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DEVELOPMENT OF AN APPROACH TO MANAGING DRY FRUIT SUPPLY CHAINS USING EXPERT SYSTEMS

Khudhair Abed Thamer
PhD
Department of Computer Science
Al – Maaref University College
Ramadi, 330, Anbar, Iraq, 31001
E-mail: Kder.abd@mail.ru
Rahimi Yashar
Postgraduate Student
Department of Software Engineering
National Aerospace University
“Kharkiv Aviation Institute”
Chkalova str., 17, Kharkiv, Ukraine, 61070
E-mail: rahimi.yashar@gmail.com

The paper outlines an approach to the management of dry fruit supply chains (DSC) using expert systems (ES), which implies modernization of the concept of supply chain management by complementing it with knowledge-oriented tools of decision-making support. It was shown that the technologies of ES development existing in engineering are not effective in organizing a unified information space within the DSC. In the framework of this approach, we considered the methodical approach to decomposition of the general problem of business processes management in the DSC into a series of interconnected functional sub-problems and the procedure of synthesis of a typical decision-making support unit (DMSU) by the DSC participants in the form of ES. The essence of the approach is to represent the DSC management process as a multi-layered hierarchical structure of problems, which can be implemented by a totality of interconnected typical DMSU by correspondent DSC participants. At the same time, a specialized ES shell was developed for each type of DMSU. Application of the approach under discussion will in practice ensure the homogeneity of the general information space of the DSC due to: clear positioning of each DMSU in the general management structure; widespread use of typical solutions in the synthesis of information support tools for DSC participants. The effectiveness of the described approach is shown using the example of implementation of the ES shell for the problem of choosing a rational route of delivery of dried fruit batches from foreign suppliers to wholesalers in Ukraine. The results of the study can be used by logistics companies in the formation of a rational route for the delivery of a batch of goods for various purposes from foreign suppliers to a focus company

Keywords: supply chain management, decision making support, expert system, rational delivery route, fuzzy logic, dried fruit supply

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1. Introduction

Rational management of complete dry fruit supply chains (DSC) is a non-trivial problem, namely, the creation and purposeful support of a set of interconnected material, financial and information flows, including the flows of services from sources of raw materials to the end consumer. The main factors for emerging of the high level of uncertainty in the processes of formation and decision making by the DSC participants are:

– diversity of the world regions, which are dry fruit suppliers,

– a wide range of supplied products,

– a harvest rate of fruit trees,

– currency fluctuations, etc.

One of the main factors determining the effectiveness of DSC functioning is the rational management and organization of transportation within a chain. This raises the important task of determining a rational route of delivery of goods within the DSC, taking into consideration a large number of heterogeneous factors affecting the cost and strict keeping to the transportation schedule.

It is impossible to manage supply chains without analyzing them at various levels – strategic, tactical, and operational. By its very nature, the DSC is a complex stochastic system [1, 2]. Its functioning is characterized by the following features:

– a relatively large number of legally independent participants of business processes (including customs brokers);

– the character of interaction between often competing DSC participants, which is difficult to formalize;

– existence of own objective function for each participant, contrary to the interests of others;

– high dynamics of changing connections within the system;

– the non-stationarity of most processes that take place in the DSC operation.

The specified circumstances determine the insufficient effectiveness of the existing DSC and dictate the need to modernize them by expanding the concept of SCM (supply chain management) [3, 4] by supplementing it with knowledge-oriented decision-making support tools [5–7]. Development of an expert system of decision-making support on the formation of the DSC will provide an opportunity to improve the efficiency of business processes in a chain by reducing financial and temporal costs, in particular, ensuring timely delivery of goods for sale to consumers. This effect will be achieved by reducing the risk of making erroneous decisions by logisticians in the organization of transportation within the DSC.

2. Literature review and problem statement

It is shown in papers [7–9] that one of the main factors determining the effectiveness of the DSC operation is the rational transportation organization within a chain. This raises an important problem of determining the rational route of goods delivery within the DSC, taking into consideration a large number of heterogeneous factors affecting the cost of transportation and strict keeping to their schedule. The concept of the DSC construction involves a comprehensive representation of processes, beginning from the production of raw materials (fresh fruit), and encompasses all suppliers of goods, services and information that add value to consumers and other stakeholders, as shown in papers [6, 8]. Thus, effective DSC operation involves the integration of key business processes: managing relationships with consumers; customer services; demand analysis; order management; ensuring production processes; supply management. Article [7] shows that the main mechanism for enhancing the DSC efficiency is to minimize production costs, including reducing the transportation costs while sticking to the "just-in-time" principle. To serve the DSC, many different schemes, techniques, and methods were developed. Their choice depends on the factors that describe the dynamics of operation of a particular chain implementation option, as reflected in article [8].

The authors of [9, 10] show that the global practice of creating, deploying, and maintaining the operation of complete logistics chains is characterized by the relatively broad introduction of expert systems (ES) to support decision making by managers at different levels of the corporative hierarchy. The results of research [7, 9], on the other hand, are prerequisites for the creation of unified information space within the DSC. Paper [10] shows that expert systems are used at various stages of the logistics process, making it easier to solve problems that require considerable experience and time consumption. The authors of research [11, 12] talk about the studies and applications related to the ES use in logistics and supply chains, namely, about the limitations of the latter, although they play an important role in a physically distributed corporate environment.

The authors of the considered studies proposed to use the means of intellectualization of the DSC management in the form of ES. However, the way proposed by the authors is ineffective, as the complexity and heterogeneity of the problems solved within the DSC require the development and subsequent maintenance in the relevant state of a very complex ES. Thus, the application of a totality of functionally interconnected expert systems seems logical in this case.

At the same time, the traditional technology of creation and deployment of ES has a number of fundamental drawbacks that prevent the efficient use of such systems in integrated logistics, as reflected in papers [7, 13]. Firstly, the ES shells, based on which expert systems are mainly created, do not make it possible to take into consideration both the features inherent in the technology of organization of complete logistics supply chains and the specifics of operation of particular logisticians. Secondly, the use of such shells requires painstaking work to establish a knowledge base (KB) for each DSC participant, numbering in the dozens. These circumstances prevent the comprehensive informatization of the processes of DSC management with the use of the ES. Thirdly, ES are by their very nature are closed systems, which is at odds with the concept of creating a unified information space within the DSC.

The above problems can be effectively addressed by using typical specialized ES shells as an environment for constructing complete DSCs.

3. The aim and objectives of the study

The aim of this study is to develop an approach to the intellectualization of the process of the DCS life cycle management process by decomposition of the general problem of management of a complete supply chain into a series of sub-problems, in accordance with decision-making levels. This will reduce the risk of making erroneous decisions by logisticians in the transportation organization within the DSC.

To achieve the goal, the following tasks were set:

– to develop a methodical approach to creating, deploying, and supporting a unified knowledge space in the form of an orderly totality of expert systems, each of which performs a specific functional sub-task;

– to develop a procedure for the synthesis of a typical unit to support decisions made by DSC participants in the form of ES;

– to demonstrate, using a scenario example, the results of solving a typical sub-problem, which arises during the DSC implementation.

4. A methodical approach to creating, deploying and supporting a unified knowledge space within the DSC

The structure of any decision-making center included in the DSC will be represented as a hierarchy of layers. The hierarchy of decision-making layers arises from three main aspects of the decision-making problem in the face of uncertainty, namely:

1) selection of a strategy used in the decision-making process;

2) decrease in the influence of uncertainty on the results of the obtained decision;

3) search for a specific way of action under assigned conditions [14].

Based on it, it is appropriate to represent the hierarchy of decision-making layers in the form of three layers: selection, adaptation, and self-organization. The tasks of these layers are, accordingly, in choosing the mode of action **M,** specifying a set of uncertainties **U** (which exist in the selection layer). The structures and strategies of the underlying layers, which bring the whole system as close as possible to the general goal, are also chosen. This general goal is usually difficult to formalize, but it is possible to separate limitations (in the form of a structure and strategies) for underlying layers, in which the goals are formed more specifically. The tasks of the self-organization layer include the selection of the structure and action strategy for underlying layers. Addressing these challenges should bring the entire DSC as close as possible to the global goal of managing it. The layer under consideration covers the managing structures of a target company [15]. The problems of synthesizing the structure of the underlying layers and determining their functions are solved in the creation of the DSC. They can be adjusted during its functioning when the external environment changes and under the influence of parametric perturbations, that is, by feedback information from other layers. Thus, at the top level of the decision-making hierarchy, the strategy of dry fruit delivery implementation as a whole is determined, rather than the structure of complete DSC.

The adaptation layer in the context of creation and support of the complete DSC is represented by **3PL-** and **4PL-**providers [9]. The problems of this layer include specification and decreasing the layer of uncertainties that may arise at the lower decision-making level – the selection level.

The problems at the level of a selection layer are related to determining a particular mode of action, that is, the problems of this class can already be considered operational and fairly well formulated. This layer is lower in the hierarchy of decision-making layers. On this layer, the problems of choosing a mode of action are solved, that is, the tasks for logisticians of the DSC lower level are formed directly. This layer is represented by DSC participants from managers of companies-suppliers. The problem of decision-making support on this layer is the subject of separate scientific research and has been partially highlighted in paper [7]. The selection layer in the hierarchy of DSC management problems is directly approximated to the production capacities and commercial capabilities of companies – dry fruit suppliers.

Thus, the application of the discussed approach in practice makes it possible to implement to the full the principle of dividing the general problem of management of a complex system, in this case, the DSC, into smaller-scale sub-problems. Solving these problems separately provides a cumulative solution to the general management problem. At the same time, solving a complex problem of decision making as a whole is replaced by solving a family of consistently ordered more simple problems, so the structure shown above was called a multi-layered decision-making system.

Formally, the multi-layered hierarchy of decision making in the complete DSC is represented in the following form:

$$S_1 : W_1 \times C_1 \times U \rightarrow M,$$

$$S_2 : W_2 \times C_2 \rightarrow U,$$

$$S_3 : W_3 \rightarrow C_1 \times C_2, \qquad (1)$$

where W_1 is the set of feedback signals from business processes within the DSC;

C_1 is the set of incoming signals from layer 3 (self-organization), determining the structure of the selection layer and the strategy of DSC operation as a whole (managing influence from top managers of a focus company in the form of directives and plans);

U is the set of signals from layer 2 (adaptation) that specifies uncertainties for layer 1 (results of the formation of supply chains of specific batches of goods);

W_2 is the signals from the external environment (including the signals in the form of information from the lower selection layer, because this layer can not directly influence decision making in the adaptation layer);

C_2 is the set of signals (parameters) through which the upper layer (self-organization) determines the structure of the adaptation layer, similarly to signals C_1 in the selection layer;

U is the set of signals specifying uncertainties in the selection layer;

W_3 is the feedback information, arriving from lower layers to the self-organization layer; this information also includes information about the environment and influences the formation of the structure of lower-lying layers, as well as the strategy used by them in the process of the DSC operation.

It can be argued that set $C \supseteq C_1 \cup C_2$, essentially determines the structure of the complete DSC. That is why sub-problems in each decision-making layer can be implemented in relevant units, the type of each of which corresponds to the decision making layer.

The described approach to the management of the life cycle of complete DSC using the ES makes it possible to organize a unified information DSC space in the form of an interconnected totality of typical decision-making support units. At the same time, each type is the shell of the ES, specialized in accordance with the tasks of a certain layer.

5. The procedure of synthesis of a typical decision-making support unit by DSC participants

The procedure for developing an ES shell to justify the choice of a rational dried fruits transportation route includes the following steps:

1) synthesis of a fuzzy model of knowledge-based inference in the MATLAB environment using the Fuzzy Logic Toolbox package [16];

2) determining the methods for sub-conditions aggregation;

3) formation of term-sets;

4) synthesis of a fuzzy model of knowledge-based inference using the graphic tools of the MATLAB system;

5) determining the membership function of terms for input and output variables of the model of fussy knowledge-based inference (output machine) of the ES;

6) formation of the knowledge base of the ES in the form of fuzzy rules;

7) development of tools for analysis of route options formed by the ES;

8) development of tools of visualization of ES operation results.

6. Results of studying the possibilities of intellectualization of the process of DSC life cycle management

In the management structure described above, the selection layer by the amount of processed information ranks at the top among all decision-making layers in the complete DSC. Among the sub-problems implemented in this layer, those that are associated with the rational organization of transportation within the chain are of particular importance. The key role of transportation in DSC logistics is explained both by the large proportion of transport costs in the total amount of logistics costs and by the fact that the DSC existence is impossible without transportation. In the process of procurement and delivery of material resources within the DSC, there arise challenges related to determining the transport mode, various logistic partners, as well as operations related to warehouse logistics within the DSC [4, 5, 8]. Transportation sub-problems, as well as other sub-problems in the selection layer, are primarily characterized by the uncertainty generated by fuzzy information. Based on these circumstances, the use of a mathematical apparatus of fuzzy logic is appropriate as a methodical basis for the development of the shells of corresponding ES [17].

Research [18] described (for the selection layer) the technology of synthesis of the typical decision-making support unit in the form of the ES shell regarding the selection of the type of transport for delivery of dried fruit batches for different DSC links. Input data for the formation of the ES core were:

– cargo character (weight, volume, consistency);

– number of shipped batches (used container);

– the urgency of cargo delivery to the customer;

– destination location with regard to weather, climatic and seasonal characteristics;

– the distance of cargo transportation;

– cargo value (insurance);

– the proximity of a delivery point to transport communications;

– cargo security, failure to perform delivery [18].

During the operation of the explored ES and during substantiation of the choice of a transport mode for the dried fruit transportation, 6 main factors that influence decision making, in this case, are taken into consideration: delivery time; transportation costs; reliability of keeping to a cargo shipping schedule; shipment frequency; capability to transport different cargoes; capability to deliver a cargo to any DSC node. The time and costs of delivery are accepted as optimal criteria for making decisions. The same article outlines a scenario example for forming a well-grounded decision on choosing road transport as a means of delivering a dried fruit batch from a supplier to a wholesaler.

As part of this study, we explored the procedure of synthesis of the ES shell to implement the decision-making support unit in the above lying layer – the adaptation layer. At the same time, we will describe the scenario of implementation of a transport logistics sub-problem that is typical for the adaptation layer, namely, the substantiation of the rational route of delivery of dried fruit batch by road transport within the DSC. Obviously, this sub-problem is directly related to the problem of choosing the type of transport, solved in the selection layer.

Consider the solution to the problem of substantiation of the selection of a rational route of dried fruit delivery in the complete DSC, which has a focus company ("East plus", Ukraine, Kharkiv) and foreign suppliers, shown in Table 1 and Fig. 1.

The formation of the DSC uses a general database (DB) about participating enterprises, which records their current commercial capabilities. This database is created using standard tools at the first stage of the DSC development and is not discussed in this study. Access to this database is implemented via the Internet.

Consider possible transportation routes, using the example of transportation of a dried fruit (raisins) batch from Iran on the international route (Table 2).

Four linguistic variables were assigned as input parameters of the model of fuzzy knowledge-based inference: changeable weather conditions; quality of road cover; the number of speed limits encountered; time of customs clearance. The above-listed input variables are measured in points in the interval of real numbers from 0 to 10, where the lowest score of each variable is 0, and the highest score is 10. In accordance with the optimality criteria, output variables were chosen: time and cost of transportation of dried fruit batch. The scheme of fuzzy inference is based on the Mamdani method.

In all the rules of the knowledge base of the ES, the operation of fuzzy conjunction (operation "AND") was applied as a logical link for sub-conditions, and the min-conjunction operation was applied as the aggregation method. The max-disjunction method was applied to accumulate the conclusions of rules, the gravity center method was used for defuzzification of the obtained result.

The term-set for linguistic variable 1 "Weather conditions" (Pogoda), T_1={"satisfactory", "good", "excellent"). For input variable 2 "Quality of road cover" (Pokrutie), T_2={"bad", "so-so", "excellent'}. For linguistic variable 3 "Speed limit" (Ogran_skorosti), T_3={"very much", "much", "little"}. For linguistic variable 4 "Customs clearance" (Tamozhen_postu), T_4={"slow-ly", "fast", "very fast"}. As a term-set of output variable 1 "Transportation time" (Vrema), T_5={"excellent", "good", "so-so", "bad", "very bad"}. As term-set of output linguistic variable 2 "Transportation costs" (Stoimost), T_6={"very low", "low", "medium", "high", "very high"}.

Fig. 2 shows the graphical interface of the FIS editor, called by fuzzy function ("marschrut"') – "Route choice".

Fig. 3 shows the editor of the rules of the knowledge base of the ES regarding the choice of the rational route of delivery of dry fruit batch from a supplier to a focus company.

Fig. 1. The topology of location of dry fruit supplying companies to focus company "East plus"

For the particular scenario, given as an example, we obtained the following values of the input variables (Fig. 4): "Weather conditions" – 5 points, "Quality of road cover" – 4 points, "Speed limit" – 6,8 points, "Customs clearance" – 7 points.

As a result, the machine of fuzzy knowledge-based inference gave the values of the output variables "Transportation time" and "Transportation costs" equal to 41.5 hours and 12.7 cond. units, respectively (Fir. 4). Order View\Rules shows the graphic interface of the rules view program (Fig. 4, 5).

Table 1

The range of goods supplied within the DSC and information about suppliers

No., of entry	Goods	Suppliers (company, country, city)
1	Dried apricot	«Zulal Food» Turkey, Malatya
2	Raisins	«TAK 507» Iran, Malayer
3	Raisins	«ASAL» Iran, Bushehr-Brodjan
4	Raisins	«RAISINS GOLD» Iran, Urmia
5	Dates	«ARAJA PART» Iran, Ahvaz
6	Dates	«RAISINS» Tajikistan, Dushanbe
7	Dates	«COMETTE» Algeria, Dubai
8	Dates	«SALIM HADDOUD» Algeria, Dubai
9	Sun-cured persimmon	«AZER HORMA» Azerbaijan, Ganja
10	Prune	«777 4 Seasons» Uzbekistan, Tashkent

To analyze alternative route 2, the values of input variables were estimated in the following way: "Weather conditions" – 5 points, "Quality of road cover" – 7 points, "Speed limit" – 4.5 points, "Customs clearance" – 3.5 points. As a result, the ES formed the values of output variables "Transportation time" and "Transportation costs" equal to 49.2 hours and 15.6 cond. units, respectively (Fig. 5). Evidently, formed route 1 is more rational.

Visualization of the surface of fuzzy inference of the considered model for the input variables "Speed limit" and "Customs clearance" is shown in Fig. 6.

Table 2

Routes of international transportation of dried fruits

Kind of goods	Raisins
Suppliers	«TAK 507», «ASAL», «RAISINS GOLD»
Route 1	Route 2
Malayer (Iran)→Ghirdalan (Azerbaijan)→Gaptsakh (Dagestan)-Gudermes (Republic of Chechnya)→Rostov-on-Don (Russia)→Kharkiv (Ukraine)	Ahvaz (Iran)→Mari (Turkmenistan)→Dushanbe (Tajikistan)→Tashkent (Uzbekistan)→Shymkent (Kazakhstan)→Saratov (Russia)→Kharkiv (Ukraine)

The surface of the fuzzy inference shown in Fig. 6 makes it possible to establish the dependence between the values if the output variable on the values of separate input variables of a fuzzy model. Analysis of these dependences is the basis for changing the membership functions of input variables or fuzzy rules in order to improve the adequacy of the fuzzy inference model underlying the ES operation.

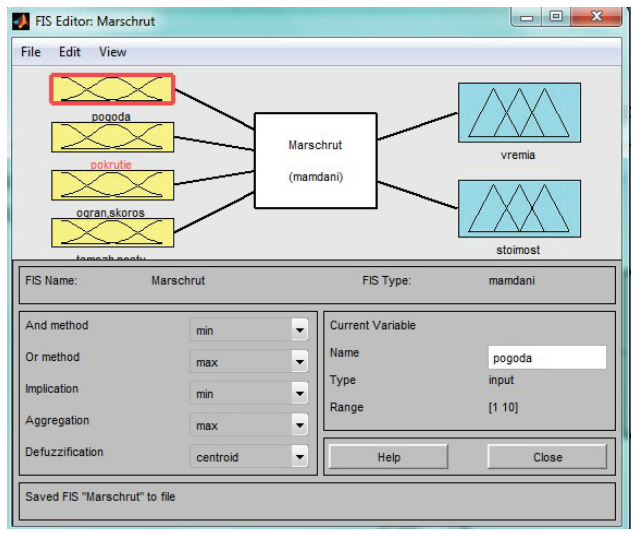

Fig. 2. Graphic interface of the FIS editor of substantiation of a rational route of dry fruit delivery by road

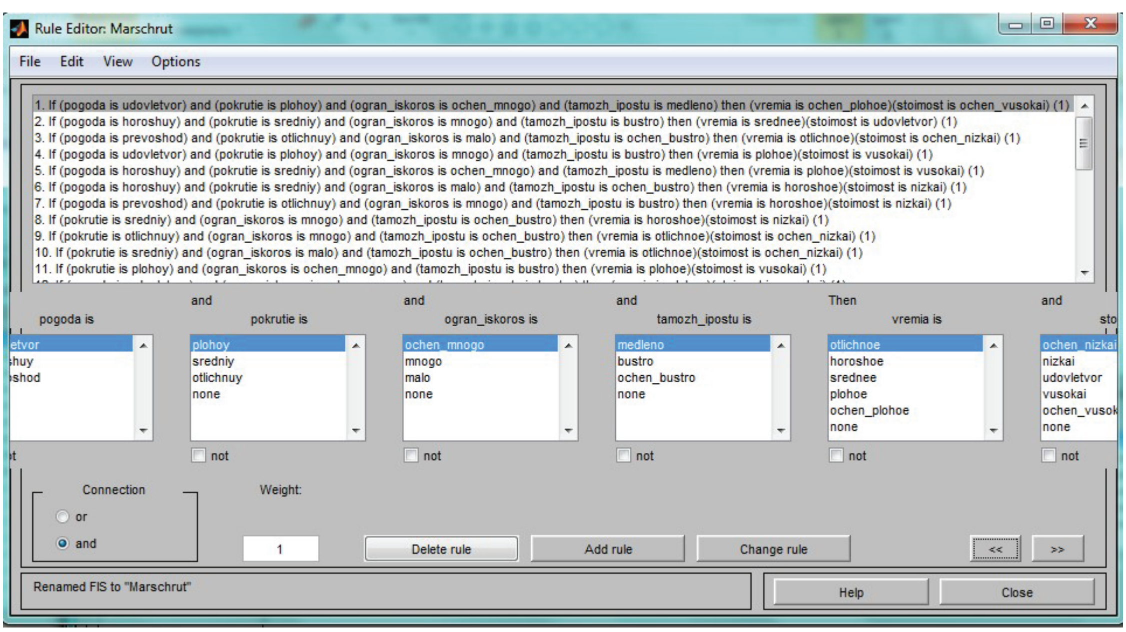

Fig. 3. Editor of ES knowledge base rules

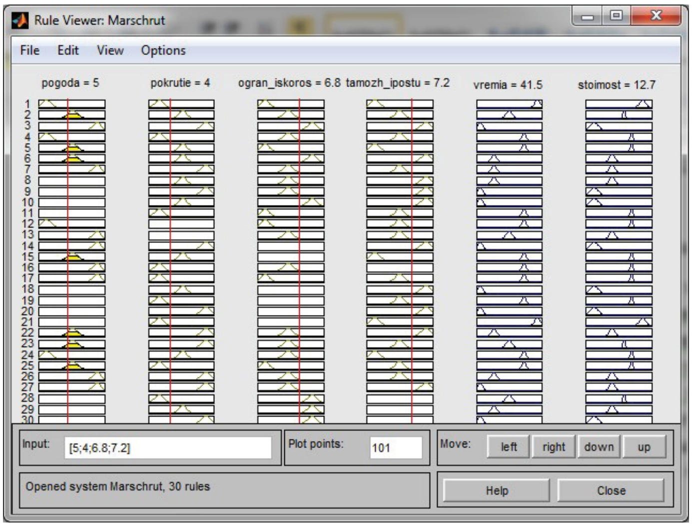

Fig. 4. Graphic interface of rule viewer of the ES knowledge base for route 1

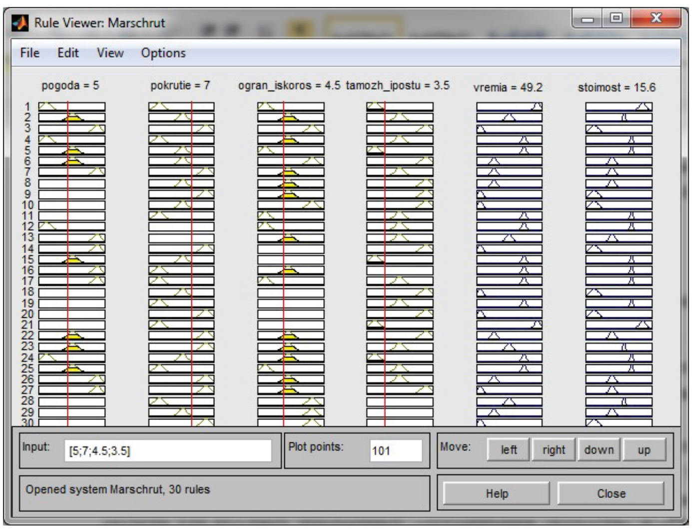

Fig. 5. Graphic interface of rules viewer of the ES knowledge base for route 2

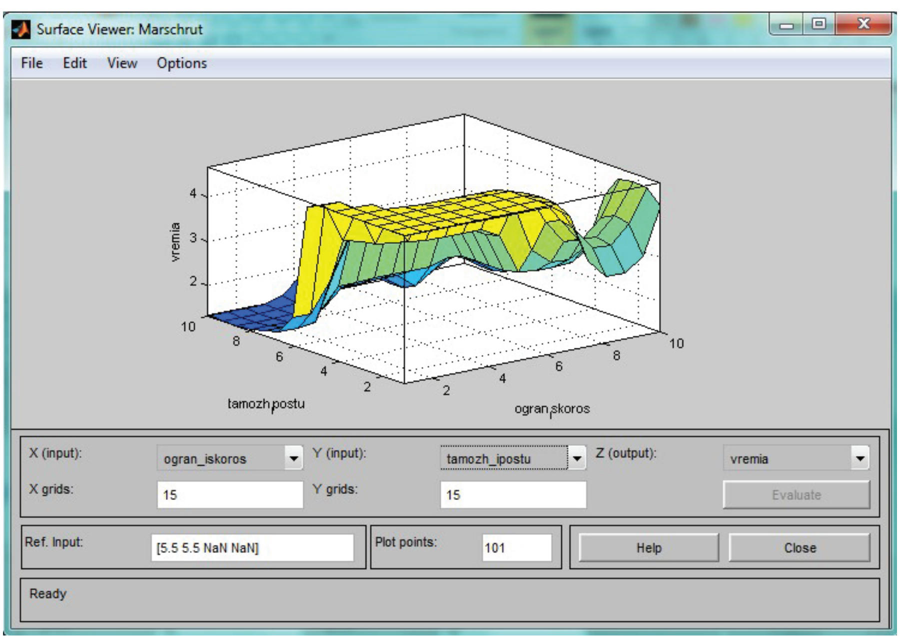

Fig. 6. Visualization of fuzzy inference surface for output variable "Transportation time"

7. Discussion of results of studying the organization of managing dry fruit supply chains using expert systems

To implement the described approach, a layered structure of the business process management system in the DSC in the form of an orderly set of typical decision-making support units for DSC participants was proposed. Each unit is designed to address a specific sub-problem of the DSC management and is developed using a specialized ES corresponding to the shell layer.

The implementation of the specified approach is shown using the example of solving a typical sub-problem that arises during the DSC implementation, namely, the rational transportation organization within a chain. We considered the scenario example of the process of solving a typical sub-problem arising in the DSC implementation, namely, substantiation of choosing a rational route of delivery of a dried fruit batch from foreign suppliers to a focus company. As a result, the values of output variables "Transportation time" and "Transportation costs" are equal: for route 1 – to 41.5 hours and 12.7 cond. units, for route 2 – to 49.2 hours and 15.6 cond. units. The obtained data indicate that it is necessary to follow route 1 for dried fruit transportation.

The benefits of this approach include the possibility to ensure the homogeneity of the unified information space of the DSC due to:

– distinct positioning of each decision-making support unit in the general management structure;

– the wide use of typical solutions in the synthesis of tools of information support of DSC participants.

Financial constraints prevent the extensive application of the results in practice because it is necessary to involve a significant number of cognitive specialists to form and administer knowledge bases for relevant expert systems.

The main limitation of the discussed approach is related to the need to administer information support tools (ES knowledge bases), which requires the involvement of IT professionals.

The direction of further research is related to the development of more effective methods of point-based assessment of separate quantitative values of input and output linguistic variables. This will certainly enhance the adequacy of the models of fuzzy inference of the ES as a part of the relevant decision-making support units for the DSC participants.

8. Conclusions

1. A methodical approach to the creation, deployment, and support of the unified knowledge space within the DSC was developed. The novelty of the approach is in the representation of the general goal of DSC management in the form of a layered hierarchy of local problems. At the same time,

each unit in the DSC management system is designed to solve a specific sub-problem of the DSC management and is developed using a specialized ES, corresponding to the shell layer.

2. We described the procedure of synthesis of a typical decision support unit for DSC participants in the form of the ES for the adaptation layer as the middle level in the hierarchy of decision making on the DSC management. The application of such a procedure in the course of the DSC intellectualization will make it possible to decrease significantly the temporal and financial costs of developing decision-making support tools for corresponding DSC participants.

3. A scenario example of the process of solving a typical sub-problem that arises during the DSC implementation, specifically, substantiation of choosing a rational route of delivery of a dried fruit batch from foreign suppliers to a focus company was presented.

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