Partner Selection in Formation of Virtual Enterprises using Fuzzy Logic

Shahrzad Nikghadam[1], Bahram Lotfi Sadigh[1], Ahmet Murat Ozbayoglu[2], Hakki Ozgur Unver[3] and Sadik Engin Kilic[4]

[1]*Department of Mechanical Engineering, Middle East Technical University, Ankara, Turkey*

[2]*Department of Computer Engineering, TOBB University of Economics and Technology, Ankara, Turkey*

[3]*Department of Mechanical Engineering, TOBB University of Economics and Technology, Ankara, Turkey*

[4]*Department of Mechanical Engineering, Atilim University, Ankara, Turkey*

Keywords: Virtual Enterprise, Partner Selection, Fuzzy Logic.

Abstract: Virtual Enterprise (VE) is a temporary cooperation among independent enterprises to build up a dynamic collaboration framework for manufacturing. One of the most important steps to construct a successful VE is to select the most qualified partners to take role in the project. This paper is a survey of ranking the volunteer companies with respect to four evaluation criteria, proposed unit price, delivery time, quality and enterprises' past performance. Fuzzy logic method is proposed to deal with these four conflicting criteria, considered as input variables of the model. As each criterion is different in nature with the other criterion, various membership functions are used to fuzzify the input values. The next step is to construct the logical fuzzy rules combining the inputs to conclude the output. Mamdani's approach is adopted to evaluate the output in this Fuzzy Inference System. The result of the model is the partnership chance of each partner to participate in VE. A partner with highest partnership chance will be the winner of the negotiation. Implementation of this model to the illustrative example of a partner selection problem in virtual enterprise and comparing it with fuzzy-TOPSIS approach verifies the feasibility of the proposed approach and the computational results are satisfactory.

1 INTRODUCTION

In today's increasingly competitive dynamic global market, traditional manufacturing concepts cannot satisfy the diverse customer demands. Small companies are suffering from limited resources while large companies are inflexible (Huang, et al., 2004). Providing adequate resources for Small and Medium Sized Enterprises (SMEs) are often very costly and time consuming. Constructing a synergic cooperation between these enterprises will aid companies to share their resources without losing the flexibility. Virtual Enterprise (VE) is proved to be one of the effective cooperation platforms.

VE is a network based temporary alliance between independent and geographically dispersed enterprises to share skills, core competencies and resources, in order to catch business opportunities (Camarinha-Matos & Afsarmanesh, n.d.).This kind of consortium will help companies for responding quickly to unanticipated demands from customers.

Lifecycle of VE consists of three main phases; Formation, Operation and Dissolution. The Formation phase of a VE is usually triggered by a request for quote from customer. Based on the project, design specifications and manufacturing requirements, production processes are decomposed into individual task(s). The main step of VE formation phase is to select the best partners to participate in forthcoming VE consortium. In order to fulfil the project, each individual task should be completed by selected VE partner(s). After the operation phase of VE which includes manufacturing and assembly processes, getting customer's consent and achieving the goal(s) VE project is finalized and it can be dissolved.

The most important part of VE formation phase is the partner selection step. In order to form up a successful VE consortium it is crucial to select the most appropriate partners from list of potential partners registered in virtual breeding environment. This is why there are lots of researches conducted in this field. However, due to neglecting the dynamic

Nikghadam S., Lotfi Sadigh B., Murat Ozbayoglu A., Ozgur Unver H. and Engin Kilic S..
Partner Selection in Formation of Virtual Enterprises using Fuzzy Logic.
DOI: 10.5220/0005293000820088
In *Proceedings of the International Conference on Operations Research and Enterprise Systems* (ICORES-2015), pages 82-88
ISBN: 978-989-758-075-8

nature of VE and heterogeneity of customer preferences (decision making criteria), much of the proposed methods are not generic solutions and cannot be implemented directly in different decision making problems.

Partner selection is not a simple optimization problems (Sari, et al., 2007). Regarding the fact that, it is very difficult to express the qualitative criteria with precise values in digits and considering the nature of quantitative criteria which are represented in numbers, handling the quantitative criteria mathematically is much easier than including qualitative criteria in mathematical models (Ye, 2010).

The other difficulty of decision making is that it involves conflicting criteria. If there is a potential partner with best score in all criteria surely that company is the best; however generally this is not the case in practical applications. For instance a high quality product usually comes with expensive price. Hence there is an inevitable trade-off between criteria which is done on the basis of customer's preferences.

Importance of partner selection problem along with complexity of this subject drew the attention of many researchers. Some approaches use Artificial Intelligence techniques such as Genetic Algorithm to solve the partner selection's mathematical model (Fuqing, et al., 2005), where Sari et al. propose Analytic Hierarchy Process (AHP) to perform pairwise comparisons between criteria and alternatives (Sari, et al., 2007). In these methodologies quantitative criteria are assigned with a crisp value, neglecting the subjective nature of them. In contrast, most of the papers in the literature are hybrid fuzzy approaches which are capable of handling the imprecision of input data. Mikhailov and Fei propose Fuzzy-AHP and Fuzzy-TOPSIS methods respectively (Ye, 2010), (Mikhailov, 2002).

In a study conducted by Bevilacqua and Petroni fuzzy logic is employed in specifying the relative importance (weight) given to criteria and in determining the impact of each supplier on the attributes considered (Bevilacqua & Petroni, 2010). Yet this study is conducted in the field of supplier selection of supply chain management (SC) and there is insufficient research for applying fuzzy logic approach in partner selection problem of VE.

Selection of partner enterprises in creation of virtual enterprise has much in common with supplier selection of supply chain management. They both evaluate the companies and try to find the best alternative with respect to number of factors. However they are not completely identical. VE is more dynamic in comparison to SC. Supplier selection of SC designed for a specific set of processes, while VE can emerge for fulfilling different types of projects and customers so VE is more dynamic in comparison to SC.

The method proposed in this paper is based on applying fuzzy logic to deal with uncertainty of the problem; in addition it considers "criteria-specific membership functions" which is a fact neglected in the literature to the best of our knowledge.

The remainder of this paper is organized as follows: Section 2 reviews some background information about fuzzy logic. Section 3 explains and discusses the developed model in details. An illustrative example is presented in section 4 and the results of proposed model is compared with fuzzy-TOPSIS model. Conclusions are discussed and future research scopes are recommended in the last section.

2 FUZZY LOGIC

Lotfi A. Zadeh published the theory of fuzzy set mathematics in 1965 and fuzzy logic by extension. (Zadeh, 1965). Fuzzy set is a valid supporting tool to overcome uncertainty (Bevilacqua & Petroni, 2010). Fuzzy Inference system is a popular reasoning framework based on the concepts of fuzzy set theory, fuzzy logic and fuzzy IF-THEN rules. Fuzzy Inference systems make decisions based on inputs in the form of linguistic variables derived from membership functions. These variables are then matched with the preconditions of linguistic IF-THEN rules called fuzzy logic rules, and the response of each rule is obtained through fuzzy implication as a crisp value (Shing & Jang, 1993).

Mamdani fuzzy inference is the most commonly used inference method introduces by Mamdani in 1975 (Mamdani & Assilian, 1975). The fuzzy inference involves four steps: 1. Fuzzification of input variables, 2. Rule Evaluation, 3. Aggregation of the rule outputs, 4. Defuzzification.

The first step of fuzzy inference system is calculating the membership degree of inputs to their belonging fuzzy sets. In the second step fuzzified values of inputs are used to evaluate fuzzy rules. Fuzzy rules are contain fuzzy operators (AND or OR). The next step is aggregating the fuzzy outputs of all rules. The last step of fuzzy inference process is defuzzifying the output, conclude the final crisp value and rank the results.

3 PARTNER SELECTION MODEL

Among tens of aspects to evaluate the partners to join virtual enterprise, in this research, four main criteria are taken into account; proposed unit price, proposed delivery time, company's products quality and its past performance. According to the industry experts, these four criteria are believed to be the most essential aspects to evaluate the enterprises.

First two criteria are proposed by each enterprise during negotiation process. The values of last two criteria are imported from quality and performance evaluation models which are available in the system. The proposed values of price and delivery time are normalized using Euclidean normalization method. After calculating the values of enterprises for each criterion, these values are fuzzified with respect to the corresponding membership functions. Due to different nature of each criterion, different sets and membership functions are defined.

3.1 Input Variables of Fuzzy Logic

First step to implement the model is to translate the linguistic variables into fuzzy numbers through defining the appropriate membership functions. Using different membership functions to calculate the value of each criterion is the novelty introduced in this paper, compared to the researches in the literature. i.e. different types of membership functions are selected in order to fit the actual pattern of each factor.

3.1.1 Unit Price

Since the price proposals are absolute values, the corresponding membership functions must be linear in order to maintain the competitiveness between candidates. Even a dollar less, means cheaper price. This should not be ignored in fuzzification process. So, three triangular membership function are used to model the fuzzy behaviour of unit price proposed by enterprises, as shown in Fig.1.

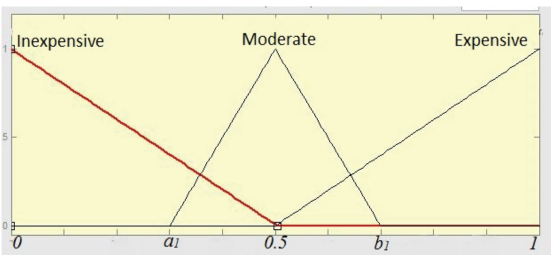

Figure 1: Unit Price's membership functions.

The membership function are as follows:

Inexpensive (0; 0; 0.5)
Moderate (a_1; 0.5; b_1)
Expensive (0.5; 1; 1)

3.1.2 Delivery Time

The membership functions of delivery time are also linear. However, they consist of domains which, within that range, the fuzzified values of scores are equal. Generally Project Evaluation Review Technique (PERT) is used to calculate the Earliest Finish and Latest Finish. The range between these two due dates is a favourable domain.

If a task cannot be completed on time it will be back order charging some penalties (Nikghadam, et al., 2011). If lateness exceeds, the order will be lost and it cannot be compensated, this is a domain which membership function has a constant value equal to one. As too early delivery imposes storage costs its trend is similar to late delivery. Trapezoidal membership function is providing all the characteristics required to model the delivery time. The membership functions are shown in Figure 2.

Too Early (0; 0; a_2; c_2)
Favourable (b_2; d_2; e_2; g_2)
Late (f_2; h_2; 1; 1)

3.1.3 Quality

Similar to delivery time, there are constant-valued domains for membership functions of quality. Quality specifications are generally defined by an acceptable "range", all the values within these limits are satisfactory. Furthermore, considering the marginality of human decisions bell-shaped membership function are most suitable to model the problem as shown in Figure 3. Parameters of a_3 and b_3 are determining the shape of the curves.

Less than Required (a_3; b_3; 1.5; 0)
Satisfactory (a_3; b_3; 0.5)
More than Required (a_3; b_3; 1)

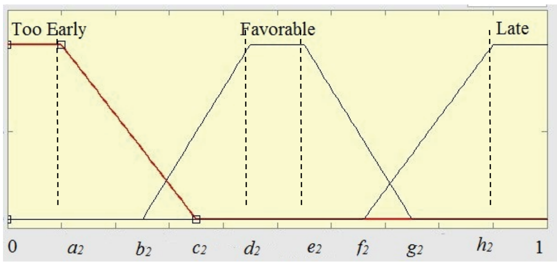

Figure 2: Delivery time's membership functions.

Figure 3: Quality's membership functions.

3.1.4 Past Performance

Past performance of a company is a criterion representing the customer's satisfaction degree, which is influenced by several factors such as after sale service; respond to changes; communication openness and etc. Similar to the nonlinear trend of quality, past performance's membership function is not linear due to marginality. Increasing customer's consent is more demanding at higher scores. So two simple Gaussian membership functions are defined. These membership functions are shown in Fig. 4. Parameter a_4 is specifying the shape of the curves.

Poor (a_4; 0)
Good (a_4; 1)

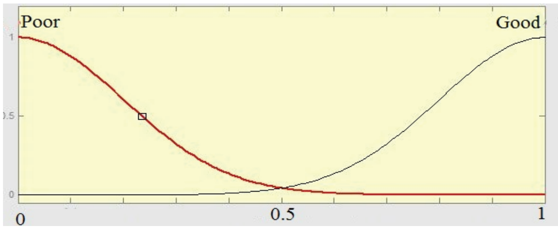

Figure 4: Past performance's membership functions.

3.2 Output Variable of Fuzzy Logic

Output variable of this model is partner's acceptance chance to join VE consortium. This model reveals a method to calculate this value by getting two bidding proposals (price and delivery time) and two performance evaluation value from enterprise background (quality and enterprise past performance). An enterprise with competitive proposals and good background will have higher chance to be picked out as a winner to take role in virtual enterprise rather than other rival enterprises.

3.2.1 Partnership Chance

As shown in Fig. 5 three triangular membership functions are used to define fuzzy set of the output. Usually enterprises violating the project requirements belong to the first membership function and their partnership chance are low. The third membership function members are those which can satisfy almost all the necessities of four inputs and the enterprises belonging to this set are most likely to be accepted as partner. While the members of second membership function, are potential partner enterprises which cannot be classified in first or third membership function groups and have the medium partnership chance.

Low (0; 0; 0.5)
Medium (a_5; 0.5; b_5)
High (0.5; 1; 1)

3.3 Fuzzy Logic Rules

Once the inputs are fuzzified, fuzzy rules should be defined. Fuzzy rules made up of linguistic statements which describe how to make decisions considering the inputs.

If *(input 1 is membership function1)* AND/*OR* *(input 2 is membership function 2)* THEN *(Output n is membership function n)*

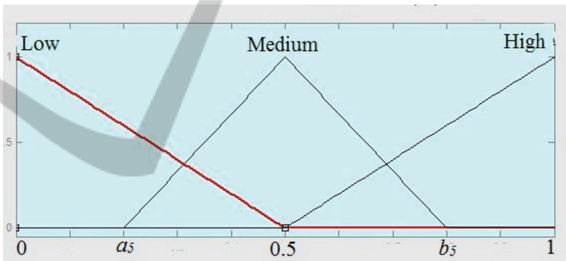

Figure 5: Partnership chance's membership functions.

Rules are established based on customer preferences. By asking the decision maker(s) to fill the questionnaire, the relative importance of each criterion is extracted.

For instance an enterprise producing the low quality product which do not met the system predefined specifications or unable to get customer consent about delivery time is not competitive, has low partnership chance.

All the possible combinations should be considered for constructing fuzzy rules to ensure the validity of the model. More descriptive fuzzy rules will be presented for the case of our study.

Establishing the IF-THEN rules are the most important step of the method since even a single improper rule will cause untrustworthy results.

According to these fuzzy rules, fuzzy inputs will be combined and evaluated by Mamdani's fuzzy inference system to find the partnership chance as this model's output.

4 ILLUSTRATIVE EXAMPLE

In order to illustrate the application of fuzzy logic method to partner selection problem in formation of virtual enterprise a simplified example is considered. A virtual enterprise has received an order from a customer to manufacture the component shown in Figure 6. There are four candidate enterprises eager to take role in project. Bidding starts in order to identify the best proposal from the best company. The evaluation procedure is based on fuzzy logic approach presented in previous section.

Bidding Proposals and candidates' scores are shown in Table 1. The values of input variables, price and delivery time are proposed by each company, while the scores of quality and past performance which are feedback-oriented are out of 10. Table 2 shows the normalized values of Table 1.

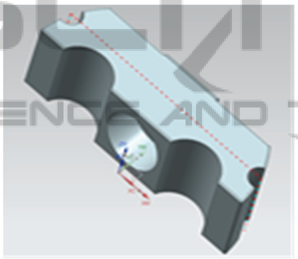

Figure 6: Component sketch for illustrative example.

Table 1: Scores of enterprises with respect to criteria.

	Unit Price ($)	Delivery Time (days)	Quality (Out of 10)	Past Performance (Out of 10)
Co. A	1700	8	4	5
Co. B	1700	10	5	4
Co. C	2000	12	5	3
Co. D	1500	10	6	5

Table 2: Normalized scores of enterprises with respect to criteria.

	Unit Price	Delivery Time	Quality	Past Performance
Co. A	0.49	0.396	0.396	0.577
Co. B	0.49	0.495	0.495	0.346
Co. C	0.577	0.594	0.495	0.462
Co. D	0.432	0.495	0.594	0.577

These values are fuzzified according to the membership functions specified for each criterion. Regarding the customer preference based- fuzzy rules shown in Table 4, companies' partnership chance is evaluated and tabulated in Table 4.

With three levels for unit price, delivery time, quality and two levels for past performance there are total of 3×3×3×2=54 possible combinations if all the rules are defined by 'AND' operator. Though, to simplify the rule list, one rule is defined as below;

If *(Delivery time is Late)* OR *(Quality is Less than Required)* THEN *(Partnership Chance is Low)*

Table 3: Set of fuzzy rules.

IF							THEN
Price		Delivery Time		Quality		Past Performance	Partnership Chance
-		Late	OR	Less than req.		-	Low
inexpensive	And	too early	And	satisfactory	And	poor	medium
inexpensive	And	too early	And	satisfactory	And	good	medium
inexpensive	And	too early	And	more than req.	And	poor	medium
inexpensive	And	too early	And	more than req.	And	good	medium
inexpensive	And	favorable	And	satisfactory	And	poor	high
inexpensive	And	favorable	And	satisfactory	And	good	high
inexpensive	And	favorable	And	more than req.	And	poor	high
inexpensive	And	favorable	And	more than req.	And	good	high
average	And	too early	And	satisfactory	And	poor	low
average	And	too early	And	satisfactory	And	good	low
average	And	too early	And	more than req.	And	poor	low
average	And	too early	And	more than req.	And	good	medium
average	And	favorable	And	satisfactory	And	poor	medium
average	And	favorable	And	satisfactory	And	good	medium
average	And	favorable	And	more than req.	And	poor	High
average	And	favorable	And	more than req.	And	good	high
expensive	And	too early	And	satisfactory	And	poor	low
expensive	And	too early	And	satisfactory	And	good	medium
expensive	And	too early	And	more than req.	And	poor	low
expensive	And	too early	And	more than req.	And	good	medium
expensive	And	favorable	And	satisfactory	And	poor	low
expensive	And	favorable	And	satisfactory	And	good	medium
expensive	And	favorable	And	more Than req.	And	poor	low
expensive	And	favorable	And	more Than req.	And	good	medium

By doing this, just two levels are left for delivery time and quality. As (3×2×2×2)+1= 25, all the possible combinations are included by defining 25 rules to build up a reliable model for the case of our study.

The output of the model is calculated using fuzzy logic toolbox of MATLAB software. And tabled in Table 4.

Table 4: Companies' partnership chance based on fuzzy logic.

	Partnership Chance (%)
Co. A	53.5
Co. B	51.8
Co. C	39.9
Co. D	61.0

In order to verify the fuzzy logic based model, the results are compared with Fuzzy-TOPSIS method developed by Chen et al. (Chen & Tsao, 2008). Customer preferences are calculated using pairwise comparisons and allocating fuzzy numbers for their subjective terminations. The final results of criteria weights for our sample are set to be 0.394, 0.277, 0.257, and 0.106 for unit price, delivery time, quality and past performance respectively (The rules of fuzzy logic are also constructed considering these preferences). Using the normalized values of Table 2 and multiplying them by their corresponding weights are results in weighted performance matrix. Then applying the TOPSIS procedure step by step companies are ranked based on their closeness to the ideal solution as shown in Table 5. The closest candidate to the positive ideal solution has higher partnership chance.

Regarding Table 6 the ranking lists proposed by these two methods are same and both choose Company D as a winner. However, their partnership chances are not equal. There are two main reasons which explains these differences. First, for constructing fuzzy logic model different types of functions; constant, linear and nonlinear are used.

Table 5: Companies' partnership chance based on fuzzy TOPSIS.

	Distance from Positive Ideal Solution	Distance from Negative Ideal Solution	Closeness (%)
Co. A	0.056	0.069	55.3
Co. B	0.05	0.051	50.2
Co. C	0.084	0.028	25.2
Co. D	0.027	0.085	75.5

This ability makes the model to be more sensitive to changes in specific domains. Moreover, for criteria such as delivery time and quality which have the predefined "acceptable domain" all of the values within this domain are identically same and does not affect the overall score of candidate. These are the facts neglected in Fuzzy-TOPSIS approach.

Table 6: Candidates ranking based on Fuzzy Logic and Fuzzy TOPSIS methods.

	Fuzzy Logic Ranking List	Fuzzy TOPSIS Ranking List
1st	Co. D	Co. D
2nd	Co. A	Co. A
3rd	Co. B	Co. B
4th	Co. C	Co. C

5 CONCLUSIONS

In this study, a fuzzy logic based model is proposed for formation of virtual enterprise. The developed approach provides an effective tool for ranking the enterprises with respect to both quantitative and qualitative criteria and selecting the best partner to participate in virtual enterprise.

Unless many other techniques in literature, specific membership functions are defined for each criterion regarding their characteristics in order to acquire more reliable outcomes. Besides, the other strength of this method is; it provides a flexible model to change the policies in a way decision maker prefers. Not only fuzzy rules can be edited considering customer preferences, but also membership functions of four inputs and output can be modified corresponding to bidding properties. In contrast, models reliability is highly dependent on stablishing reasonable fuzzy rules. Thus, the way to get more accurate results and enhanced models trustworthy is to define precise fuzzy rules by consulting experienced industrial experts.

This study is a preliminary validation of the model for further implementations in industry. The verified model will be implemented in partner selection process of forthcoming VE platform which is going to be established in OSTIM organized industrial park in Ankara.

ACKNOWLEDGEMENTS

This study is being funded by SAN-TEZ project No. 00979.stz.2011-12 of Turkish Ministry of Science, Technology and Industry. Authors are sincerely thankful for continuous support of OSTIM Industrial Park management.

REFERENCES

Bevilacqua, M. & Petroni, A., 2010. From traditional purchasing to supplier management: A fuzzy logic based approach to supplier selection. *International Journal of Logistics: Research and Application*, pp. 235-255.

Camarinha-Matos, L. & Afsarmanesh, H., n.d. The virtual enterprise concept. In: *Infrastructure for virtual enterprises: networking Industrial enterprises. London: Kluwer Academic Publishers*, pp. 3-14.

Chen, T.-Y. & Tsao, C.-Y., 2008. The interval-valued fuzzy TOPSIS method and experimental analysis. Fuzzy Sets and Systems, 159(11), pp. 1410-1428.

Fuqing, Z., Yi, H. & Dongmei, Y., 2005. A multi-objective optimization model of the partner selection problem in a virtual enterprise and its solution with genetic algorithms. *The International Journal of Advanced Manufacturing Technology*, 28(11-12), pp. 1246-1253.

Huang, X., Wong, Y. & Wang, J., 2004. A two-stage manufacturing partner selection framework for virtual enterprises. *International Journal of Computer Integrated Manufacturing*, 17(4), pp. 294-304.

Mamdani, E. & Assilian, S., 1975. An experiment in linguistic synthesis with fuzzy-logic-controller, *Int. Journal of Man-Machine studies*, pp.1-13.

Mikhailov, L., 2002. Fuzzy analytical approach to partnership selection in formation of virtual enterprises. *The international journal of management science*, Volume 30, pp. 393-401.

Nikghadam, S., Kharrati Shishvan, H. & Khanmohammadi, S., 2011. Minimizing earliness and tardiness costs in job-shop scheduling problems considering job due dates, *Proceedings of AIPE*.

Sari, B., Sen, T. & Kilic, S. E., 2007. AHP model for the selection of partner companies in virtual enterprises. *The International Journal of Advanced Manufacturing Technology*, 38(3-4), pp. 367-376.

Shing, J. & Jang, R., 1993. Adaptive-Network-Based fuzzy inference system. s.l., *Transactions on Systems, Man and Cybernetics*, pp. 665-685.

Ye, F., 2010. An extended TOPSIS method with interval-valued intuitionistic fuzzy numbers for virtual enterprise partner selection. *Expert Systems with Applications*, 37(10), pp. 7050-7055.

Zadeh, L. A., 1965. Fuzzy Sets. Information and Control, Volume 8, pp. 338-353.