Fuzzy Cognitive Maps for Decision Making of Complex Logistic Systems

Evangelia Bourgani, Chrysostomos D. Stylios

Dept. of Computer Engineering, TEI of Epirus, Artas, Greece
(email: ebourgani@gmail.com; stylios@teiep.gr)

Abstract. Logistics systems are characterized as complex as there is a huge amount of data and information that they have to take into consideration in order to make decisions at any of the three levels i.e. operational, tactical and strategic. Fuzzy Cognitive Maps is an abstract modeling methodology that has successfully used to model complex systems and perform decision making tasks. Here Fuzzy Cognitive Maps are proposed for Strategic Decision Making and they are tested for performing strategic decision making tasks for the port complex at Trieste, Italy.

Keywords: Fuzzy Cognitive Maps, Soft Computing, Logistic Systems, Decision Making

1 Introduction

Most of today's systems are characterized by complexity. There are many various and complementary factors and alternatives that are taken into consideration before concluding to a final decision. The requirements of world economy and trade include cost and right services. Thus, effective methods and techniques should be developed in order to model and provide solution of real situations and suggest alternatives for succeeding a detailed analysis and evaluation of logistic systems design and management alternatives [1].

Logistic systems are characterized as autonomous or semiautonomous business entities collectively responsible for distribution and handling activities associated with one or more families of related products. There are different constraints and objectives; however all entities are highly interrelated and independent and the overall performance is based 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 systems 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 that characterizes any production, logistic and enterprise structure. 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 exploit the experts' knowledge and experience. Therefore, modeling and description of such systems require the use of methods that can utilize human experience, will have learning capabilities and take under consideration the uncertainty and imprecision, which characterize the real world systems [2].

2 Strategic Decision Support Systems

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 such applications, the DSS should be dynamic being 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 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 were 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 involve significant commitment of various 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 easily used and they are combined with learning algorithms to perform optimized solutions. FCM models 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 FCMs for Medical Decision Support Systems

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 the behavior 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 C_i to affected concept C_j 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.

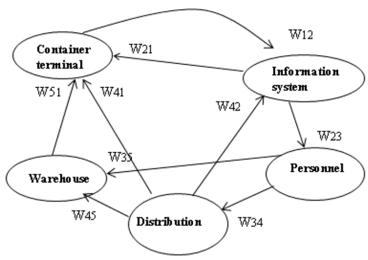

Fig. 1. The fuzzy cognitive map model for a logistic system

Nodes of the graph are concepts, which correspond to variables, states, factors and other characteristics that are used in the model and describe the behavior of the system. The nodes stand for the concepts that are used to describe the behavior 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.

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

A_i^{k+1} is the value of concept C_i at simulation step k+1, A_j^k 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:

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

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 Fuzzy Cognitive Maps for Logistic Decision Support Systems

Logistics are complex systems that include various and different procedures that should be co-evaluated for the final decision. The ever-increasing complexity of logistic systems 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, some of them are time consuming; FCM can enhance the overall performance of the system and offer optimized solutions. Many FCM based applications have been developed; 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. As 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 an integrated FCM. This attribute has been used to model reversed logistics, which includes manufacture, logistic center and retail components. 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 Fuzzy Cognitive Maps for Strategic Decision Making

The decision making process to evaluate and choose the best strategy is a highly complicated procedure. It requires to define all the possible factors and to determine their involvement in the system's corporate and competitive strategies., The executive has to produce and test more than one alterative strategy, to compare them based on some metrics and then to select the optimal one. It is expected that the selection of the best alternative depends mainly on the metrics and it is usually a highly subjective procedure as it is based on the decision maker experience and judgment. Usually the decision maker has to examine and test different scenarios and to replanning the overall strategies, because of new restrictions and to include and/or exclude a number of different internal and external aspects. Generally the strategic planning involves fitting the internal capabilities to the external environment by choosing the best alternative.

Fuzzy Cognitive Map being an abstract knowledge representation approach is suitable for strategic decision making so that to analyze and examine different alternatives and choices for a coupling intermodal port and dry port. This is the case under investigation for the port of Trieste (Italy) and the accompanied dry port of Fernetti. As it is known the 'dry port' denotes an inland terminal directly linked to maritime port that both perform the same procedures and they have to cooperate in a harmonized way so that to achieve the optimal performance of both.

For the coupling two ports system of Trieste & Fernetti, a decision maker has more than one alternative to consider handling the increase of transportation bulks and achieving the optimal solutions such as to operate an extra gate, establish a railway connection or establish a shuttle service between the two ports (Fig 2). Any alternative has its advantages and disadvantages that are represented by the degree of influencing the corresponding criteria being at the intermediate level at Fig 2.

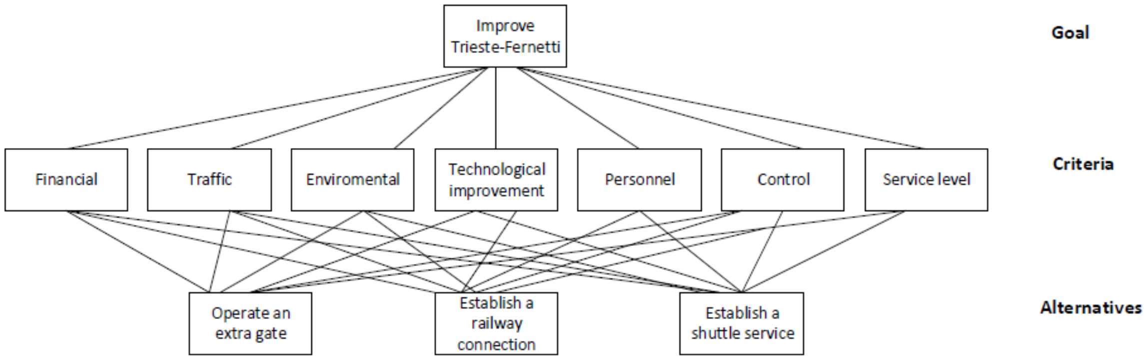

Fig 2: A hierarchical structure of the interconnected criteria influencing the strategic decision related with Trieste-Fernetti improvement

Strategic decisions refer to the top management and it supposes a hierarchical process. The decision maker being at the upper level has to consider the main 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.

Based on the illustration presenting in Fig. 2 it is obvious that the Fuzzy Cognitve Map will be consisted of the seven (7) criteria concepts and the three (3) decision / concepts. The most essential step of designing the Fuzzy Cognitive Map for supporting the decision makers requires the determination of weights among concepts.

A group of experts is asked to express in linguist terms the degree of influence from once concept to another. All the linguistic weights that are proposed to describe the dependence of one concept to the other, are aggregated using a fuzzy logic based approach and then are transformed into a numerical value (weight) through a defuzzification methods. In this way, the Fuzzy Cognitive Map for examining the different alternatives that correspond to Trieste-Fernetti coupling port is developed and presented at Fig. 3.

It is underlining the highly complexity of the FCM model, as there are included all the possible interconnections among arcs. The arcs link the concepts while the weights (w_{ij}) show the degree of interconnections. There are two different approaches in order to assign weights in the interconnection among concepts either by experts who are asked to determine the influence from one concept to another or by existing known numerical value describing the correlation of two values, based on experience and/or solutions from other similar cases. The concepts C1-C7 are the criteria-concepts and the bold ones, C8-C10 are the decision concepts. It is mentioned that here it is also applied the competitive rule among the decision concepts, so that at the end the FCM concludes to just one decision.

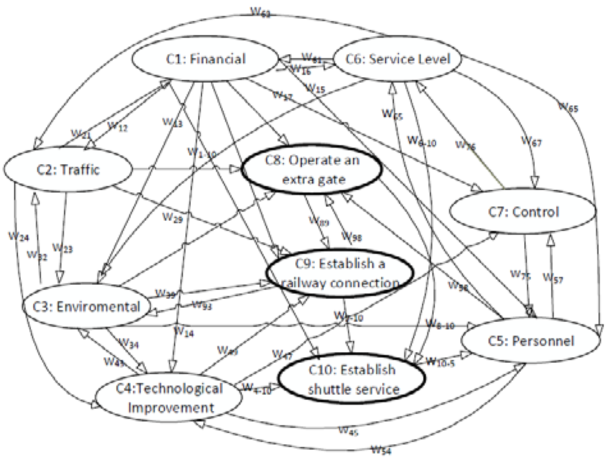

Fig.3: FCM for strategic decision for Trieste port

Using the developed FCM-Decision Making Tool, the decision maker can run different scenario and 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 ultimate goal (improve Trieste-Fernetti). Using this model the decision maker can have immediate results for long lasting procedures and behaviors. 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.

6 A Fuzzy Cognitive Map Decision Making (FCM-DM) Tool

A software tool has been developed to support the procedure of FCM development. The tool can easily be used for evaluating different scenarios by setting different values/inputs for the concepts and changing the control conditions. In this way, different scenarios can be evaluated and judged for their result (if they meet the expectations or not). The FCM-tool provide also the opportunity to explore the behavior of the system under different circumstances and test the system's behaviour either for small or large changes. The FCM tool can easily be used to simulate any complex procedure and to infer to a result/decision following the FCM approach. In addition to this, it will be used as a mean to evaluate various scenarios/criteria so that to suggest the best selections that 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 FCM tool is consisted of two main stages : the FCM construction stage mainly by experts and the stage to initialize the concept values for different cases.. Figure 4 illustrates the first stage where there is an interface for experts who can add factor-concept and decision-concepts. The experts design the FCM determining the concepts, the way that one concept affects other(s) concepts and the degree (weight) of this influence. In this stage the expert(s) define the concepts and their interrelationships. They can describe the interconnection degree linguistically; they decide how concept C_i affects the concept C_j selecting one of the following linguistic values: 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 influence from one concept to the other.

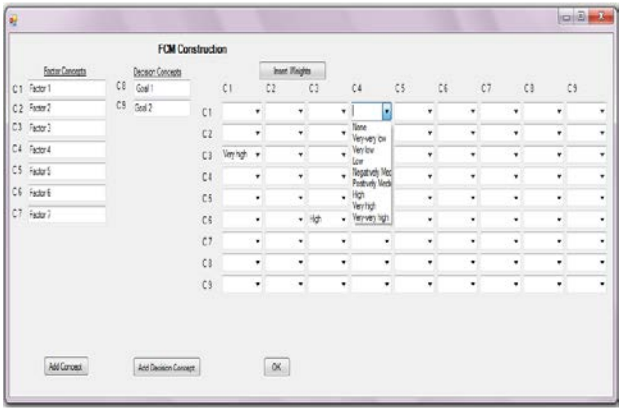

Figure 4: Add Factors and Decisions/Alternatives. Determine their relationships (weights).

After the FCM construction stage, the FCM-tool can be used to simulate different scenarios. The decision maker has to initialize and assign values to the factor concepts. He may be use his own experience or information from literature or any other available source to assign initial values to Factor concepts. . 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 of decision concepts is acceptable or not. Moreover,, the decision maker is able to set a minimum distance between the decision concepts for each scenario that he runs. (Fig.5)

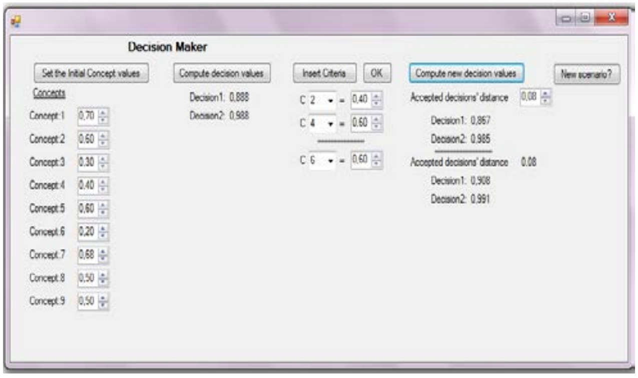

Fig 5: The decision values are computed for each scenario

An example is presented at Fig. 5 where the initial concept values have been set and the result of FCM running is presented. For this case, the Decision 2 is going to be selected when the related concepts –factors are running for these particular initial values. The decision maker is also able to change his/her 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. 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 fulfils the requirements. 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.

7 An example from Logistics

The FCM-DM tool that has been described in the previous section will be implemented for an example from the logistics area. In order to compare the implementation of the DCM-DM with other approaches it has been applied for the example presented in [9]. Based to the example presented by Huang *et al.* [9], there was developed the FCM model consisted of nine (9) factor concepts and two (2) decision concepts. The input data for the concepts/factors of 3PLs and the weights are selected based on the example described in [9]. The decision maker defines the main decisions/goals and how these decisions will meet the required goal. The procedure of 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.

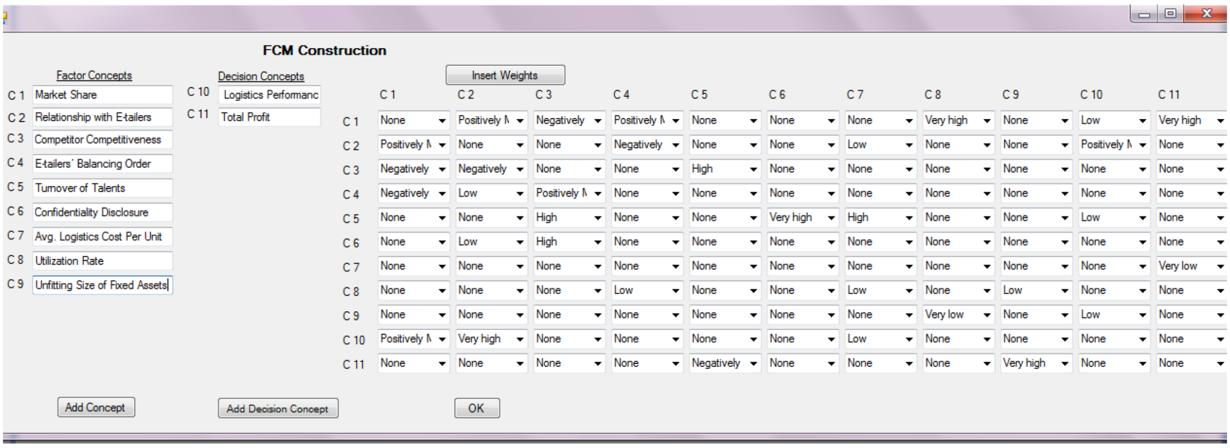

Fig 6: FCM construction for third-Part Logistics providers according to [9]

The proposed FCM-DM 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 the 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.

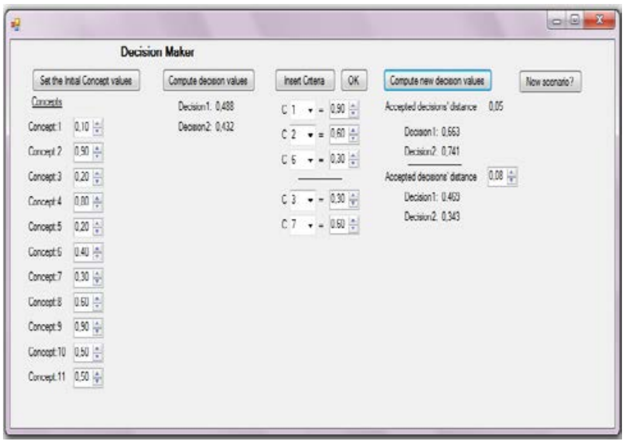

Fig 7: Decision values for an initial and two more scenarios

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 tested and changes can be proposed in order to examine what input values lead to the desirable results. So that to conclude the alternatives in accordance with the dominant decision and the company's goal. Thus, by trying various what-if scenarios decision makers can examine 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.

8. Conclusion -Comments

Logistic systems are complex ones that they need appropriate modelling and planning. There are many and varied factors that are involved to achieve an effective 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 methodology is easily applied, adaptive and flexible to new situations and knowledge.

Making a decision is a subjective process such as 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.

In future work we will investigate a hierarchical model to better achieve the Trieste-Fernetti improvement. The illustrated model of Fig. 3 will be at 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

Acknowledgments

This work was supported by the E.U. FP7–PEOPLE–IAPP–2009, Grant Agreement No. 251589, Acronym: SAIL.

References

1. Swaminathan, J.M., Smith, S.F. and Sadeh, N.M. (1998) 'Modeling Supply Chain Dynamics: A Multiagent Approach', *Decision Sciences*, vol. 29, no. 3, pp. 607-632.
2. Dickerson, J.A. and Kosko, B. (1997) 'Virtual Worlds as Fuzzy Cognitive Maps', *Fuzzy engineering*, pp. 125-141.
3. Stylios, C.D. (2002) 'The knowledge based technique of fuzzy cognitive maps for modeling complex systems,', Proceedings of 16th European Meetingson Cybernetics and Systems Research (EMCSR), Austria, 524-529.
4. Tan, P.S., Lee, S.S.G. and Goh, A.E.S. (2012) 'Multi-criteria decision techniques for context-aware B2B collaboration in supply chains', *Decision Support Systems*, vol. 52, pp. 779–789.
5. Ngai, E.W.T., Leung, T.K.p., Wong, Y.H. and Lee, M.C.M. (2012) 'Design and development of a context-aware decision support system for real-time accident handling in logistics', *Decision Support Systems*, vol. 52, pp. 816–827.
6. Condea, C., Thiesse, F. and Fleisch, E. (2012) 'RFID-enabled shelf replenishment with backroom monitoring in retail stores', *Decision Suppot Systems* , vol. 52, pp. 839-849.
7. Kosko, B. (1986) 'Fuzzy Cognitive Maps', *International Journal of Man-Machine Studies*, pp. 65-75.
8. Axelrod, R. (1976) Structure of Decision: the cognitive maps of political elites, NJ: Princeton.
9. Huang, Y.K., Feng, C.M., Yeh, W.C. and Lin, L.Y. (2010) 'A fuzzy cognitive map modeling to explore the operation dynamics of third-party logistics providers', Logistics Systems and Intelligent Management, 1266 - 1270
10. Stylios, C.D. and Georgoulas, G. (2011) 'Modeling Complex Logistics Systems using Soft Computing Methodology of Fuzzy Cognitive Maps', IEEE Conference on Automation Science and Engineering, Trieste, Italy, 72-77.
11. Li, Y.F., Ng, S.H., Xie, M. and Goh, T.N. (2010) 'A systematic comparison of metamodeling techniques for simulation optimization in Decision Support Systems', *Applied Soft Computing* , pp. 1257-1273.
12. Barton, R.R. and Meckesheimer, M. (2006) 'Metamodel-Based Simulation Optimization', in Nelson, S.G.H.a.B.L. (ed.) *Handbook in OR & MS, Elsevier.*
13. Trappey, A.J.C., Trappey, C.V. and Wu, C.R. (2010) 'Genetic algorithm dynamic performance evaluation for RFID reverse logistic management', *Expert Systems with Applications*, vol. 37, no. 11, pp. 7329-7335

14. Kim, M.C., Kim, C.O., Hong S, R. and Kwon, I.H. (2008) 'Forward-backword analysis of RFID-enabled supply chain sing fuzzy cognitive and genetic algorithm', Expert Systems with Applications, 1166-1176.

15. Rushton, A., Phip, C. and Baker, P. (2010) *The handbook of Logistics and Distributed management*, 4th edition, Library of congress Cataloging -in-Publication data.