$$

The result of a fuzzy composition of fuzzy relations (1) and (2) can be presented as a matrix of the resulting fuzzy relationship:

$$M_{S*T} = \begin{bmatrix} 0{,}5 & 0{,}6 & 0{,}5 & 0{,}7 & 0{,}3 & 0{,}5 \\ 0{,}4 & 0{,}7 & 0{,}7 & 0{,}8 & 0{,}7 & 0{,}7 \\ 0{,}8 & 0{,}7 & 0{,}7 & 0{,}7 & 0{,}3 & 0{,}6 \\ 0{,}3 & 0{,}3 & 0{,}3 & 0{,}3 & 0{,}3 & 0{,}7 \\ 0{,}8 & 0{,}6 & 0{,}4 & 0{,}4 & 0{,}3 & 0{,}3 \\ 0{,}4 & 0{,}7 & 0{,}7 & 0{,}9 & 0{,}7 & 0{,}7 \end{bmatrix}. \qquad (3)$$

As an example, consider the procedure for calculating one of the values of the membership function, specifically, $\mu_{S*T}(<x_1, z_1>)=0{,}5$. First, the minimum values of the membership function of all pairs of elements of the first row of the matrix (6) are given and the first column of the matrix (7) is calculated as $min\{0{,}5\ 0{,}8\}=0{,}5$; $min\{0{,}7\ 0{,}4\}=0{,}4$; $min\{0{,}3\ 0{,}3\}=0{,}3$; $min\{0{,}2\ 0{,}4\}=0{,}2$; $min\{0{,}3\ 0{,}4\}=0{,}3$; $min\{0{,}3\ 0{,}4\}=0{,}3$. After that, the maximum of 6 obtained values is determined, which will be the desired value of the membership function: $\mu_{S*T}(<x_1, z_1>)=max\{0{,}5\ 0{,}4\ 0{,}3\ 0{,}2\ 0{,}3\ 0{,}3\}=0{,}5$. The rest of the values of the membership function are found in a similar manner.

As a result of the analysis of the calculated values of the membership function, the best option according to the criteria "Delivery time" and "Delivery cost" will be the use of road transport, since the membership functions are equal to $\mu_{S*T}(<x_3, z_1>)=0{,}8$, $\mu_{S*T}(<x_3, z_6>)=0{,}6$, respectively.

The solution to the problem of choosing a mode of transport does not in itself ensure the efficiency of the processes of dried fruits transporting within the CSC framework; the quality and speed of transportation is directly influenced by the optimal choice of the route. The safety of the cargo and the extraction of the actual maximum profit is achieved by drawing up an optimal route [5]. When drawing up an optimal route, it is necessary to take into account the location of the final point of delivery, the dimensions and weight of the cargo, as well as its characteristics. Taking into account the listed parameters, a necessary transportation vehicle is selected.

While designing the CLCS, a route which takes into account all the driver's possible stoppage places for meals and overnight accommodation as well as the customs control points is drawn up. In addition, it is necessary to take into account the state of the road surface and the time required for crossing the borders of other states as well as the characteristics of each region on the route of the cargo transportation. Also it is necessary to take into account the road's width. The quality of the pavement's surface and the weather conditions that affect the conditions of the road. To ensure just-in-time delivery, the speed limits on certain segments of the route must be considered.

In order to choose the optimal transportation route, it is recommended to build a fuzzy model in the MATLAB tool environment and develop an expert system while functionality will be based on fuzzy inferences. The interactive mode is provided by using the Fuzzy Logic Toolbox package, which is a part of the MATLAB environment [9].

Four fuzzy linguistic variables must be used as input parameters of the fuzzy inference system to determine the rational transportation route: weather conditions; the quality of the pavement surface; the number of speed limits encountered; time required for passing the customs post. In this case, the output variables will be: transportation time and transportation cost.

The Mamdani method is used as a fuzzy inference scheme; therefore, the activation method will be MIN [8]. The center of gravity method was used as a defuzzification method for the obtained result.

To build a fuzzy model for choosing an optimal transportation route, it is assumed that all considered input variables are measured in points in the range of real numbers from 0 to 10, where the lowest estimate of the value of each of the variables is 0, and the highest is 10.

Term set for the first input linguistic variable "Weather conditions" (Pogoda) are: T_1 *={"fair", "good", "excellent"}.* For the second input variable "Pavement quality" (Pokrutie): T_2 *={"bad", "medium", "excellent"}.* For the third input linguistic variable "Speed limits" (Ogran_skorosti) T_3 *={"very many", "many", "a few"}.* For the fourth input linguistic variable "The customs post passing" (Tamozhen_postu): T_4 *={"slowly", "fast", "very fast"}.*

As a term set of the first output linguistic variable "Delivery time" (Vrema): T_5 *={"excellent", "good", "medium", "bad", "very bad"}.* As a term set of the second output linguistic variable "Transportation cost" (Stoimost): T_6 *={"very low", " low ", "medium", "high ", "very high"}.*

The problem of fuzzy modeling was solved based on the Mamdani rule, while the parameters of the developed fuzzy model were proposed by MATLAB on default were the following items remained unchanged: logical operations (min for a fuzzy logical "AND", max for a fuzzy logical "OR"), implication method (min), aggregation method (max) and defuzzification method (centroid). After that, while solving the problem, the membership functions of the terms were determined for each of the four inputs and one output variable of the considered fuzzy inference system. Further, for the developed expert system, a knowledge base of 30 rules was formed. Figure 2 shows the editor of the rules included in the fuzzy knowledge base of the expert system, called by the *ruleedit* ('marschrut') function. Then the analysis of the constructed fuzzy inference system for the considered problem of choosing a rational route for the transportation of a batch of dried fruits along the international route is carried out. By entering the value of the input variables for the first option of the route, the value of the input variable "weather conditions" is set up as 5 points, the value of the input variable "Pavement quality" is 4 points, the value of the input variable "speed limit" is 6.8 points, and the value of the input variable "The customs post passing" is 7 points.

As a result, the fuzzy inference procedure implemented using the MATLAB system for the developed fuzzy model, gives the value of the output variables "Delivery time" and "Transportation cost", equal to 41.5 hours and 12.7 thousand UAH respectively.

```
1. If (pogoda is udovletvor) and (pokrutie is plohoy) and (ogran_iskoros is ochen_mnogo) and (tamozh_ipostu is medleno) then (vremia is ochen_plohoe)(stoimost is ochen_vusokai) (1)
2. If (pogoda is horoshuy) and (pokrutie is sredniy) and (ogran_iskoros is mnogo) and (tamozh_ipostu is bustro) then (vremia is srednee)(stoimost is udovletvor) (1)
3. If (pogoda is prevoshod) and (pokrutie is otlichnuy) and (ogran_iskoros is malo) and (tamozh_ipostu is ochen_bustro) then (vremia is otlichnoe)(stoimost is ochen_nizkai) (1)
4. If (pogoda is udovletvor) and (pokrutie is plohoy) and (ogran_iskoros is mnogo) and (tamozh_ipostu is bustro) then (vremia is plohoe)(stoimost is vusokai) (1)
5. If (pogoda is horoshuy) and (pokrutie is sredniy) and (ogran_iskoros is ochen_mnogo) and (tamozh_ipostu is medleno) then (vremia is plohoe)(stoimost is vusokai) (1)
6. If (pogoda is horoshuy) and (pokrutie is sredniy) and (ogran_iskoros is malo) and (tamozh_ipostu is ochen_bustro) then (vremia is horoshoe)(stoimost is nizkai) (1)
7. If (pogoda is prevoshod) and (pokrutie is otlichnuy) and (ogran_iskoros is mnogo) and (tamozh_ipostu is bustro) then (vremia is horoshoe)(stoimost is nizkai) (1)
8. If (pokrutie is sredniy) and (ogran_iskoros is mnogo) and (tamozh_ipostu is ochen_bustro) then (vremia is horoshoe)(stoimost is nizkai) (1)
9. If (pokrutie is otlichnuy) and (ogran_iskoros is mnogo) and (tamozh_ipostu is ochen_bustro) then (vremia is otlichnoe)(stoimost is ochen_nizkai) (1)
10. If (pokrutie is sredniy) and (ogran_iskoros is malo) and (tamozh_ipostu is ochen_bustro) then (vremia is otlichnoe)(stoimost is ochen_nizkai) (1)
11. If (pokrutie is plohoy) and (ogran_iskoros is ochen_mnogo) and (tamozh_ipostu is bustro) then (vremia is plohoe)(stoimost is vusokai) (1)
```

pogoda is	pokrutie is	ogran_iskoros is	tamozh_ipostu is	vremia is	sto
etvor	plohoy	ochen_mnogo	medleno	otlichnoe	ochen_nizkai
huy	sredniy	mnogo	bustro	horoshoe	nizkai
shod	otlichnuy	malo	ochen_bustro	srednee	udovletvor
	none	none	none	plohoe	vusokai
				ochen_plohoe	ochen_vusok
				none	none

Connection: ○ or ● and

Weight: 1

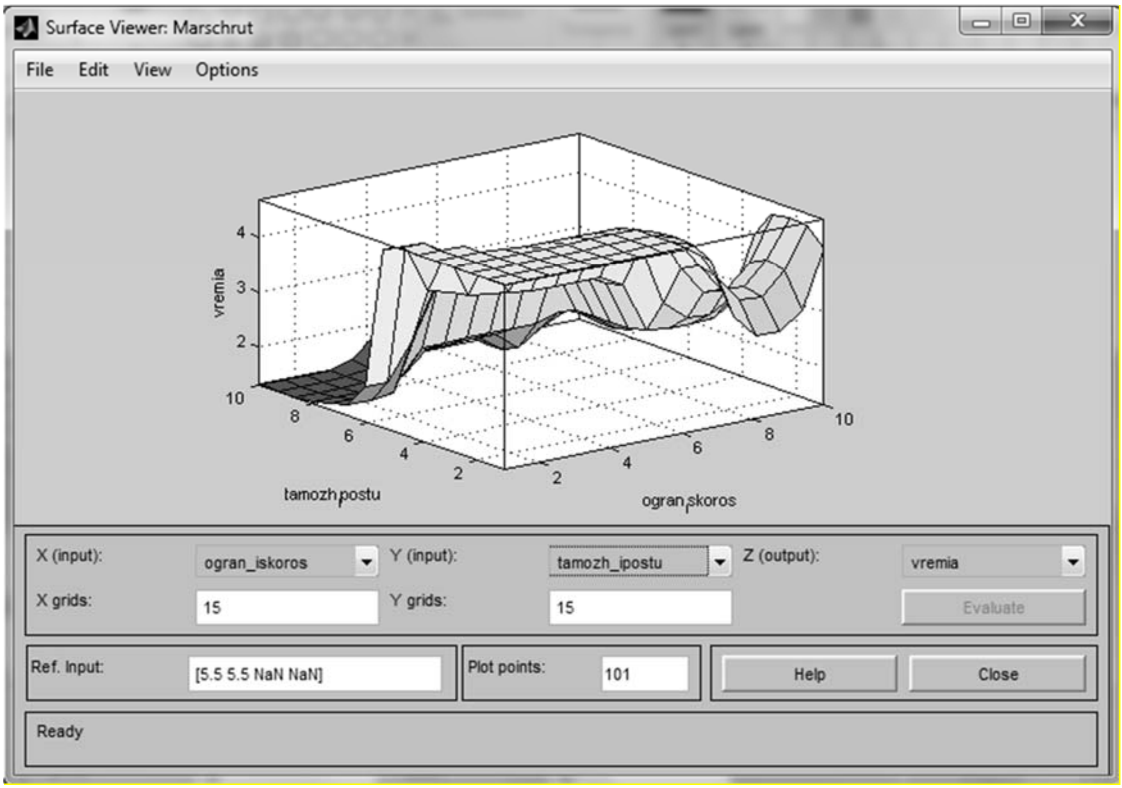
Renamed FIS to "Marschrut"

Figure 2 – The editor of the rules of the expert system of fuzzy knowledge base for selecting optimal transportation routes within the CSC framework.

For the second route, the value of the input variable "Weather conditions" was estimated as 5 points, the value of the input variable "Pavement quality" as 7 points, the value of the input variable "Speed limit" as 4.5 points, and the value of the input variable "The customs post passing" as 3.5 points. As a result, the fuzzy inference procedure made it possible to obtain the values of the output variables "Delivery time" and "Transportation cost" equal to 49.2 hours and 15.6 thousand UAH respectively. Obviously, based on the results obtained for this example, it is more profitable to transport goods within the framework of the CSC using the first route option.

The considered fuzzy model produces sufficiently adequate results. However, for achieving a higher level of precision, it is necessary to use additional rating methods of individual quantitative values for input and output linguistic variables. In practice, to solve this problem, it is reasonable to use such tools that would be highly transparent and visual and would facilitate an interface with the software system without having advanced knowledge and skills in the field of software engineering.

Figure 3 shows the visualization process of the fuzzy inference surface of the considered model for the input variables "Speed limits" and "The customs post passing". This visualization tool facilitates establishing the relationship between the output variable values and the individual input variables values of the fuzzy model. The analysis of these relationships serves as the basis for changing the membership functions of input variables or fuzzy rules in order to improve the adequacy of the fuzzy inference system.



X (input): ogran_iskoros
Y (input): tamozh_ipostu
Z (output): vremia
X grids: 15
Y grids: 15
Ref. Input: [5.5 5.5 NaN NaN]
Plot points: 101
Ready

Figure 3 – Visualization of the fuzzy inference surface for the output variable "Delivery time".

The visualization tools applied in Figure 3 enable the decision-maker to comprehensively assess the quality of the settings of the parameters in the fuzzy model, which, in fact, is an inference machine of the expert system and, if necessary, correct the parameter values.

Conclusions.

1. A model of the complete supply chain has been created in the form of a nested Petri net, which reflects the hierarchy of the chain structure, namely its upper level (focal company), and lower levels - raw material suppliers, providers and retailers.
2. A method is proposed for representing time dependences on the network model of the CSC, which makes it possible to identify fluctuations from the schedule during the operation of the circuit, and to assess the influence level of these fluctuations in order to comply with the "just-in-time" principle.
3. An advanced method for the formation of rational routes of cargo transportation within the framework of the CSC is described, which is based on fuzzy mathematics, and makes it possible to reduce the level of uncertainty of time and financial costs during the operation of the supply chain
4. The methodological tools developed in the course of the study served as the basis for the development of intelligent information technology to support the adoption of rational decisions on the organization of cargo transportation between the participants of the CSC, which enables to reduce financial and time risks.

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