Supplier selection problem in fuzzy environment considering risk factors

Maria Drakaki
Department of Industrial Engineering and Management
International Hellenic University
Thessaloniki, Greece
drakaki@autom.teithe.gr

Hacer Güner Gören
Department of Industrial Engineering
Pamukkale University
Denizli, Turkey
hgoren@pau.edu.tr

Panagiotis Tzionas
Department of Industrial Engineering and Management
International Hellenic University
Thessaloniki, Greece
ptzionas@autom.teithe.gr

***Abstract*— Supplier selection is one of the most important and challenging issue in supply chain management and is usually tackled with multi-criteria decision making (MCDM) methods. Considering sustainability, the complexity of the supplier selection problem has increased in recent years, yet, the various sustainability criteria. However, these criteria are usually considered independent of each other. Therefore, in this paper, to take into account the interdependency among criteria, Fuzzy Cognitive Maps (FCM) have been used. Moreover, supply chains are susceptible to various endogenous and exogenous risks which need to be considered in the decision-making processes in order to meet market needs and sustainability requirements. In order to integrate risks into the decision problem, fuzzy axiomatic design approach with risk factors (RFAD) has been utilized. The proposed method is applied to a case study adapted from literature.**

Keywords*— *Supplier selection, sustainability, fuzzy cognitive maps, risk factors, supply chain risk management.

I. INTRODUCTION

More attention should be paid in recent years on supply chains to stay competitive in the tough market conditions, due to the increase in prices of energy, industrial contamination, scarcity of raw material and natural resources [1]. Enabled by implementation of Industry 4.0 concepts, smart supply chains will benefit from digital integration as well as servitisation, whereas in the context of buyer-supplier relationships, suppliers will receive production order in real-time [2]. The supply chain network performance is affected by the relationships between the members of the chain. Being the first member of the supply chain, suppliers are crucial and thus choosing the appropriate suppliers directly has an important effect. The supplier selection problem can be defined as choosing appropriate suppliers who can comply with company's requirements based on evaluation criteria [3]. While evaluating suppliers, economic criteria have been widely used.

However, in recent years, the focus of supply chain performance has changed. In the past, pure economic profitability has been the major issue but now economic, environmental and social aspects have been taken into account. The performance of supply chains with respect to sustainability is measured in terms of operations that meet the needs of current population which do not compromise future needs [4]. The dimensions of sustainability are called as Triple Bottom Line (TBL) dimensions [5] which include economic, environmental and social ones. Human rights, education and training are considered in social sustainability. To maximize the income flow is considered in economic sustainability [6]. On the other hand, environmental sustainability is roughly related to the rates of renewable and non-renewable resource depletions and pollution creation. It helps to ensure that the needs of current generation are met without compromising the ability of future generations to meet their needs [7]. In the context of supply chain management, environmental legislations are used to define environmental sustainability which ensures that the organization's activities should comply with environmental legislations, not risk ecosystems and minimize the use of water and energy leading to less pollution, defects and over production. Globalisation is a key driver for integration of sustainability in supply chain management [8]. However, risks increase in global supply chains, whereas sustainability integration could address these risks [9]. To determine appopriate mitigation and contingency strategies, supply chain risk management (SCRM) approaches generally consider supplier attributes or the supply chain structure [10, 11].

Tang [12] states that supply network design is strategically important for SCRM. The factors within supply chains and outside along with environmental forces can cause the risk of disruptions and this subject has taken the attention of both practitioners and researchers. As stated in [13], increased use of out- sourcing, globalisation, reduction of the supplier base, reduced buffers, increased demand for on-time deliveries or shorter product lifecycles are some of the trends that enhance exposure to risks. This is highlighted by several practical examples in literature [14]. Therefore, for the identification, assessment, analysis and treatment of areas of vulnerability and risks in SCs, SCRM is needed [15].

Currently, SCRM approaches seek to measure either supplier attributes or the Supply Chain (SC) structure. The results are then used to prepare response strategies. Identifying potential losses, understanding the likelihood of potential losses, and assigning significance to these losses are considered in SCRM [16]. Frequently, only disruptive events (such as bankruptcy, natural disaster or the possibility of a terrorist attack) are included. However, continuous changes due to a turbulent environment (e.g. a change in customer tastes, technology shifts or supplier priorities) are generally ignored. Moreover, these approaches usually neglect the fact that the market, technology and environmental turbulence in the supplier's

978-1-7281-3021-7/19/$31.00 ©2019 IEEE
DOI 10.1109/DeSE.2019.00146

particular market segment are significant factors influencing the relationship between supplier attributes, performance in a SC and the potential for disruptions. Since various suppliers (and suppliers' suppliers) operate in different markets and environments, their turbulence varies and therefore the forces influencing a supplier also differ.

Risk can be defined as the probability of the occurrence of a particular event or outcome [17]. Risks can be classified as operational and disruption risks [12]. Another classification can be done as strategic, tactical and operational risks [17]. Capacity limitation, technology incompatibility, supply disruptions, currency fluctuations or disasters are defined as the origins of risks [18]. Risks can also be classified based on their probability and importance [19]. Moreover, risk subsets can be further classified. For example, uncertainty from customers/demand, suppliers, and technology are all classified under the risks from the environment [20, 21].

Since risk factors have important effects on the SCs, literature focusing on supplier selection problem considering risk factors is rather limited. Most of the studies treat risk factors as evaluation criteria however, risk factors cannot be treated in that way and should be integrated into the evaluation process. One of the main contributions of this study relies on this statement. In this paper, risk factors have been integrated into the methodology using RFAD. The interdependency among criteria has been identified using FCM and then RFAD has been utilized to solve the supplier selection problem considering risk factors.

The rest of the paper is organized as follows. The second section describes the methodology proposed in this study where the case study is presented in the third section. The last section is the conclusion section in which the findings and future research directions are presented.

II. METHODOLOGY

The proposed method consists of the following steps:

a) Identification of sustainable supplier selection criteria and risk factors.

b) Calculation of the weights of the criteria using Fuzzy Cognitive Maps.

c) Supplier ranking evaluation using RFAD.

A. Identification of sustainable supplier selection criteria and risk factors

The first step of the proposed approach determines the criteria and risk factors used in evaluating the sustainable suppliers. In this study, the sustainability criteria from [1] shown in Table I, have been used.

TABLE I. SUSTAINABILITY CRITERIA

Economic criteria	**Environmental criteria**	**Social criteria**
Price - C_1 (0.089)	Environmental management system - C_9 (0.073)	Occupational health and safety management system - C_{12} (0.051)
Productivity - C_2 (0.078)	Environmental friendly product design - C_{10} (0.075)	
Capacity of the supplier - C_3 (0.052)	Resource consumption - C_{11} (0.101)	
Long-term relationship- Continuity- C_4 (0.114)		
Lead Time - C_5 (0.077)		
Quality - C_6 (0.071)		
Production technology - C_7 (0.102)		
Responsiveness - C_8 (0.06)		

**Initial weights are shown in parentheses*

B. Weight Matrix Calculation Using FCM

The weights of criteria have been calculated using FCM in the second step of the proposed approach. As an extension to cognitive maps, FCMs are based on both fuzzy logic and neural networks and have been developed by Kosko [22]. FCMs can model complex dynamic systems characterised by abstraction and fuzzy reasoning. Both static and dynamic analysis of the modeled systems can be performed using FCMs. A system is modeled as a directed weighted graph of interconnected nodes (concepts) with the connections between nodes showing the cause-effect relationships between the concepts. The direction of causality is shown by the direction of the connection between nodes whereas the value of the weight of the connection shows the amount of influence of the interconnection between nodes. The influence between concepts is represented by the sign of the weight. To construct the configuration of the map, human knowledge by an expert or by a group of experts or historical data can be used. The development phase of an FCM includes three main steps, namely (i) the identification of important concepts, (ii) identification of causal relationships between the concepts and (iii) estimation of the strength of causal interconnections [23]. The values of the causal relationships (influences) are determined by domain experts. They use fuzzy linguistic terms which are then mapped to numerical values in the range [-1,1]. FCMs have been used for decision support in diverse domains such as in [24, 25, 26].

Let us consider a FCM which consists of *N* concepts, C_i, where i=1,…, *N*. Each concept, *i*, has a value in either [0, 1] or [-1, 1]. The weights on edges, w_{ij} shows the influence of concept (cause node) *i* on concept (effect node) *j* and have values in the interval [-1, 1]. Positive influence means that an increase in C_i will cause an increase in C_j, a negative influence shows that an increase of C_i will cause a decrease in C_j, whereas $w_{ij}=0$ indicates that there is no relation between concepts (nodes) *i* and *j*.

Through an iteration procedure, each concept value (C_i) is updated [24]. In iteration k+1, C_i is updated according to

$$C_i^{(k+1)} = f\left(C_i^{(k)} + \sum_{j \neq i, j=1}^{N} w_{ji} C_j^{(k)}\right) \quad (1)$$

Threshold function is represented by the function *f*. Concept values take values in the interval [0, 1] when the sigmoid function $f(x) = \frac{1}{1+e^{-x}}$ is used. Iteration continues until a convergence is achieved.

C. Supplier ranking evaluation using RFAD

The ranking of the suppliers have been done using extended Hierarchical Fuzzy Axiomatic Design Approach with Risk Factors (RFAD) in the third step. The RFAD has been proposed by Gören and Kulak [27] in which the risk factors are integrated into the methodology of Fuzzy Axiomatic Design Approach (FAD). The FAD approach is based on Axiomatic Design approach (AD) which has two axioms such as Independence Axiom and Information Axiom. Information axiom has been widely used as a Multi Criteria Decision Making (MCDM) approach in recent years [28, 29, 31]. In terms of decision making, it can be stated that the alternative with the minimum information content is the most appropriate alternative. For more information on FAD, the reader can refer to Kulak et al. [28]; Kulak and Kahraman [29].

To integrate risk factors in the decision making, RFAD calculates the information content as shown in (1) where *r* is a risk factor of a criterion taking a value between zero and one.

$$I = \log_2\left(\frac{System\ \ range}{Common\ \ range\ \ (1-r)}\right) \qquad (2)$$

The system ranges (the features of alternatives) and design ranges (the features that the most appropriate alternative has to have in order to be selected) for each alternative under each criterion are determined in the first step of the RFAD approach. Therefore, the experts determine design ranges. The information contents are calculated in the second step considering risk factors. In the last step, the overall information content for each alternative is calculated and the alternative with the minimum information content is selected as the most appropriate alternative [30]. For more information on RFAD, the reader should refer to Kulak et al. [30].

III. CASE STUDY

The case study has been taken from Goren [1]. In Goren [1], the author proposes a three-stage decision framework for sustainable supplier selection and order allocation problem. The first and second stages are related to the supplier selection whereas the third section determines the order quantities that should be allocated to the suppliers determined in the first two stages.

TABLE II. RISKS CONSIDERED AND ASSOCIATED CRITERIA

Risks	**Sustainability criteria (in parenthesis the value of risk is shown)**
Quality risk	Price - C_1 (0.2) Productivity - C_2 (0.1) Quality - C_6 (0.3)
Service risk	Capacity of the supplier - C_3 (0.1) Production technology - C_7 (0.2) Responsiveness - C_8 (0.1)

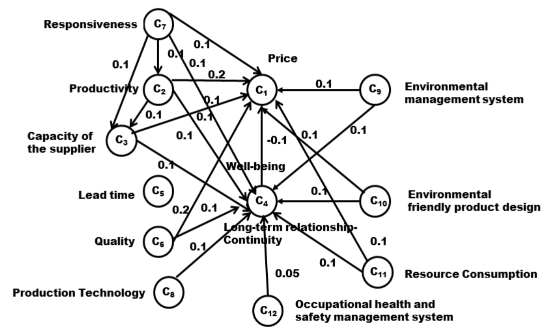

Fig. 1. The FCM for the case study.

TABLE III. THE FCM WEIGHT MATRIX

C_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
C_1	0	0	0	0	0	0	0	0	0	0	0	0
C_2	0.2	0	0.1	0.1	0	0	0	0	0	0	0	0
C_3	0.1	0	0	0.1	0	0	0	0	0	0	0	0
C_4	0	0	0	0	0	0	0	0	0	0	0	0
C_5	0	0	0	-0.1	0	0	0	0	0	0	0	0
C_6	0.2	0	0	0.1	0	0	0	0	0	0	0	0
C_7	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0.1	0.1	0
C_8	0	0	0	0.1	0	0	0	0	0	0	0	0
C_9	0.1	0	0	0.1	0	0	0	0	0	0	0	0
C_{10}	0.1	0	0	0.1	0	0	0	0	0	0	0	0
C_{11}	0.1	0	0	0.1	0	0	0	0	0	0	0	0
C_{12}	0	0	0	0.05	0	0	0	0	0	0	0	0

TABLE IV. THE FINAL WEIGHT VALUES

C_1	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**
0.047	0.065	0.02	0.097	0.062	0.026
C_7	**C_8**	**C_9**	**C_{10}**	**C_{11}**	**C_{12}**
0.14	0.010	0.030	0.040	0.128	0.011

In our study, we also focus on the supplier selection problem i.e. determining the weights of the criteria and selecting the most appropriate supplier. Different from Goren [1], we consider the risk factors inherited in the supplier selection problem. The interested reader can refer to Goren [1] for more information about the case study.

The final weight values of the sustainability criteria in Goren [1] are used as initial input concept values to the FCM (Table I). The FCM arrows shows the interdependence between concepts (sustainability criteria), whereas the weights of the arrows have been chosen based on expert evaluation (Figure 1). The FCM weight matrix is shown in Table III. The output values of FCM concepts (sustainability criteria), shown in Table IV, are used as final weight values. Using the final weight values, the RFAD method is used in order to rank suppliers. The values of risks for each supplier in the context of associated criteria are shown in Table II. Design ranges as well as system ranges for each supplier have been taken from Goren [1]. The final ranking of suppliers, shown in Table VI, has been calculated based on the information contents of each supplier. The supplier with the minimum information content is the best supplier. According to the results, supplier S3 is the best supplier.

Analyzing the results presented in Goren [1], it can be seen that supplier two is the most appropriate supplier. However, there is an important difference between this study and Goren [1]. This study considers the risk factors related to the criteria whereas Goren [1] does not take into account these risks. Therefore, it is not meaningful to compare the results obtained.

TABLE V. SUPPLIER RANKING RESULTS

Supplier	C_1	C_2	C_3	C_6	C_7	C_8
S1	0.1	0.1	0.3	0.2	0.2	0.2
S2	0.2	0.2	0.1	0.1	0.1	0.2
S3	0.3	0.1	0.1	0.2	0.1	0.1
S4	0.3	0.3	0.1	0.2	0.2	0.1
S5	0.2	0.2	0.3	0.1	0.2	0.3
S6	0.2	0.1	0.2	0.1	0.2	0.3

TABLE VI. SUPPLIER RANKING RESULTS

Supplier	Information Content	C_1
S1	0.088	4
S2	0.0839	2
S3	0.0682	1
S4	0.1156	6
S5	0.1005	5
S6	0.0856	3

IV. CONCLUSION

Supply chains are susceptible to various endogenous and exogenous risks which need to be considered in the decision-making processes in order to meet market needs and sustainability requirements. Supplier selection is one of the most important and challenging issues for supply chain management, and it is usually tackled with MCDM approaches. Sustainability has increased the complexity of the supplier selection problem, yet, the various sustainability criteria considered in the literature usually do not account for risk factors. Moreover, the various criteria are usually considered independent of each other. Therefore, in this paper, supplier selection is assessed based on FCM to take into account the interdependency among criteria into the calculation final criteria weight matrix, and RFAD in order to integrate risks into the supplier selection method. The proposed method is applied to a case study. The future research direction can be to include the order allocation phase into the problem therefore the quantities that should be allocated to the suppliers can be determined.

REFERENCES

[1] H. Guner Goren, "A decision framework for sustainable supplier selection and order allocation with lost sales," Journal of Cleaner Production, vol. 183, pp. 1156-1169, 2018.

[2] E. Hofmann and M. Rüsch, "4.0 and the current status as well as future prospects on logistics," Computers in Industry, vol. 89, pp. 23–34, 2017.

[3] S. Khurrum Bhutta and F. Huq, "Supplier selection problem: a comparison of the total cost of ownership and analytic hierarchy process approaches," Supply Chain Management: An International Journal, vol. 7, no. 3, pp. 126-135, 2002.

[4] F.C., Krysiak, "Risk management as a tool for sustainability," Journal of Business Ethics, vol. 85, no. 3, pp. 483-492, 2009.

[5] J. Elkington, Cannibals with forks: The triple bottom line of the 21st century. Stoney Creek/CT: New Society, 1998.

[6] Z. Molamohamadi, N. Ismail, Z. Leman, and N. Zulkifli, "Supplier Selection in a Sustainable Supply Chain," Journal of Advanced Management Science, vol. 1, no. 3, pp. 278-281, 2013.

[7] J. Morelli, "Environmental Sustainability: A Definition for Environmental Professionals," Journal of Environmental Sustainability, vol. 1, no. 1, pp. 1-8, 2011.

[8] M. Drakaki, H. Güner Gören, and P. Tzionas, "A multi-agent based decision framework for sustainable supplier selection, order allocation and vehicle routing problem," in Proc. of the 5th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS), Crete, Greece, pp. 621-628, 2019, doi: 10.5220/0007833306210628.

[9] M. Giannakis and T. Papadopoulos, "Supply chain sustainability: a risk management approach," International Journal of Production Economics, vol. 171, pp. 455-470, 2016.

[10] A. Oke and M. Gopalakrishnan, "Managing disruptions in supply chains: a case studyof a retail supply chain," International Journal of Production Economics, vol. 118, no. 1, pp. 168-174, 2009.

[11] Peter Trkman and Kevin McCormack, "Supply Chain risk in turbulent environments- A conceptual model for managing supply chain network risk," International Journal of Production Economics, vol. 119, pp. 247-258, 2009.

[12] C. S. Tang, "Perspectives in supply chain risk management". International Journal of Production Economics, vol. 103, no. 2, pp. 451–488, 2006.

[13] A. Norrman and U. Jansson, "Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident," International Journal of Physical Distribution and Logistics Management, vol. 34, no. 5, pp. 434-456, 2004.

[14] S. Chopra and M. Sodhi, "Managing risk to avoid supply-chain breakdown," Sloan Management Review, vol. 46, no. 1, pp. 53-61, 2004.

[15] D. Neiger and K. Rotaru, "Supply chain risk identifiaction with value-focused process engineering," Journal of Operations Management, vol. 27, no. 2, pp. 154-168, 2009.

[16] L. Giunipero and R. Eltantawy, “Securing the upstream supply chain: aa risk management approach,” International Journal of Physical Distribution and Logistics Management, vol. 34, no. 9, pp. 698-713, 2004.

[17] B. Ritchie and C. Brindley, “Supply chain risk management and performance: a guiding framework for future development,” International Journal of Operations and Production Management, vol. 27, no. 3, pp. 303-322, 2007.

[18] A.Z. Zeng, P. D. Berger, and A. Gerstenfeld, “Managing the supply-side risks in supply chains: taxonomies, processes and examples of decision-making modelling,” Applied Optimization Series, vol. 92, pp. 141-160, 2005.

[19] L. M. Hunter ,C. J. Kasouf, K. G. Celuchc, and K. A.Curry “A classification of business-to-business buying decisions: risk importance and probability as a Framework for e-business benefits,” Industrial Marketing Management, vol 33, no. 2, pp. 145–154, 2004.

[20] S. Li and B. Lin, “Accessing information sharing and information quality in supply chain management,” Decision Support Systems, vol. 42, no. 3, pp. 1641-1656, 2006.

[21] I. Chen and A. Paulraj, “Towards a theory of supply chain management: the constructs and measurements,” Journal of Operations Management, vol. 22, no. 2, pp. 119-150, 2004.

[22] B. Kosko, “Fuzzy cognitive maps,” International Journal on Man-Machine Studies, vol. 24, 1986.

[23] M. S. Khan and M. Quaddus, “Group decision support using fuzzy cognitive maps for causal reasoning,” Group Decision and Negotiation, vol. 13, pp. 463–480, 2004.

[24] E. I. Papageorgiou and J. L. Salmeron, “A Review of Fuzzy Cognitive Maps Research, During the Last Decade,” IEEE Transactions on Fuzzy Systems, vol. 21, pp. 66-79, 2013.

[25] Z. Xiao, W. Chen and L. Li, “An integrated FCM and fuzzy soft set for supplier selection problem based on risk evaluation,” Applied Mathematical Modelling, vol. 36, pp. 1444–1454, 2012.

[26] M. Drakaki, H. Güner Gören, and P. Tzionas, “Fuzzy cognitive maps as a tool to forecast emotions in refugee and migrant communities for site management,” in: Springer, Cham, Editors: Freitas P., Dargam F., Moreno J., Decision Support Systems IX: Main Developments and Future Trends (EmC-ICDSST 2019), Lecture Notes in Business Information Processing, vol. 348, pp. 3-14, 2019.

[27] H. Guner Goren and O. Kulak, “A new fuzzy multi-criteria decision making approach: Extended hierarchical fuzzy axiomatic design approach with risk factors,” EWG-DSS III Edition of the Springer-LNBIP Book on "Impact of Decision Support Systems for Global Environments", LNBIP, vol. 184, pp. 141-156, 2014.

[28] O. Kulak, M. B. Durmusoglu, and S. Tufekci, “A complete cellular manufacturing system design methodology based on axiomatic design principles,” Computers & Industrial Engineering, vol. 48, no. 4, pp. 765-787, 2005.

[29] O. Kulak and C. Kahraman, “Multi-attribute comparison of advanced manufacturing systems using fuzzy vs. crisp axiomatic design approach,” International Journal of Production Economics., vol. 95, no. 3, pp. 415-424, 2005.

[30] O. Kulak, H. Güner Gören and A. Supçiller, “A new multi criteria decision making approach for medical Imaging systems considering risk factors,” Applied Soft Computing, vol. 35, pp. 931-941, 2015.

[31] M. Drakaki, H. Güner Gören, and P. Tzionas, “ An intelligent multi-agent based decision support system for refugee settlement siting,” International Journal of Disaster Risk Reduction, vol. 31, pp. 576-588, 2018.