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ORGANIZATION THE INFORMATION SUPPORT OF FULL LOGISTIC SUPPLY CHAINS WITHIN THE INDUSTRY 4.0

Abstract: *Ways to improve the efficiency of the functioning of complete logistic supply chain (CLSC) in the framework of the concept of Industry 4.0 are described. It is shown that the key features of Industry 4.0, namely the integration of production and network communications, the formation of direct links of production chains from ordering a product to receiving it by the consumer as soon as possible with maximum process efficiency, determine the inadequate effectiveness of traditional means for information supporting on the functioning of CLSCs. It is proposed to modernize the mathematical and information support of CLSC by supplementing the currently used AnyLogic modeling environment with artificial intelligence and knowledge engineering. The technology of multi-agent systems (MAS) has been used as such a tool. The use of MAS technology will provide the opportunity to adequately present in the AnyLogic environment the dynamics of CLSC functioning, taking into account a large number of heterogeneous, time-varying factors that directly affect the efficiency of CLSC functioning.*

Keywords: *Complete logistic supply chain; Industry 4.0; Multi-agent systems; Artificial intelligence; Knowledge engineering*

1. Introduction

The technologies that provide Industry 4.0, have a cardinal impact on the methods of conducting, organizing a business and providing its resources (Matyshenko et al., 2019a, 2019b). The introduction of these technologies leads to the emergence of new business models that fundamentally transform production, consumption, transportation and delivery systems (Ghadge et al., 2020; Memon et al., 2017).

The manifestations of the Industry 4.0 in the field of logistics consist in large-scale application in the creation of logistics digitalization systems, in particular, the technologies of the industrial Internet of things and BlockChain (Shostak et al., 2019). The introduction of these technologies in the creation, deployment and operation of logistics systems fundamentally changes all processes of transportation of goods, which will inevitably entail a reduction in both time and material costs (Digiteum, 2019).

One of the main factors determining the effectiveness of the functioning of the supply chain (SC) is the rational organization of transportation within the chain. At the same time, an important task arises of determining a rational route for the delivery of goods within the framework of the SC, taking into account a large number of heterogeneous factors affecting the cost of transportation and the strict implementation of their schedule.

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To analyze the effectiveness of logistics routes, there are currently a large number of different models and methods (Stoke & Lambert, 2005; Bowersox & Kloss, 2008) the choice of specific tools depends on factors that describe the dynamic functioning of a particular implementation of the chain.

The concept of building SC in the conditions of Industry 4.0 implies a comprehensive presentation of processes, starting from the production of raw materials and covers all suppliers of goods, services and information that add value to consumers and other interested persons (Wu et. al., 2016). Thus, the effective functioning of SC involves the integration of key business processes: customer relationship management; customer service; demand analysis; order management; ensuring production processes; supply management. At the same time, the main mechanism for increasing the efficiency of SC functioning is minimization of production costs, including by reducing the cost of transportation, subject to the principle of "just-in-time" (Shostak & Rahimi, 2018).

The aim of the article is to describe the process of developing a specialized expert system, with the implementation of a fuzzy knowledge conclusion, to support decision-making on the choice of a rational route in the framework of creating a complete logistics supply chain in "just-in-time" mode.

1.1. State of the Problem

The development of a decision support system for the formation of SC will make it possible to increase the efficiency of business processes in the chain by reducing financial and time costs, in particular, ensuring timely delivery of goods for sale to consumers. This effect will be achieved by reducing the risk of mistaken decisions by logisticians when organizing transportation within the SC. At the same time, there is the problem of using standard tools for developing expert systems due to the specifics of the subject area under consideration, which involves taking into account fuzzy factors in the functioning of SC. Thus, the problem described in this article is related to the synthesis of a fuzzy model of transport mode choosing to ensure efficient transportation within the supply chain, according to the criteria of minimum transport costs and delivery time. For solving this problem it is proposed by developing a special expert system with a fuzzy knowledge conclusion to support decision-making by logisticians in organizing transportation.

2. Experimental

The basis for choosing the type of transport that is optimal for a particular transportation is information about the characteristic features of various transport types (road, rail, sea, air).

Consider the advantages and disadvantages of using vehicles from the point of view of SC organization (Table 1).

To determine the type of transport for transporting goods, it is necessary to take into account six main factors that influence decision making: delivery time; transportation cost; reliability of adherence to cargo delivery schedule; frequency of departures; ability to transport various goods; ability to deliver cargo to anywhere.

In the process of procurement and delivery of material resources within SC, as well as distribution of finished products to consumers (Sergeyev, 2014), the manufacturer can use various types of transport, various logistics partners, as well as various transportation options (Wagner, 2006; Bespalov, 2007).

Let us select the optimal mode of transport for the formation of SC, considering the delivery time and delivery cost as a criterion of optimality. We will choose the type of transport using artificial intelligence methods, namely fuzzy modeling.

Table 1. Advantages and disadvantages of the transport types used in SC (Brodetskiy, 2006)

Transport type	Advantages	Disadvantages
Automobile transport	High maneuverability; door-to-door delivery with the necessary degree of urgency; regularity of delivery; the possibility of deliveries in small batches; the least stringent requirements for product packaging.	High cost of transportation; urgency of unloading; the possibility of theft of cargo and theft of vehicles; relatively low load capacity, etc.
Railway transport	Transportation of large consignments in any weather conditions; relatively fast cargo delivery over a long distance; regularity of transport; convenient organization of loading and unloading; relatively low cost of transportation of goods, the availability of discounts.	Low speed of movement; limited number of carriers; theft and loss; small possibility of delivery to points of consumption.
Sea transport	Low freight rates; high carrying capacity, etc.	Low speed; limited ability to deliver to points of consumption; stringent requirements for packaging and securing of goods; low frequency of shipments; dependence on weather and navigation conditions.
Air transport	The highest delivery speed; the ability to deliver to remote areas; high cargo safety	High freight rates; limited batch size; dependence on weather conditions (leads to unpredictability of delivery schedules).

As a rule, the apparatus of the theory of fuzzy relations is used in a qualitative analysis of the relationships between the objects of the system under study, when the links are dichotomous in nature and can be interpreted in terms of "link is present", "link is absent", or when the methods of quantitative analysis of relationships are inapplicable for any reason and relationships artificially reduced to a dichotomous appearance. For example, when the magnitude of the connection between objects takes values from the rank scale, the choice of the threshold for the strength of the connection allows you to convert the connection to the desired form.

Since each fuzzy relation is a fuzzy set, then with respect to fuzzy relations, all operations that apply to fuzzy sets are true. The operations of the algebraic product (Eq. (1)) and the algebraic sum (Eq. (2)) are performed over fuzzy relations (Pegat, 2011).

$$\mu_{Q*R}(x,y) = \mu_Q(x,y) \times \mu_R(x,y), \quad (1)$$

$$\mu_{Q+R}(x,y) = \mu_Q(x,y) + \mu_R(x,y) - \\ -\mu_Q(x,y) \cdot \mu_R(x,y) \quad (2)$$

where: $\mu_Q(x,y)$ – relationship membership function Q; $\mu_R(x,y)$ – relationship membership function R.

Let Q and R – finite or infinite binary fuzzy relations. Moreover, the fuzzy relation $Q=\{<x_i, x_j>, \mu_Q(<x_i, x_j>)\}$ is given on the Cartesian product of universes $X_1 \times X_2$, and the fuzzy relation $R=\{<x_j, x_k>, \mu_R(<x_j, x_k>)\}$ – on the Cartesian product of universes $X_2 \times X_3$.

The fuzzy binary relation defined on the Cartesian product $X_1 \times X_3$ and denoted by $Q \times R$, is called the composition of binary fuzzy relations Q and R, and its membership function is determined by the following expression (Pegat, 2011):

$$\mu_{Q*R}\left(<x_i,x_k>\right)= = \max_{x_i\in X_2}\left\{\min\left\{\begin{matrix}\mu_Q\left(<x_i,x_j>\right),\\ \mu_R\left(<x_j,x_k>\right)\end{matrix}\right\}\right\}, \quad (3)$$
$$\left(\forall <x_i,x_k>\in X1\times X3\right).$$

The composition of binary fuzzy relations defined in this way is called (max-min) —the composition or convolution of fuzzy relations; it can also be written in the following form (Pegat, 2011):

$$\mu_{Q*R}(<x_i,x_k>) = \vee_{x_i}\begin{pmatrix}\mu_Q(<x_i,x_j>)\\ \wedge\,\mu_R(<x_j,x_k>)\end{pmatrix}. \quad (4)$$

For (max-min) - composition of the relations Q and R, the operation $\wedge$ can be replaced by any other for which the same restrictions are fulfilled as for $\wedge$: associativity and monotonicity for each argument. Then:

$$\mu_{Q*R}(<x_i,x_k>) = = \vee_{x_i}\begin{pmatrix}\mu_Q(<x_i,x_j>)\ \times\\ \times\ \mu_R(<x_j,x_k>)\end{pmatrix}. \quad (5)$$

In particular, the operation $\wedge$ can be replaced by algebraic multiplication, then we speak of a (max-prod) -composition.

Let's make a choice of a type of transport for delivery of raw materials from suppliers to the manufacturer. To this end, we construct a fuzzy model based on two binary fuzzy relations S and T. The first of these fuzzy relations is built on two basis sets X and Y, and the second - on two basis sets Y and Z. Here X describes the set of modes of transport, according to which can be transported, Y is the set of transportation options, and Z is the set of factors that characterize the transportation. The fuzzy relation S informatively describes the relationship of the type of transport with the transportation option, and T describes the assessment of various transportation options for each of the factors.

For specificity:

- $X = \{x_1, x_2, x_3, x_4, x_5, x_6\}$;
- $Y = \{y_1, y_2, y_3, y_4, y_5, y_6\}$;
- $Z = \{z_1, z_2, z_3, z_4, z_5, z_6\}$.

Elements of universes have the following meaningful meaning:

- x_1 - “railway transport”, x_2 - “road transport”, x_3 - “water transport”, x_4 - “pipeline transport”, x_5 - “air transport”, x_6 - “sea transport”;
- y_1 - “unimodal”, y_2 - “mixed”, y_3 - “combined”, y_4 - “intervocal”, y_5 - “terminal”, y_6 - “multimodal”;
- z_1 - “delivery time”, z2 - “frequency of departures”, z_3 - “reliability of adhering to schedules”, z_4 - “ability to transport different goods”, z_5 - “ability to transport goods to any geographical point”, z_6 - “cost of transportation ".
- Specific values of the membership functions $\mu_S(<x_i,\ y_j>)$ and $\mu_T(<y_j,\ z_k>)$ considered fuzzy relationships are presented in Table 2 and Table 3.
- The matrices of these fuzzy relationships are:

$$M_S = \begin{bmatrix}0{,}5 & 0{,}7 & 0{,}3 & 0{,}2 & 0{,}3 & 0{,}3\\ 0{,}1 & 0{,}8 & 0{,}8 & 0{,}3 & 0{,}7 & 0{,}5\\ 0{,}8 & 0{,}7 & 0{,}8 & 0{,}3 & 0{,}3 & 0{,}3\\ 0{,}3 & 0{,}3 & 0{,}2 & 0{,}2 & 0{,}2 & 0{,}2\\ 0{,}8 & 0{,}3 & 0{,}4 & 0{,}3 & 0{,}3 & 0{,}3\\ 0{,}1 & 0{,}8 & 0{,}9 & 0{,}4 & 0{,}7 & 0{,}5\end{bmatrix}, (6)$$

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

Table 2. Fuzzy relationship matrix S

Type of transport	Transportation options					
	Unimodal	Mixed	Combined	Intermodal	Terminal	Multimodal
Railway	0,5	0,7	0,3	0,2	0,3	0,3
Water	0,1	0,8	0,8	0,3	0,7	0,5
Car	0,8	0,7	0,8	0,3	0,3	0,3
Air	0,8	0,3	0,4	0,3	0,3	0,3
Sea	0,1	0,8	0,9	0,4	0,7	0,5

Table 3. Fuzzy relationship matrix T

Transportation options	Transportation factors					
	Delivery time	Departure frequency	Reliability of adherence to schedules	Ability to transport various goods	Ability to transport goods to any geographical location	Transportation cost
Unimodal	0,8	0,6	0,4	0,3	0,3	0,3
Mixed	0,4	0,6	0,5	0,7	0,3	0,5
Combined	0,3	0,7	0,7	0,9	0,3	0,6
Intermodal	0,4	0,5	0,6	0,8	0,9	0,7
Terminal	0,4	0,5	0,6	0,8	0,9	0,8
Multimodal	0,4	0,5	0,6	0,8	0,9	0,7

Since the fuzzy relations under consideration satisfy the formal requirements necessary to fulfill their fuzzy composition according to Eq. (4), the result of the fuzzy composition operation of these relations can be represented as a matrix of the resulting fuzzy relationship:

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

Represent fuzzy composition of the two original relations in the Table 4.

Let us consider how one of the values of the membership function of the composition is obtained, for example, the value $\mu_{S*T}(<x_1, z_1>)=0,5$. First, we find the minimum values of the membership function of all pairs of elements of the first row of Table 2 and the first column of Table 3:

$$\min\{0,5\ 0,8\}=0,5;\ \min\{0,7\ 0,4\}=0,4;$$
$$\min\{0,3\ 0,3\}=0,3;\ \min\{0,2\ 0,4\}=0,2;$$
$$\min\{0,3\ 0,4\}=0,3;\ \min\{0,3\ 0,4\}=0,3.$$

After that, we find the maximum of 6 obtained values, 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 remaining values of the membership function are found similarly.

Table 4. Fuzzy relationship composition

Type of transport	Transportation factors					
	Delivery time	Departure frequency	Reliability of adherence to schedules	Ability to transport various goods	Ability to transport goods to any geographical location	Transportation cost
Railway	0,5	0,6	0,5	0,7	0,3	0,5
Water	0,4	0,7	0,7	0,8	0,7	0,7
Car	0,8	0,7	0,7	0,7	0,3	0,6
Air	0,8	0,6	0,4	0,4	0,3	0,3
Sea	0,4	0,7	0,7	0,9	0,7	0,7

Table 4. shows the assessment of modes of transport for a variety of factors. After analyzing the result, you can select the transport for transportation inside the SC. Since the delivery time and delivery cost were chosen as the main criteria of optimality, the use of automobile transport will be most suitable, in this case, because the membership functions are $\mu S*T(<x3, z1>)=0,8$, $\mu_{S*T}(<x_3, z_6>)=0,6$, respectively.

To confirm the result, we apply an alternative operation of composition of two binary fuzzy relations (max-prod)-composition (Eq. (5)). The result of the operation of the fuzzy composition is presented in Table 5.

Table 5. Fuzzy (max-prod)-composition of two fuzzy relationships

Type of transport	Transportation factors					
	Delivery time	Departure frequency	Reliability of adherence to schedules	Ability to transport various goods	Ability to transport goods to any geographical location	Transportation cost
Railway	0,40	0,42	0,35	0,49	0,27	0,35
Water	0,32	0,56	0,56	0,72	0,63	0,56
Car	0,64	0,56	0,56	0,72	0,27	0,48
Air	0,64	0,48	0,32	0,36	0,27	0,24
Sea	0,32	0,63	0,63	0,81	0,63	0,56

Following the general recommendations of applied system analysis regarding the principle of multi-model, we can draw the following conclusion. Using different models, the same results were obtained; this fact indicates the presence of a stable relationship or pattern between the individual elements of the models. In relation to the fuzzy models under consideration, the coincidence of the results obtained on the basis of the operations of (max-min) - composition and (max-prod) -composition provides the basis for more confident conclusions regarding the choice of an automobile mode of transport for transporting goods from the manufacturer to the wholesale buyer.

The developed model can be used to implement a wide range of tasks related to the management of business processes, for example, described by (Chalyi et al., 2018) and showed by (Levykin & Chala, 2018).

3. Results and discussion

Solving the problem of choosing a mode of transport does not in itself ensure the efficiency of the processes of transporting goods within the SC; the rational choice of the route directly affects the quality and speed of transportation. The safety of the cargo and the maximum profit in practice are achieved by drawing up a rational route (Stoke & Lambert, 2005; Bowersox & Kloss, 2008). When drawing up a rational route, it is necessary to take into account the location of the final delivery point, the dimensions and weight of the cargo, as well as its characteristics. Based on the above parameters, the vehicle necessary for transportation is selected.

During the design of the SC, a route should be drawn up that takes into account possible stopping places for meals and overnight for the driver, and customs control points are considered. In addition, it is necessary to take into account the state of the road surface and crossing the borders of other states. In addition, the features of each region along the route of cargo are taken into account. It is also necessary to take into account the width of the road and the quality of the pavement and weather conditions affecting the condition of the road. To ensure delivery in “just-in-time” mode, the speed limits on individual sections of the route should be taken into account.

As described by (Bowersox & Kloss, 2008), customary to distinguish three main methods of cargo transportation: the pendulum method (carried out between two points); ring (loading-unloading is carried out throughout the route); delivery (unloading is carried out in several places).

Delivery and ring transportation methods are the most profitable, since the motor vehicle practically does not remain empty along the entire route. In this case, the route pays off, which means that the cost of transportation decreases. For pendulum routes, a special calculation is necessary so that the car does not remain empty on the return trip. In this case, you can calculate the options for returning vehicles in another way in order to load the transport and recoup the cost of the return trip.

In transport logistics, as noted by (Bowersox & Kloss, 2008), any route can be assigned to one of four categories: urban routes - are carried out within the same city or settlement and the boundaries of the city line do not intersect; suburban routes that are designed to provide communication between the city and points within a radius of 50 km from the city limits; long-distance routes covering the entire territory of the country; international routes involving crossing state borders. The city route is planned taking into account morning and evening traffic jams in certain areas of the city, the presence of traffic lights on the way, ongoing road construction works. Suburban routes should take into account traffic density at the exit of the city. When planning the route of international cargo transportation, it is necessary to calculate the time that can be spent when passing the customs post, the condition of the roadway and the rules for using highways abroad (many roads are tollable abroad).

When transporting goods within the framework of SC, an important criterion is the time of delivery of raw materials, related materials and finished products. The cost of transportation of goods is included in the cost of goods, on the basis of this, there is a direct relationship between the duration of the route and the cost of goods.

To choose a rational transportation route, it is advisable to build a fuzzy model in MATLAB and develop an expert system, the functioning of which will be based on fuzzy inference. The interactive mode is ensured through the use of the Fuzzy Logic Toolbox package, which is part of the MATLAB environment (D'yakonov, 2002).

As input parameters of the fuzzy inference system, to determine the rational route for international transportation, we consider four fuzzy linguistic variables: weather conditions; road surface quality; the number of speed limits encountered; customs checkpoint time. The output variables will be: transportation time; transportation cost.

As a fuzzy inference scheme, we use the Mamdani method, therefore, the activation method will be MIN (Pegat, 2011). As a method of defuzzification of the result, we use the method of center of gravity.

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

The term set for the first input linguistic variable, Weather Conditions (Pogoda): T_1 = {“satisfactory”, “good”, “excellent”}. For the second input variable “Coverage Quality” (Pokrutie): T_2 = {“poor”, “average”, “excellent”}. For the third input linguistic variable “Speed limits” (Ogran_skorosti) T_3 = {“very much”, “many”, “few”}. For the fourth input linguistic variable “Customs clearance” (Tamozhen_postu): T_4 = {“Slow”, “fast”, “very fast”}.

As a term-set of the first output linguistic variable “Transportation Time” (Vrema): T_5 = {“excellent”, “good”, “average”, “bad”, “very bad”}.

As a term set, the second output linguistic variable “Transportation Cost” (Stoimost): T_6 = {“very low”, “low”, “medium”, “high”, “very high”}.

The fuzzy modelling problem is solved based on the Mamdani rule. At the same time, the parameters of the developed fuzzy model proposed by the MATLAB system by default are left unchanged: logical operations (min for fuzzy logical “AND”, max for fuzzy logical “OR”), implication method (min), aggregation method (max) and defazzification method (centroid). Then, in the course of solving the problem, the membership functions of the terms were determined for each of the four input and one output variables of the fuzzy inference system under consideration. Further, for the developed expert system, a knowledge base of 30 rules was formed. Figure 1 shows the editor of the rules included in the fuzzy knowledge base of the expert system, called by the ruleedit function (‘marschrut’). Then, an analysis of the constructed system of fuzzy inference for the considered problem of choosing a rational route for transporting a consignment of goods along the international route is carried out. By entering the value of the input variables for the first route option, the value of the input variable “weather conditions” is 5 points, the value of the input variable “quality of coverage” is 4 points, the value of the input variable “speed limits” is 6.8 points, the value of the input variable is “ Passage of customs posts ”- 7 points.

As a result, the fuzzy inference procedure performed using the MATLAB system for the developed fuzzy model yields the value of the output variables “Transportation time” and “Transportation cost” equal to 41.5 hours and 12.7 thousand hryvnias, respectively. For the second route, the value of the input variable "weather conditions" was estimated at 5 points, the value of the input variable "quality of coverage" - 7 points, the value of the input variable "speed limits" - 4.5 points, the value of the input variable "Passage of customs posts" - at 3.5 points. As a result, the fuzzy inference procedure made it possible to obtain the values of the output variables “Transportation Time” and “Transportation Cost” equal to 49.2 hours and 15.6 thousand hryvnias, respectively.

Figure 1. Editor of the fuzzy knowledge base rules of the expert system for choosing rational transportation routes within the SC

After analyzing the results obtained, the value of the output variables "Transportation time" and "Transportation cost", we can conclude that it is more profitable to carry out cargo transportation within the SC according to the first route option.

Figure 2 shows the process of visualizing the surface of the fuzzy inference of the model under consideration for the input variables "Speed limits" and "Passage of customs posts". This visualization tool makes it possible to establish the dependence of the values of the output variable on the values of the individual input variables of the fuzzy model. An analysis of these dependencies serves as the basis for changing the membership functions of input variables or fuzzy rules in order to increase the adequacy of the fuzzy inference system.

The considered fuzzy model has sufficient adequacy. However, for its finer tuning, it is necessary to use additional methods for scoring individual quantitative values of input and output linguistic variables.

Fuzzy inference systems created using the Fuzzy Logic Toolbox package allow integration with the Simulink package tools (D'yakonov, 2002), which allows modeling systems in the framework of the latter.

As an example, Figure 3 shows a model of a control system for choosing a rational transportation route inside SC for parameters {5, 4, 6.8, 7.2}, a similar model was built for parameters {5, 7, 4.5, 3.5}. As a result of comparing the simulation results, it was found that the values of the output variables "Transportation time" and "Transportation cost" are: for the first route option 41.54 hours and 12.75 thousand hryvnias, for the second route option 49.33 hours and 15.62 thousand hryvnias. These results confirm that for the transportation of goods it is advisable to use the first route option.

The advantages of the proposed approach is to increase the efficiency of the process of creating, deploying and supporting the functioning of SC by reducing the level of uncertainty in decision-making by managers at various levels. In this case, the uncertainty is considered in the aspect of fuzziness.

The disadvantage of this approach is the need to create and administer a knowledge base as the main element of the intellectual core of a specialized expert system with the implementation of fuzzy knowledge output.

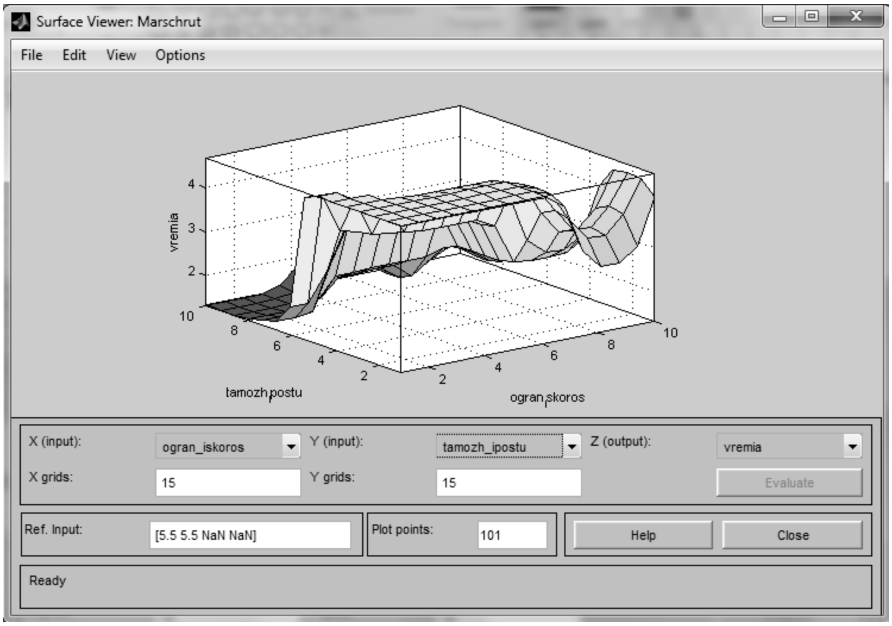

Figure 2. Visualization of the surface of the fuzzy output for the output variable "Transportation time

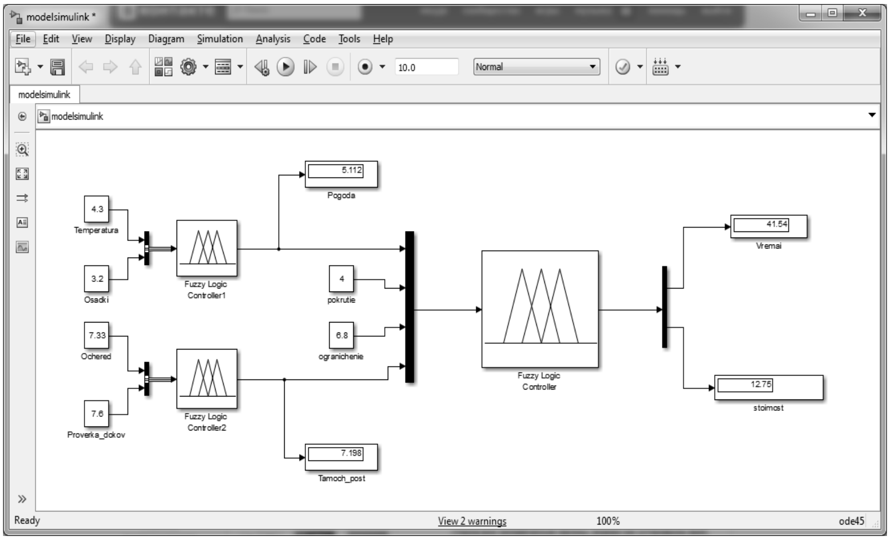

Figure 3. Control system model for the first variant of the transportation route within the SC

4. Conclusion

For the effective functioning of the complete logistics supply chain in the conditions of Industry 4.0, it is necessary to solve the problem of choosing rational routes for the goods transportation. An option is proposed for solving this problem by developing a special expert system with a fuzzy knowledge conclusion to support decision-making by logisticians in organizing transportation. Automobile transport was chosen as a delivery means of goods to SC. The toolkit for developing the expert system was the Fuzzy Logic Toolbox, which is part of the MATLAB environment. An example of justification using the developed expert system, the choice of a rational route, the duration and cost of transportation, from two possible options is considered.

Based on the foregoing, can draw the following conclusions:

- The task of choosing a rational mode of transport for organizing transportation of raw materials, materials and finished products within the framework of organizing a complete logistics supply chain is one of the main factors determining the efficiency of such a chain.
- A high level of uncertainty in the decision-making on the organization of SC is mostly fuzzy.
- The model for choosing the type of transport for carrying out transportation within the SC, it is advisable to implement on the basis of the mathematical apparatus of fuzzy logic.
- A fuzzy model of choosing the optimal mode of transport based on the criterion of minimum time and cost of delivery is described.
- An illustrative example of the choice of the optimal mode of transport for servicing the conventional section of the SC is given.

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