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FUZZY COGNITIVE MAPS FOR STRATEGIC DECISION MAKING OF LOGISTICS SYSTEMS

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Abstract. Today supply chain and logistics systems are extremely complex, characterized by a huge amount of available data and information that are taken into consideration to make decision in any of the three levels, at operational, tactical and strategic. Fuzzy Cognitive Map is an abstract modeling methodology that has successfully used to model complex systems. Here it is proposed a methodology for applying Fuzzy Cognitive Maps for Strategic Decision Making. The proposed approach tested and implemented for strategic decision making tasks for the port and services environment of the Trieste area.

Keywords: fuzzy cognitive maps; strategic decision making; logistics systems; port and services environment.

1. INTRODUCTION

Nowadays systems are characterized by complexity. I it is essential to take into consideration many various and complementary factors and reengineering alternatives before conclude to a final decision. The requirements of nowadays trade and the general economy include cost and services and set the needs for effective supply chain networks. Thus, effective methods and techniques should be developed in order to model and provide simulation of real situations and suggest alternatives for succeeding a detailed analysis and evaluation of supply chain design and management alternatives [1].

Supply chain is defined as a network of autonomous or semiautonomous business entities collectively responsible for procurement, manufacturing and distribution activities associated with one or more families of related products. The entities of supply chain have different constraints and objectives; however they are highly interrelated and independent when it comes to improving the overall performance of supply chain, such as on time delivery, quality assurance and cost minimization. Therefore, the overall performance depends on each entity and how they can be coordinated for achieving better results. Logistics is part of supply chain and it plan, implement and control the flow and storage of goods (both forward and reverse flow) based on the necessary information between the origin and consumption.

One goal of a logistics system is to obtain and move supplies as timely and affordable as it is possible to the various places. What make such system complicated are the various procedures that products have to be checked before reach to the end user. Modern logistics systems are characterized by uncertainties with high degree and great complexity as it is observed in any production, logistics and enterprise structures. Thus, the efficient logistics management is required for better coordination of the process. Modeling and simulation approaches are used to check the final decision based mainly on approaches that model the experts' knowledge and experience. Therefore, modeling and description of such systems require the use of methods that can exploit human experience, will have learning capabilities and take under consideration the uncertainty and imprecision, which characterize the real world systems [2].

2. DECISION SUPPORT SYSTEMS AND STRATEGIC DECISIONS

Decision support can provide assistance during the process of decision making, which involves selecting the best (or optimal) strategy for achieving some given goals among the alternative strategies. Many stages of supply chain management such as logistics, planning, production planning require decision making process. For such cases Decision Support Systems (DSS) are available, which can handle vast amounts of data, information and knowledge. For these applications, the DSS should be dynamic in order to be able to represent the changes in time and change their relationship among the objects. Besides, these systems should make visible the way that interact the objects that involve with each other, recognize emerging trends and undertake protective action for succeeding to the predefined goals [3].

A well designed DSS can help the decision maker to extract useful information from documents, raw data, personal knowledge and/or business models with the objective of identifying and solving problems and making decisions. The decision support in supply chain and logistics management can have various forms. There have been developed various DSS for different stages of supply chain. Tan *et al*. proposed a multi-criteria decision making (MCDS) technique to support decision making in context-aware B2B collaboration [4]. The results showed that it is an effective system with stability and robustness, while it can handle the sensitivity of the sequence to changing weights in the criteria. Ngai *et al.* proposed the Context-aware Fleet Management System (CFMS) [5]. It used for real-world settings for potential users and for field logistics experts as they can handle real-time accidents and can reschedule the decision. Condea *et al*. [6] evaluate the contribution of RFID for retail store operations and especially the use of technology to automate self replenishment decisions.

Strategic decisions are complex because they involve significant commitment of resources. A strategic logistics planning involves the processing of considerable amounts of data in order to completely describe the system. Data are obtained from various sources and a thorough analysis must be accomplished within a reasonable time for taking a decision so as the strategic planning to be effective. Strategic DSS support executives in their management activities as they need methods with simplicity to knowledge representation, flexibility to model design, and adaptability to different situations. Fuzzy Cognitive Maps (FCMs) can be used for these purposes. FCMs are easy to be used and they can be combined with learning algorithms, succeeding optimized solutions. FCMs are used for DSS as they can represent knowledge efficiently, handle fuzziness, model complex systems, model situations that include uncertainty descriptions, are adaptive to different situations, are flexible to new knowledge while they are simple and transparent to decision makers.

3. FUZZY COGNITIVE MAPS

Fuzzy Cognitive Map (FCM) is a soft computing modeling technique for complex systems, originated from the combination of Fuzzy Logic and Neural Networks. It introduced [7] as an extension to Cognitive Maps [8]. They are a graphical representation for the description and modeling of the behavior and operation of a system. FCM is a technique used for causal knowledge acquisition, it supports causal knowledge reasoning process and belong to the neuro-fuzzy system that aim at solving decision making problems, modeling and control problems. The FCM resembles human reasoning; it relies on the human expert knowledge for domain, making associations along generalized relationships between domain descriptors, concepts and conclusions. It can model any real world system as a collection of concepts and causal relations between concepts.

FCM is an illustrative causative representation for the description and modeling of any system. Graphically is consisted of interrelated concepts. FCMs are dynamical, fuzzy signed directed graphs, permitting feedback, where the weighted edge w_{ij} from causal concept Ci to affected concept Cj describes the amount by which the first concept influences the latter, as is illustrated in Fig. 1. Experts design and develop the structure of the system, including the nodes that represent the key factors of the system operation. They determine the way of network's interconnections, using linguistic variables to describe the relationships among concepts. Then all the variables are combined and the weights are determined. Learning methods and historical data lead to the equilibrium point.

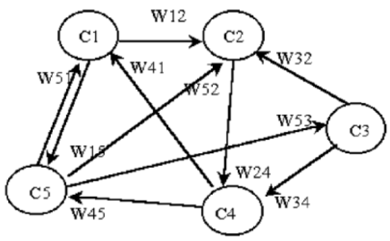

Fig. 1. The FCM model

Nodes of the graph are concepts, which correspond to variables, states, factors and other characteristics that are used in the model and describe the behaviour of the system. The nodes stand for the concepts that are used to describe the behaviour of the system. FCM is a conceptual network, which is in most of the cases built by experts, using an interactive procedure of knowledge acquisition. The connection between the signed and weighted arcs represents the causal relationships. The sign of the weight shows the causal relationship between concepts. That is, if $w_{ji} > 0$ then concept C_j increases C_i, if the weight is $w_{ji} < 0$ then concept C_j decreases C_i, while if $w_{ji} = 0$ concept C_j has no causal effect on C_i. The mathematical model of an FCM can be described from eq. 1:

$$A_i^{k+1} = f(A_i^k + \sum_{\substack{j \neq i \\ j=1}}^{N} A_j^k w_{ij}), \quad (1)$$

A_i^{k+1} is the value of concept C_i at simulation step $k + 1$, A_j^k is the value of the interconnected concept C_j at step k, w_{ji} is the weight of the interconnection between concept C_j and C_i, and f is a sigmoid threshold function:

$$f = \frac{1}{1+e^{-\lambda x}} \quad (2)$$

where $\lambda > 0$ is a parameter determining its steepness.

FCM gives the opportunity to model and simulate many problems that require decision making. The fact that FCMs can handle vague, missing or not available information renders them a versatile tool. FCMs are able to model and simulate systems in a wide variety of application areas, because of their capability to handle complexity with much and/or even incomplete or conflicting information. They can represent and handle a vast amount of information by an abstract point of view. Experts have a key role in developing the FCM as they describe a general operational and behavioral model of the system using concepts of the main aspects of the system. FCMs can use experts' knowledge and model a system based on experience and knowledge, while they have been combined with different algorithms giving optimized solutions/decisions. They represent the accumulated knowledge on the operation and behavior of the system, using concepts stands for the characteristics of the system. FCMs can simulate a scenario / procedure and help for making a decision or evaluate the correctness of a scenario and / or redesign the decision after a change.

4. FCMS FOR DECISION SUPPORT IN LOGISTICS

Logistics are complex systems that include various and different procedures that should be co-evaluated for the final decision. The ever-increasing complexity of logistics makes it difficult to achieve a clear and coherent illustration of how logistics systems are work and this complexity hinders the capability to obtain satisfactory solutions of technical problems. These characteristics led to model them in a more abstract qualitative model, which use concepts from information theory, neural network and fuzzy logic to represent and process information. FCM is an expert based technique which depends on experts' experience and knowledge for the construction and initial configuration.

As logistics systems (forward and reverse) include many procedures, which some of them is time consuming; FCM can enhance the overall performance of the system and offer optimized solutions. Many applications have been developed for the various stages. Some of them use the basic model of FCM, while others use hybrid or hierarchical models. Learning algorithms have been also used to enhance model's behavior for achieving optimized results.

The basic FCM model has been used to model third-Part Logistics providers (3PLs) [9], which examine company's survivability. Because the fact that many real world problems are too complex to be described with mathematical formulations, a well known approach that is used is Discrete Event Simulation (DES) which has been used to evaluate the behavior/performance of a system [10]. In the area of supply chain management, financial management and logistics, the systems under investigation cannot be modeled analytically in most cases. As the computation burden and the time that is required to simulate a situation with DES are high, one solution is to use metamodels, which is a 'model of the model'. These models can contribute to decrease the simulation time and search for the optimal decision set and become the prediction model for the simulation in the same way that the simulation is the prediction model for the real system [11, 12]. Logistics management includes the cooperation of different stages.

FCM can facilitate collaboration between model builders. Different FCMs from different experts can be integrated into a larger FCM. This attribute has been used to model reversed logistics, which includes manufacture, logistic center and retail site. FCM, enhanced with Genetic Algorithm, has been used to model the reverse logistic management [13]. The proposed model constitutes an assistant tool that let the manager to define the expected future. FCMs with Genetic Algorithms have been also used to illustrate an extended supply chain for forward and backward analysis of RFID-enabled supply chain [14].

5. FCM FOR STRATEGIC DECISION MAKING FOR TRIESTE PORT

FCM for strategic can be used to analyze and examine the alternatives for intermodal port and dry port transportation development. This case considers the port of Trieste (Italy) and the dry port of Fernetti, the term 'dry post' denotes an inland terminal directly linked to maritime port.

If improvement for Trieste-Fernetti transportation is needed, the decision maker has more than one alternative to consider: operate an extra gate, establish a railway connection or establish a shuttle service (Fig. 2). Each alternative has its advantages and disadvantages and the contributed concepts interrelate with each other (Fig. 2), leading to different alternatives/decisions and affecting differently the overall efficiency. As referred strategic decision is at the top management, hierarchically. This means that decision maker must consider all the individual characteristics that affect each one of these criteria. For example the financial criterion includes all the costs (warehouse / depot, inventory, administration, operating, transport costs etc.), profits, capital etc. FCM is a knowledge-based modeling approach that can handle such complex systems. It can compute the interrelations among all the contributed concepts.

Fig. 3 depicts the correspondent FCM for Trieste port, underlining the highly complexity. The arcs link the concepts while the weights (w_{ij}) show the degree of interconnections. The weights are attributed by the experts and / or databases, using the experience and solutions of other similar cases. The concepts C1–C7 are the factor-concepts and the bold ones, C7–C10, the decision concepts.

Using this model the decision maker can have immediate results for long lasting procedures and behaviors. The degree that one concept depends on other is described by a linguist variable that is transformed into a numerical value (weight). These weights are characterized linguistically and attributed to the arcs by each expert, who is the main involved actors, users and stakeholders. Using a fuzzy logic based approach these linguistic weights are aggregated and converted to single linguistic value-weight, which is transformed into a numerical value through a defuzzification method. Thus, the decision maker can experiment with the criteria/concepts and the FCM-Decision Making tool computes the decisions/alternatives in order to help him/her to reach a decision that fulfill the initial goal (improve Trieste–Fernetti).

6. FCM FOR STRATEGIC DECISION MAKING IN LOGISTICS IMPLEMENTED WITH C#

The process for a decision maker to choose a strategy as ideal for a system is highly complicated. S/he should take into account all the factors and elements of the system's corporate and competitive strategies. In order to achieve a goal, the executive may generally have more than one alterative strategy at hand. The selection of the best alternative concludes to be highly subjective and is based only on his/her experience and judgment. However, the various pressures that may be exerted to a system can lead the decision maker to consider the replanning of the overall strategies, which cover a number of different internal and external aspects. A strategic planning overview involves fitting the internal capabilities to the external environment by choosing the best alternative.

As a result the choice of a goal as the best one is a complex and difficult process. The decision maker should take into consideration many different aspects from different sources. For reducing the subjectivity of choice, the FCM model is proposed as a means to take into account both the knowledge and experience of one or more experts simultaneously and all the interdependencies among the factors. The proposed tool based on FCM model can be used as an evaluation tool for the different scenarios by inserting the appropriate values/inputs and the appropriate control conditions before the final decision. In this way, different scenarios can be evaluated and judged for their result (if they meet the expectations or not). FCM can also give the opportunity to explore the behavior of the system and examine the change of the systems in case of small or large changes. The proposed tool can simulate complex procedures and conclude to a result/decision according to the FCM theory, while it can be used as a mean to evaluate various scenarios/criteria in order to find ways to achieve different goals. The expert(s) sets the relative concepts that take part in a particular logistics process and determines the influence between them that contribute to the final goal/decision choice.

The use of FCM model need two parts: the FCM construction by experts and its initialization for particular cases by the decision maker. The experts design the FCM determining the concepts, the way that one concept affects other(s) concepts and the degree (weight) of this influence. Figure 4 illustrates the interface that experts can add factor-concept and decision-concepts. In this stage the expert(s) define the concepts and their interrelationships. They can describe the interconnection degree linguistically, as the concept C_i affects the concept C_j: very-very low, very low, low, negatively medium, positively medium, high, very high, very-very high, none (Fig. 4). The factors correspond to the interrelated factors that take part in the final decision and the weights are the degree of their partition.

After the FCM construction, the decision maker can use the experience and knowledge of experts, literature or any other available source to infer the concepts and weights.

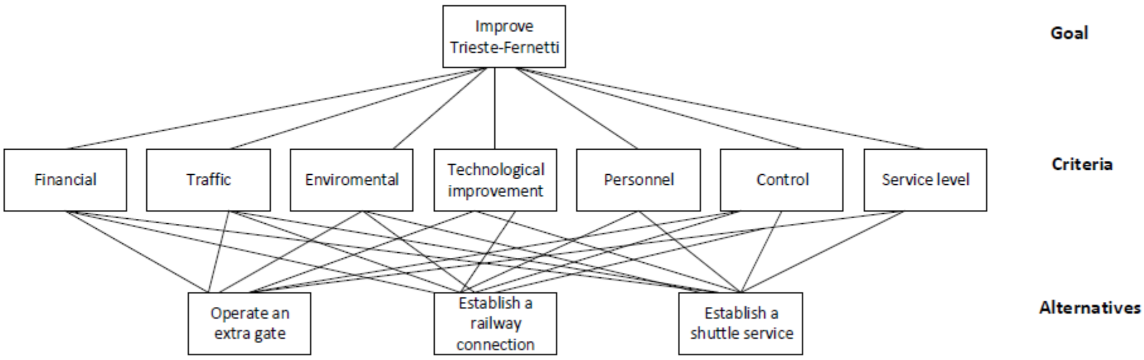

Fig. 2. Concepts for strategic decision related with Trieste-Fernetti improvement

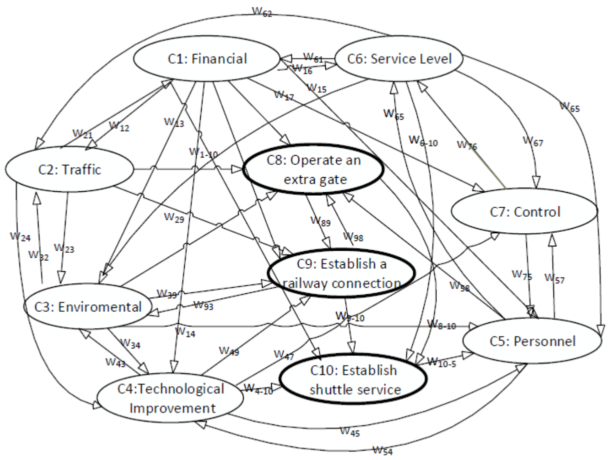

Fig. 3. FCM for strategic decision for Trieste port

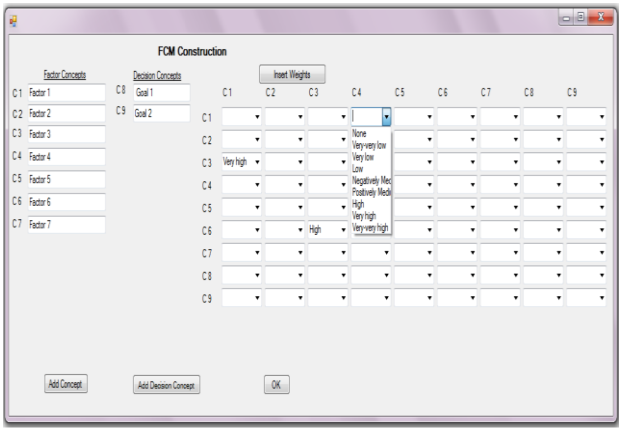

Fig. 4. Add Factors and Decisions / Alternatives. Determine their relationships (weights)

Thus, s/he can set the initial values of concepts to the constructed FCM and the method calculates the dominant alternative decision. After a number of simulations and if there is enough distance to one at least decision compared to others, the values are presented and decision maker can judge and determine if the final value is acceptable or not. The distance between the decisions can be defined by the decision maker for each scenario.

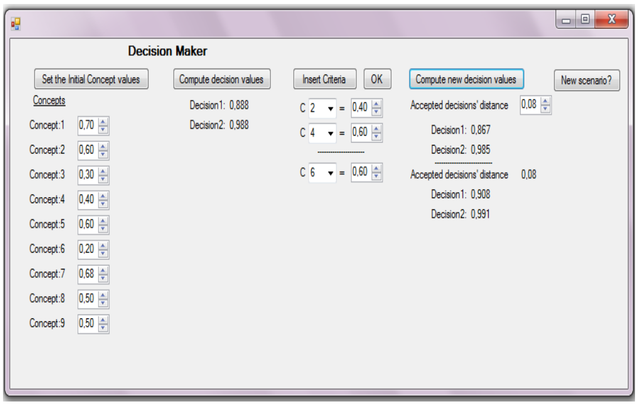

Fig. 5. The decision values are computed for each scenario

A hypothetical example with the illustrated initial concept values and their results are presented in Fig. 5. For this random example, the Decision 2 is more likely to be accomplished if the related concepts –factors take part in the process with these particular initial values. The decision maker is also able to change his/her first scenario by changing both the values of concepts- factors and the accepted distance between the decisions and s/he can notice how the new values affect the dominant decision. S/he can modify more than one of the contributed concept values (Fig. 5). The decision maker can experiment with various scenarios as many times as s/he wants, until s/he will be able to form his/her final decision. Besides, s/he can notice how a decision/goal can be succeeded better, how the changes (increase or decrease) of the factors contribution affect the final goal and propose a scenario that fulfills the requirements.

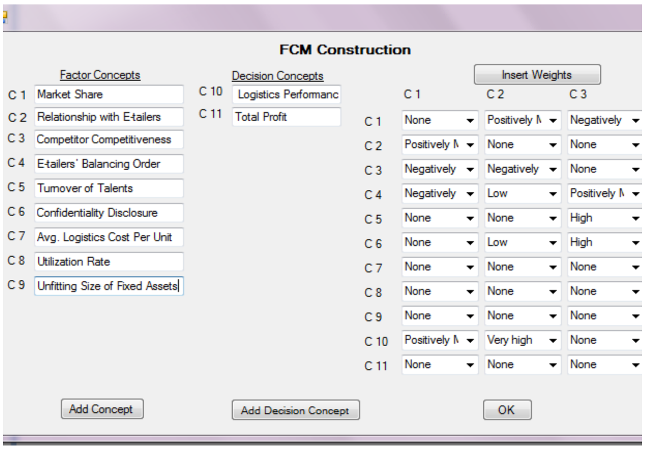

Fig. 6. FCM construction for third-Part Logistics providers according to [9]

However, the FCM-DM system may not converge to a clear decision for the required decisions' distance and for the particular initial concept values. In this case the FCM-DM tool provides a warning that the FCM may need to be redesigned.

6.1 An example from Logistics

The FCM-DM tool has been implemented for an example from the logistics area. There were used the input data for the concepts/factors of 3PLs and the defining weights as described in [9], the decision maker can define which will be the under consideration decisions/goals and make decisions that meet the ends of the required goal. The FCM construction is based on experts who are top echelon of the management at e-tailers and 3PLs. The developing FCM is illustrated in Fig. 6. Therefore, the decision maker sets the initial values and then sets a first scenario and notice how the under consideration decisions/factors (logistics performance or total profit) are being affected so as to choose the most appropriate scenario according to the company's goals.

Thus, the proposed tool helps the executive to notice how any individual concept affect the final decision, while s/he is able to change the scenario, provoking changes to particular factors and/or the distance of decisions, for a 'clearer' decision. Fig. 7 presents also th simulation results. This figure declares that the initial values lead to better logistics performance, while a simultaneous large increase in market share, a decrease in relationship with e-tailers and a slight decrease in confidentiality disclosure will lead to better total profits.

Another scenario was to slightly increase the contribution of competitor competitiveness and increase the avg. logistics cost per unit, which led to a better logistics performance. In this way various scenarios can be tried and changes can be proposed in order to have the desirable results, concluding to the alternative in accordance with the dominant decision and the company's goal. Thus, by trying various what-if scenarios decision makers can see the impact of possible changes on the variables defined in the FCM. Therefore, FCM-DM offers a tool for a decision maker to judge and compare the results and finally to choose the scenario that gives the most satisfying result. It suggests and support the decision maker during his decision process as it can merge and combine information coming from different sources.

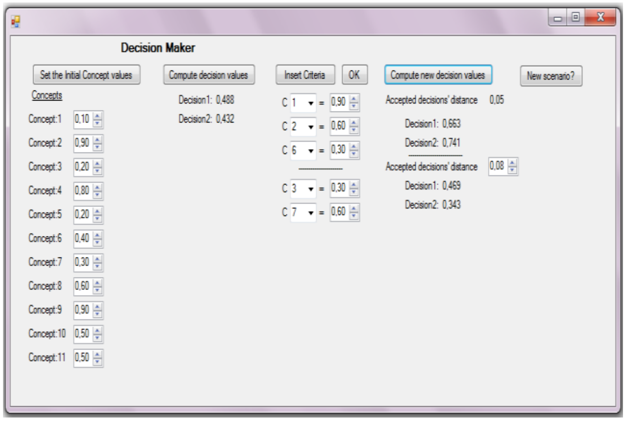

Fig. 7. Decision values for an initial and two more scenarios

7. CONCLUSIONS

Distribution and logistics are complex processes and they need appropriate planning and control. There are many and varied elements that are involved to achieve an effective distribution and logistics operation. These elements interrelate and have to be planned over suitable time horizons [15]. FCM can succeed in taking into consideration the relationships and dependencies among the different factors and reach to a decision based on these. FCM tool is easily used, adaptive and flexible to new situations and knowledge. These attributes render it a versatile tool that can be used almost to the whole supply chain.

Making a decision is a subjective process. Similarly, FCM is based on experts. The FCM model can be used as an assistant tool to enhance or dispute the initial scenario of the executive and generally help him/her to rethinking before the final choice. It enables the user to experiment with different scenarios while the system accomplishes all other data manipulation and computation in order to examine the impact of these changes to the overall performance. The Decision Makers can use the FCM-DM tool as a means to verify alternative scenarios, by activating the relevant factors.

Future work will simulate the goal of Trieste-Fernetti improvement, using a hierarchical model. The illustrated model of Fig. 3 will be the higher level and each of individual criteria / factors will be the decisions of a lower level consisting of a number of m-FCMs. Each m-FCM will have its related concepts/factors and the particular final decisions will determine the concepts of the supervisor FCM.

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МЕТАДАННЫЕ

Название: Нечеткие когнитивные карты для стратегического принятия решений в логистических системах.

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Аннотация: Сегодня цепочки поставок и логистические системы чрезвычайно сложны, характеризуются огромным количеством имеющихся данных и информации, которые принимаются во внимание, чтобы принимать решения в любом из трех уровней: оперативном, тактическом и стратегическом. Нечеткие когнитивные карты являются абстрактной методологией моделирования, которая успешно используется для моделирования сложных систем. Здесь предлагается методика применения нечетких когнитивных карт для принятия стратегических решений. Предлагаемый подход испытан и внедрен для стратегических задач принятия решений для порта и услуг окружающей среды в зоне Триеста.

Ключевые слова: нечеткие когнитивные карты; принятие стратегических решений; логистические системы; порт и среда обслуживания.

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