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SOLVING TRANSPORT LOGISTICS PROBLEMS IN A VIRTUAL ENTERPRISE THROUGH ARTIFICIAL INTELLIGENCE METHODS

Summary. The paper offers a solution to the problem of material flow allocation within a virtual enterprise by using artificial intelligence methods. The research is based on the use of fuzzy relations when planning for optimal transportation modes to deliver components for manufactured products. The Fuzzy Logic Toolbox is used to determine the optimal route for transportation of components for manufactured products. The methods offered have been exemplified in the present research. The authors have built a simulation model for component transportation and delivery for manufactured products using the Simulink graphical environment for building models.

1. INTRODUCTION

At present, information and communication technologies (ICT) are applied in all spheres of human activities. In addition, there is a strong need to improve the quality of manufactured products and to better match the demand-response. This requires one to search for new organizational forms of business management. The present paper deals with a Virtual Enterprise as a new form of business management. The Virtual Enterprise is a temporarily organized structure that has no production capacity available and is aimed at the earliest possible release of new products. It comprises a number of production units ensuring the implementation of certain activities [1-3].

The Virtual Enterprise is a networked organization whose global network is used for the necessary information exchange between geographically remote objects. All the activities are coordinated by a small headquarters [4-5].

To provide efficient and smooth operation of the virtual enterprise it is necessary to control the delivery time of specific components for manufactured goods. The virtual enterprise is aimed at reducing stores; product assembly requires on-time deliveries of all the components, which is why transportation becomes a key link in the supply chain. Thus, the present paper is concerned with solving the problems of transport logistics. The key role of transportation in logistics is due to the fact that it makes up a large proportion of transport costs within the total logistics costs and supports material flow. Within the structure of public production, transportation refers to the production of material services [6]. The choice of transport means, optimal for every particular shipment, is based on the information on the features of different types of transport (road, railway, sea, air, water and pipeline) [7-9]. There are six major factors influencing the choice of the required means of transport:
1) delivery time;
2) cost of transportation;
3) reliable compliance with the schedule of cargo delivery;
4) frequency of shipments;

5) ability to transport various cargoes;
6) ability to deliver the cargo to any destination.

While procuring and delivering material resources, the virtual enterprise can cooperate with a variety of logistic partners, as well as use various transport vehicles and transportation modes (unimodal, mixed, combined, intermodal, terminal and multimodal transportations) [10-12].

As is shown in [13-14], the application of the fuzzy logic theory is relevant when solving the problems of transport logistics. The theory of fuzzy logic is especially powerful when one cannot be sure whether an object or element within a domain is either in or out of some particular set within this domain. The benefit of the fuzzy logic theory is that instead of true and false values one uses degrees of truth that range from 0 to 1 inclusive within an infinite set of truth values. The theory of fuzzy relations is used to conduct a qualitative analysis of the relations between the objects of the system at issue when the relations are dichotomous i.e. the relation is fully in (present) or fully out (absent), or when a quantitative analysis of the relations does not work for some reason and the relations are made dichotomous on purpose. Fuzzy modeling is of particular importance when one needs to describe some technical systems and business processes, but comes across some uncertainty that makes it difficult or even impossible to apply precise quantitative methods and approaches. The study and use of mathematical tools to represent fuzzy initial information allows researchers to build models that most accurately reflect various aspects of the uncertainty when planning for optimal transportation modes and routes to deliver components for manufactured products.

In this paper, we show how to choose the optimal transport type to deliver components for the goods manufactured (e.g. a perforating punch as a consumer product) at the virtual enterprise. The priority criteria for the optimal choice are time and cost of delivery. To solve this problem, we have used artificial intelligence techniques, namely the theory of fuzzy sets [15-16]. In addition to the choice of the optimal transport means, there is a problem of choosing the optimal route for the delivery of components of manufactured goods. The authors have offered a solution to this problem through the use of fuzzy inference in the Fuzzy Logic Toolbox.

2. OPTIMAL CHOICE OF VEHICLES FOR TRANSPORTATION OF COMPONENTS FOR MANUFACTURED PRODUCTS BASED ON FUZZY RELATIONS

The theory of fuzzy sets allows one to describe vague concepts and knowledge about the world, as well as to handle this knowledge in order to obtain new information. A fuzzy set is a class of various elements such that it is not clearly seen whether an element of a certain class is a full member of the set or not [17-19].

The concept of fuzzy relations, along with the notion of a fuzzy set, should be attributed to the fundamentals of the entire fuzzy sets theory. Fuzzy relations help to determine a number of additional concepts used for building fuzzy models of complex systems. Substantially, a fuzzy relation is defined as any fuzzy subset of ordered sequences containing elements of various basic sets. In general, a fuzzy relation defined in the sets (universes) X_1, X_2, …, X_k, is a fixed fuzzy subset or the Cartesian product of these universes. In other words, if we denote an arbitrary fuzzy relation N, then $N = \{<x_1, x_2, \dots, x_k>, \mu_N(<x_1, x_2, \dots, x_k>)\}$, where $\mu_N(<x_1, x_2, \dots, x_k>)$ is a membership function of this fuzzy relation, and it is defined as a mapping μ_N: $X_1 \times X_2 \times \dots \times X_k \rightarrow [0,1]$. A fuzzy relation between the elements of two universal sets is called binary. Since every fuzzy relation is a fuzzy set, then all operations on the fuzzy sets are true for fuzzy relations. Let S and T be finite or infinite binary fuzzy relations. Through this, the fuzzy relation $S = \{<x_i, x_j>, \mu_S(<x_i, x_j>)\}$ is determined by the Cartesian product of universes $X_1 \times X_2$, and the fuzzy relation $T = \{<x_j, x_k>, \mu_T(<x_j, x_k>)\}$ is determined by the Cartesian product of universes $X_2 \times X_3$. A fuzzy binary relation determined by the Cartesian product $X1 \times X_3$ and denoted as S×T, is called the composition of binary fuzzy relations S and T, whose membership function is determined by the equation below (Formula (1)):

$$\mu_{S\otimes T}\left(\langle x_i, x_k\rangle\right) = \bigcup_{x_i} \mu_S\left(\langle x_i, x_j\rangle\right) \bigcap \mu_T\left(\langle x_j, x_k\rangle\right). \tag{1}$$

Thus, the determined composition of binary fuzzy relations is called a Max-Min composition or maximin convolution of fuzzy relations. For a Max-Min composition of S and T relations, the operation $\bigcap$ can be substituted by any other operation for which the same restrictions are true as for $\bigcap$, such as associativity and monotony of each argument. In particular, the operation $\bigcap$ can be substituted by algebraic multiplication, and then we deal with a Max-Product composition as shown in (Formula (2)):

$$\mu_{S\otimes T}\left(\langle x_i, x_k\rangle\right) = \bigcup_{x_i} \mu_S\left(\langle x_i, x_j\rangle\right) * \mu_T\left(\langle x_j, x_k\rangle\right). \tag{2}$$

To select a vehicle to deliver the components from suppliers to the product assembly center, we have built a fuzzy model based on two binary fuzzy relations S and T. The first one is built from two basic sets X and Y, and the other one is built from two basic sets Y and Z. X describes a set of vehicles that might be used for transportation, Y denotes a set of transport modes, and Z is a set of factors affecting the transportation. The fuzzy relation S conceptually describes the relation between the vehicle and the mode of transportation, and T describes the evaluation of the various transportation modes in view of each of the factors. To be specific, $X = \{x_1, x_2, x_3, x_4, x_5, x_6\}$, $Y = \{y_1, y_2, y_3, y_4, y_5, y_6\}$, $Z = \{z_1, z_2, z_3, z_4, z_5, z_6\}$. The elements of the universes have the following conceptual meaning: x_1 is for railway transport, x_2 is road transport, x_3 is waterways, x_4 is pipeline transport, x_5 is air transport, x_6 is sea transport; y_1 is unimodal transportation, y_2 is mixed transportation, y_3 is combined transportation, y_4 is intermodal transportation, y_5 is terminal transportation, y_6 is multimodal transportation; z_1 is delivery time, z_2 is frequency of shipments, z_3 is reliable compliance with the schedule of cargo delivery, z_4 is the ability to transport various cargoes, z_5 is the ability to deliver cargo to any destination, z_6 is the cost of transportation. Specific values of membership functions $\mu_S(\langle x_i, y_j\rangle)$ and $\mu_T(\langle y_j, z_k\rangle)$ of the above fuzzy relations are presented in Tables 1-2.

Table 1

Fuzzy relation S

Vehicles	Transportation Modes					
	Unimodal	Mixed	Combined	Intermodal	Terminal	Multimodal
Railway	0,5	0,7	0,3	0,2	0,3	0,3
Waterways	0,1	0,8	0,8	0,3	0,7	0,5
Road	0,8	0,7	0,8	0,3	0,3	0,3
Pipeline	0,3	0,3	0,2	0,2	0,2	0,2
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 2

Fuzzy relation T

Transportation modes	Factors Affecting the Transportation					
	Delivery Time	Frequency of Shipments	Reliable Compliance with the Schedule of Cargo Delivery	Ability to Transport Various Cargoes	Ability to Deliver Cargo to Any Destination	Cost of Transportation
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

The matrices of these fuzzy relations are as in Formulae (3) and (4) below:

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

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

Since the above fuzzy relations meet the formal requirements necessary for their fuzzy composition according to Formula (1), the operation of the fuzzy composition of these relations can be represented as a matrix of the resulting fuzzy relation in Formula (5):

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

A fuzzy composition of two initial relations is given in Table 3. Let us consider how the membership function of the composition takes one of its values, for example, the value of $\mu_{S\otimes T}$ (<x_1, z_1>) = 0,5. First, we shall find minimum values of the membership function for all pairs of elements of the first row of Table (1) and the first column of Table (2). They are: 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 shall find a maximum of 6 values obtained, which in fact, will be the desired value of the membership function: $\mu_{S\otimes T}$ (<x_1, z_1>) = max{0,5 0,4 0,3 0,2 0,3 0,3} = 0,5. The other values of the membership function are determined in the same way. Table (3) shows the evaluation of vehicle types with respect to a variety of factors. After analyzing the result, we can select a suitable vehicle for the transportation of components, as the main optimality criteria were selected to be the delivery time and the cost of transportation. Thus, road vehicles will be the most appropriate means of transport whose membership functions are $\mu_{S\otimes T}$ (<x_3, z_1>) = 0,8, $\mu_{S\otimes T}$ (<x_3, z_6>) = 0,6 respectively. To confirm this result, we shall make an alternative composition of two binary fuzzy relations i.e. Max-Product composition, ref. Formula 2. The obtained fuzzy composition is presented in Table 4.

Table 3

Fuzzy Composition of Two Fuzzy Relations

Vehicles	Factors Affecting the Transportation					
	Delivery Time	Frequency of Shipments	Reliable Compliance with the Schedule of Cargo Delivery	Ability to Transport Various Cargoes	Ability to Deliver Cargo to Any Destination	Cost of Transportation
Railway	0,5	0,6	0,5	0,7	0,3	0,5
Waterways	0,4	0,7	0,7	0,8	0,7	0,7
Road	0,8	0,7	0,7	0,7	0,3	0,6
Pipeline	0,3	0,3	0,3	0,3	0,3	0,7
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

Analyzing the results (Table 4), we can conclude that to transport the components, road vehicles will be the most appropriate, because the membership function of delivery time and cost of transportation are $\mu_{S\otimes T}$ (<x_3, z_1>) = 0,64, $\mu_{S\otimes T}$ (<x_3, z_6>) = 0,48 respectively. Thus, despite using various models, similar results have been obtained. This confirms the fact that there are strong relationships or dependencies between the individual elements of the models.

Table 4

Fuzzy Max-Product Composition of Two Fuzzy Relations

Vehicles	Factors Affecting the Transportation					
	Delivery Time	Frequency of Shipments	Reliable Compliance with the Schedule of Cargo Delivery	Ability to Transport Various Cargoes	Ability to Deliver Cargo to Any Destination	Cost of Transportation
Railway	0,40	0,42	0,35	0,49	0,27	0,35
Waterways	0,32	0,56	0,56	0,72	0,63	0,56
Road	0,64	0,56	0,56	0,72	0,27	0,48
Pipeline	0,24	0,18	0,15	0,21	0,18	0,60
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

3. CHOICE OF OPTIMAL ROUTE FOR TRANSPORTATION OF COMPONENTS FOR MANUFACTURED PRODUCTS USING FUZZY INFERENECE IN THE FUZZY LOGIC TOOLBOX

As soon as the most appropriate vehicle has been selected, the optimal route for cargo transportation must be chosen. This problem directly affects the quality and speed of the delivery. Arranging the optimal route will ensure cargo safety and profit maximization. When assembling consumer products at a virtual enterprise, one should keep in mind two important criteria, namely the time and accuracy of component delivery. The cost of cargo transportation is included in the cost of the product. Let us consider alternative transportation routes, as exemplified by transportation of components from Germany:

a) Route 1: Gerlingen (Germany) → Nürtingen (Germany) → border crossing through Schöpstal (Germany) to Jedrzychowice (Poland) → border crossing through Korczowa (Poland) to Krakovets (Ukraine) → Kharkiv (Kharkiv, Ukraine);

b) Route 2: Gerlingen (Germany) → Nürtingen (Germany) → border crossing through Obernberg (Germany) to Schellenberg (Austria) → border crossing through Nikelsdorf (Austria) to Hegyeshalom (Hungary) → border crossing through Záhony (Hungary) to Chop (Ukraine) → Kharkiv (Kharkiv region, Ukraine.

We have built an expert system to select a rational transportation route (Fig. 1). The expert system has been built as a fuzzy inference system using the interactive Fuzzy Logic Toolbox within the framework of MATLAB. The Fuzzy Logic Toolbox is a set of applications related to the theory of fuzzy sets and designed for construction of the so-called fuzzy expert and/or managing systems. The fuzzy inference relies on the Mamdani's method; therefore, the MIN-operation has been used as the implication method. A fuzzy conjunction (the AND operator) has been only used as a logical connective for sub-conditions in all the rules. The operation of min-conjunction has been used as the aggregation method; the operation of max-disjunction has been used for accumulation of the consequents across the rules, which is also used in Mamdani's fuzzy inference method; the centroid method has been used for defuzzification of the results obtained. For construction of a fuzzy model for choosing the optimal transportation route it is established that all the relevant input variables are measured in points that lie within a range of real numbers between 0 and 10, where each variable has the lowest value of 0 and the highest value of 10. Fig. 1 shows a graphical user's interface of the FIS editor, activated by a *fuzzy('ROUTE')* function for the *Route Selection*. Thus, the problem of fuzzy modelling is solved using Mamdani's fuzzy inference system.

The term-set for the first input linguistic variable *Weather Conditions* (Weather) is assigned to set T_1 = {"satisfactory", "good", "excellent"}.

The second input variable *Pavement Quality* (Pavement) is assigned to set T_2 = {"bad", "middle", "great"}.

The third linguistic variable *Speed Limit* (Speed_limit) is assigned to set T_3 = {"very_much", "much", "few"}.

The fourth linguistic variable *Customs Clearance* (Customs_posts) is assigned to set T_4 = {"slow", "fast", "very_fast"}.

The term-set for the first output linguistic variable *Delivery time* (Time) is assigned to set T_5 = {"great", "good", "middle", "bad", "very _bad"} (see Fig. 2).

The term-set for the second output linguistic variable *Cost of Transportation* (Cost) is assigned to set T_6 = {"very_low", "low", "satisfactory", "high", "very_high"}.

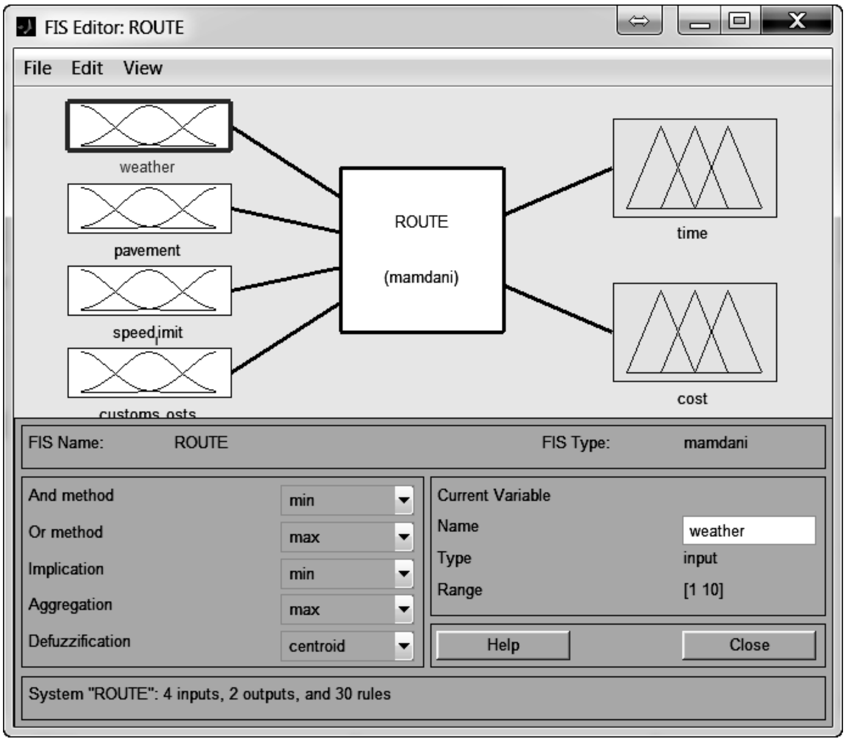

Fig. 1. Graphical Interface of FIS

The settings of the developed fuzzy model have been left unchanged, that is, with default values provided by the Fuzzy Logic Toolbox. Next, we have determined the membership functions of the terms for each of the four input and two output variables within the fuzzy inference system. For this purpose, we have used the Membership Function Editor, opened by the *mfedit* command.

Then, a set of rules has been developed for the fuzzy inference system. The *ruleedit* command opens a rule editor. The editor allows one to perform the analysis of the rules. Fig. 3 shows the rule editor, opened by *ruleedit ('ROUTE')*.

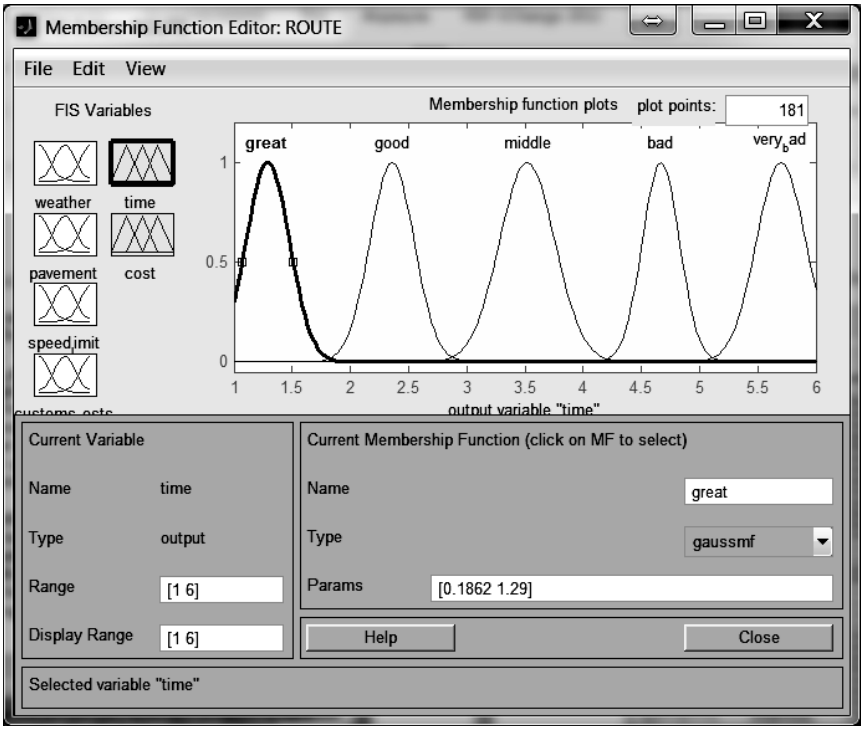

Fig. 2. Membership Function Editor for the first output linguistic variable Delivery time (Time)

The command *View\Rules* opens a graphical interface of the rule viewer. To obtain an optimal transportation route, we have opened a viewer in the Fuzzy Logic Toolbox and added the input variables for Route 1: “Weather” equal to 5.022 points, “Pavement Quality” – 4 points, “Speed_Limit” – 7 points and "Customs posts”– 8.12 points.

As a result, the fuzzy inference for the developed fuzzy expert system has shown the values of the output variables “Time” and “Cost” equal to 3.32 days and UAH 8.730 respectively (see Fig. 4).

In addition, the toolbox provides a fuzzy controller block that one can use in Simulink [19-22] to model and simulate a fuzzy logic control system. The *fuzblock* command can open the library of fuzzy blocks of Simulink. The library contains the Fuzzy Logic Controller and Fuzzy Logic Controller with Rule Viewer blocks. It also includes a Membership Functions sublibrary that contains Simulink blocks for the built-in membership functions. The Simulink extension package is used for simulation of models, built from graphic blocks with specified properties (parameters). The run of the simulation provides a mathematical simulation of the model constructed with a clear visual representation of the results. Fig. 5 shows a control system model for Route 1 of transportation of components.

Then, we have obtained the values of the output variables for Route 2. With the new values of the input variables, namely “Weather” equal to 5.06 points, “Pavement Quality” – 7 points, “Speed_Limit” – 5 points and "Customs posts”– 3.99 points, the values of the output variables “Time” and “Cost” have been equal to 3.86 days and UAH 11.000 respectively (see Fig. 6).

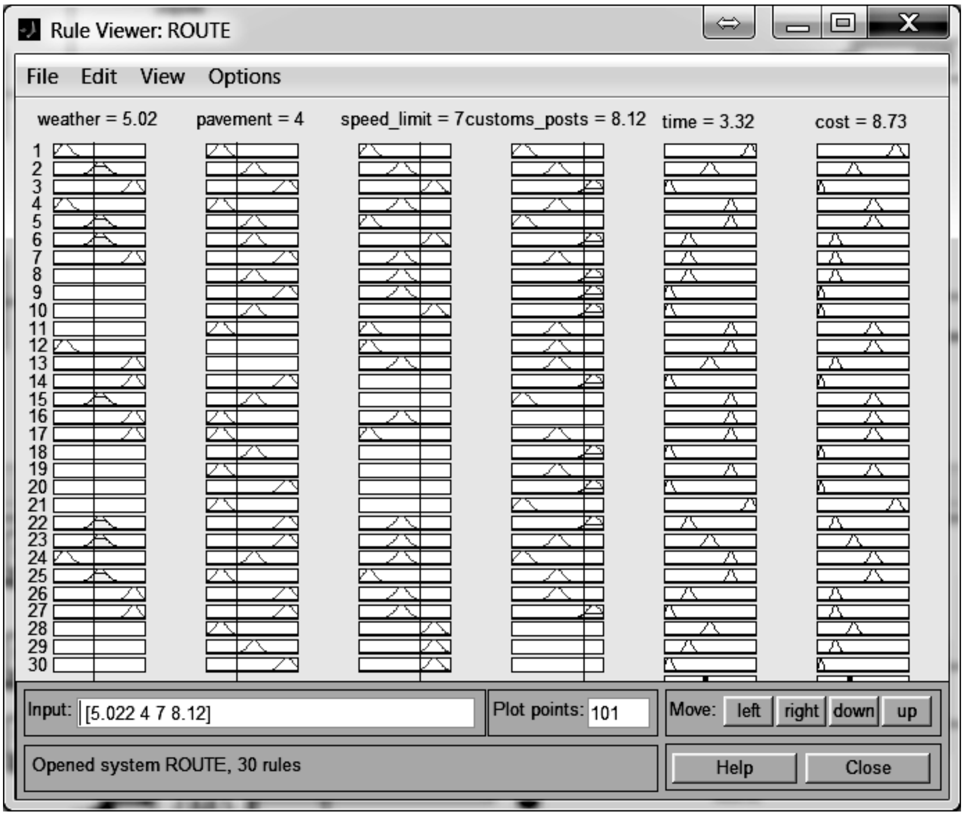

Fig. 3. Rule Editor

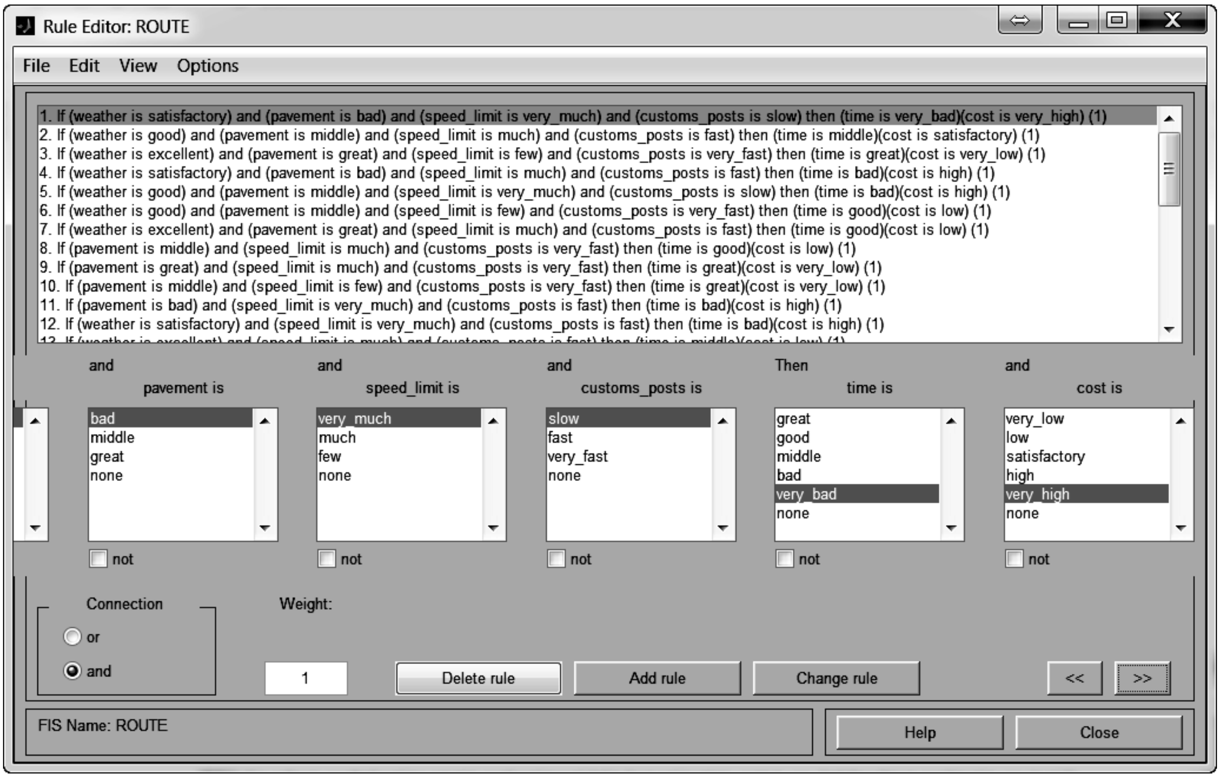

Fig. 4. Graphic Interface of Rule Viewer for Route 1

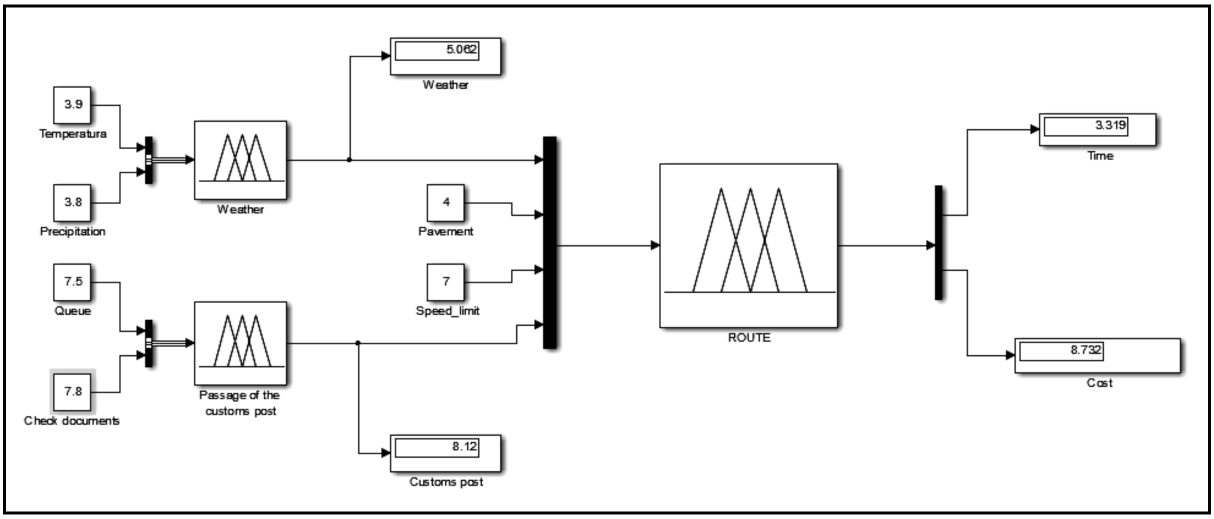

Fig. 5. Control System Model for Route 1

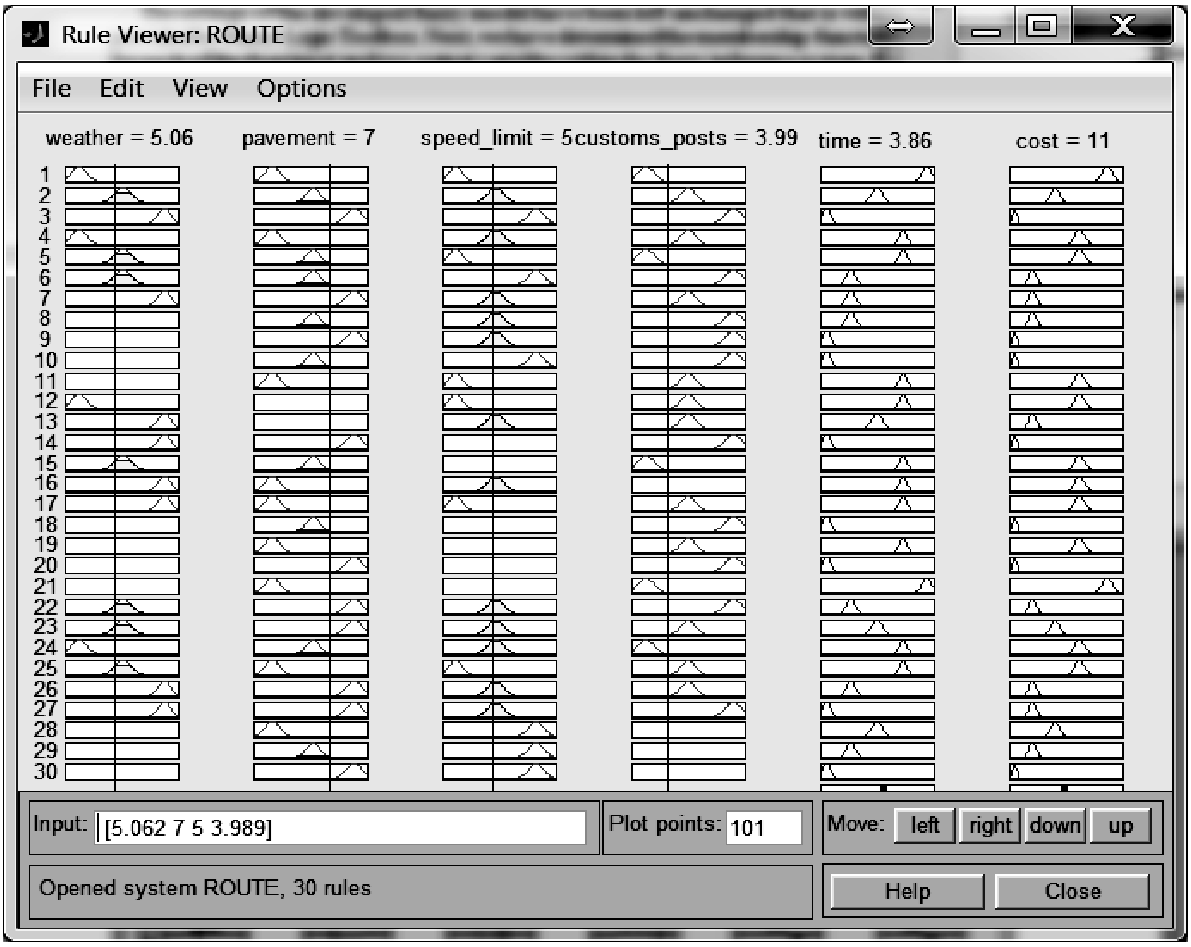

Fig. 6. Graphic Interface of Rule Viewer for Route 2

Fig. 7 shows a control system model for Route 2 of transportation of components. Thus, we have managed to obtain the values of output variables “Time” and "Cost" for both of the routes. It will take 3.32 days and UAH 8.732 for Route 1 and 3.857 days and UAH 10.960 for Route 2.

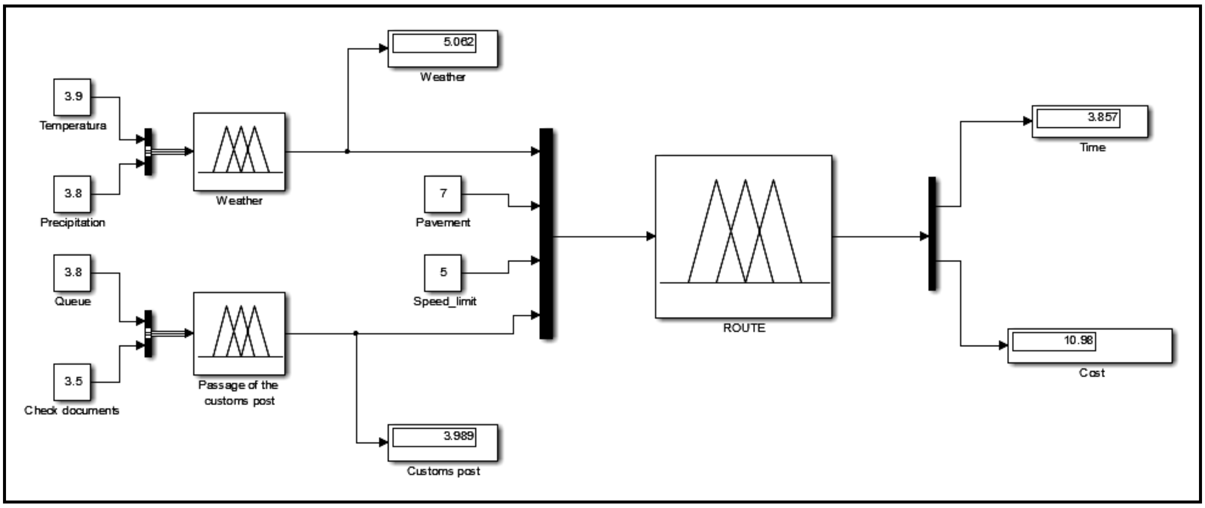

Fig. 7. Control System Model for Route 2

After analyzing the values of input variables "Time" and "Cost", we have concluded that Route 1 is more rational and profitable for transportation of components.

4. CONCLUSIONS

Research has been performed on the problems of transport logistics within the modern approach to business management and organization in the form of a virtual enterprise. The main benefits of the virtual enterprise include a rapid execution of the market order, reduced total costs, better compliance with customer targets, more flexible adaptation to environmental changes, as well as the provision of niches to enter new markets. The efficiency of the virtual enterprise directly depends on accurate and timely deliveries of components for the manufactured products. For this purpose, solutions have been offered to selection problems concerning the vehicle types and routes for component deliveries using artificial intelligence techniques.

The theory of fuzzy logic is of particular relevance to the present research and is a powerful means of solving the problems of transport logistics. Fuzzy modeling is essential when one needs to describe some technical systems and business processes, but comes across some uncertainty that makes the application of precise quantitative methods and approaches useless or even impossible. A fuzzy model has been developed based on two binary fuzzy relations. According to the model, road vehicles have proved to be optimal with respect to time and cost of transportation. Use of the Fuzzy Logic Toolbox has allowed us to build a fuzzy expert system based on a fuzzy inference system in order to select the optimal route of delivery. After considering the two potential routes and comparing the results obtained, the shortest and cheapest route for component delivery has been determined. Here is Route 1: Gerlingen (Germany) → Nürtingen (Germany) → border crossing through Schöpstal (Germany) to Jedrzychowice (Poland) → border crossing through Korczowa (Poland) to Krakovets (Ukraine) → Kharkiv (Kharkiv, Ukraine);

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