Comparative Analysis of Crisp and Fuzzy Multi- Criteria Decision Making Methods for Supplier Selection in an Automotive Manufacturing Industry

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***Abstract*— Selecting a supplier is a crucial task in today's competitive business environment. A systematic, trusted and supportive method of evaluating supplier is necessary to select the right supplier that meets customers' expectation in ensuring an efficient continuous supply chain. Multi-Criteria Decision Making (MCDM) methods are able to handle this complex problem when there are many suppliers with multiple conflict criteria. Thus, the aim of this paper is to conduct a comparative analysis of the use of crisp and fuzzy MCDM methods for supplier selection in an automotive manufacturing industry. Four methods; AHP-AHP, AHP-VIKOR, FAHP-FAHP, FAHP-VIKOR are used to calculate the relative importance of five criteria and sixteen sub-criteria and ranking eighteen suppliers. Results show that different methods provide a quite similar ranking of suppliers.**

Keywords*—Analytic Hierarchical Process; Fuzzy Analytic Hierarchical Process; Supplier Selection; VIKOR*

1. Introduction

In todays' highly competitive business environment, evaluation of supplier performance is one the most important component in supplier quality management [1]. A company needs suppliers who can provide good quality of raw materials with reasonable price and minimal lead time in order to meet both customer and company expectation. Having such supplier leads to the competitiveness of the company. Supplier selection involves many criteria which often conflict with each other. Thus, choosing the correct criteria is the essential part of the evaluation process. Dickson [2], as the first person in considering the supplier selection criteria has established twenty-three criteria which has served as a main reference for research and practical purposes. Since then many researchers have revised and provided the most significant criteria for supplier selection [3-5].

In order to evaluate the supplier performance, good analytical and supportive evaluation method would help the purchasing committee to select the best supplier that complies with the company goal and target. Many approaches have been used to solve supplier selection problem such as Multi-Criteria Decision Making (MCDM), mathematical programming and artificial intelligence [6]. MCDM method provides a decision support system for a complex decision problem involving a set multiple, conflicting and inappropriate criteria. If the decision makers are certain about their evaluations, then the crisp MCDM is preferred, but if they are not sure, then the fuzzy MCDM is much more suitable.

In this paper, crisp and fuzzy MCDM were used to select the suppliers who supply spare parts in an automotive manufacturing company. A comparative analysis is conducted to investigate the difference outcomes produced by these methods.

2. Multi-Criteria Decision Making Methods

There are many crisp and fuzzy MCDM methods that have been developed to evaluate the performance of suppliers. Among the favorable crisp methods are Analytical Hierarchy Process (AHP) [6], Data Envelopment Analysis (DEA) [7], Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [8], and

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VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), in Serbian language which means Multicriteria Optimization and Compromise Solution [9]. In dealing with the human uncertainty in making an evaluation, fuzzy theory [10] has been integrated to the crisp MCDM and known as Fuzzy MCDM [11]. Such methods that have been implemented are Fuzzy AHP (FAHP) [12] and Fuzzy TOPSIS [13].

There have been many MCDM methods and hybrid MCDM methods intensively applied in different domains including agriculture [14], manufacturing [15], and healthcare [16]. Yildiz and Yalya [17] have intensively reviewed on the MCDM methods used in various domains for evaluating and selecting suppliers.

3. Methodology

Supplier selection framework that has been implemented in this paper is illustrated in Figure 1. The criteria for the supplier selection have been established by the Purchasing and Quality Assurance's of the selected company. In order to determine the relative important for each criterion, and sub-criterion, and the quality of each supplier under the prescribed criteria, the AHP and FAHP were used. Then, AHP, FAHP and VIKOR method were used to determine the overall performance of each supplier. Finally the suppliers were ranked based on the feature of the selected method. Thus, the combinations of all mentioned methods form four methods so-called AHP-AHP, AHP-VIKOR, FAHP-FAHP, FAHP-VIKOR. Figure 1 shows the framework of the selection process whether using crisp or fuzzy MCDM methods.

3.2 Determination of relative important weight of criteria

In this paper, the evaluation of relative important or weights of criteria, sub-criteria and performance of alternatives (suppliers), under every evaluation criterion or sub-criterion, are obtained by using AHP and FAHP. AHP was introduced by Saaty [7], while Van Laarhoven and Pedrycz [11] were the first who performed FAHP. In general, AHP and FAHP describe the whole decision system by decomposing a complex problem into a hierarchical multi-level structure of goal, criteria, sub-criteria and alternatives. The procedure for determining relative important or weights of criteria using AHP and FAHP are explained in the following subsection.

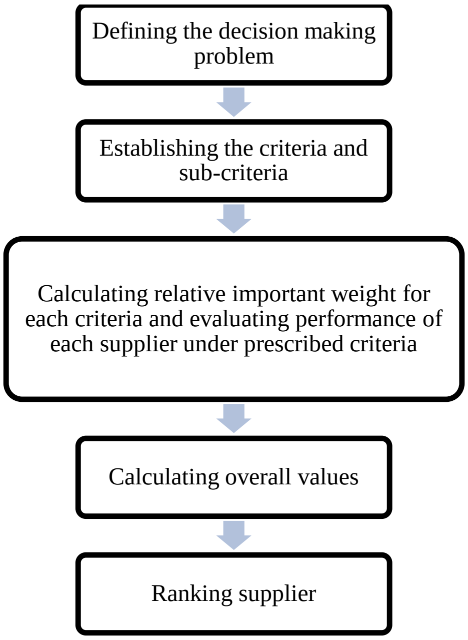

Figure 1. Supplier selection framework using crisp or fuzzy MCDM

3.2.1 *Analysis Hierarchical Process*

Step 1: Establish pair wise comparison matrix of the criteria.

Pair wise comparison matrices, A describes the importance of criterion C_i with respect to criterion C_i as follows,

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{n1} & 1/a_{n2} & \cdots & 1 \end{bmatrix}$$

Pair wise comparison between each criterion is determined using a 9-point Saaty's scale as depicted in Table 1.

Table 1.. Saaty's Scale for Pairwise Comparison

Saaty's crisp scale	Linguistic term
1	Equal Importance
2	Least Important
3	Weak Importance
4	Less Strong Importance
5	Strong Importance
6	More Strong Importance
7	Very Strong Importance
8	Extremely Importance
9	Very Extremely Importance

Step 2: Calculate and normalize the relative importance or weights of criteria.

Relative weight is obtained by dividing each element of the matrix with the sum of its column as given in Eq. 1.

$$r_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad (1)$$

Then the relative weight is normalized by averaging across the row as given in Eq. 2.

$$w_i = \frac{\sum_{j=1}^{n} r_{ij}}{n} \qquad (2)$$

Step 3: Consistency check

Consistency ratio (*CR*) is required to determine whether the weight assigned by the decision maker is correct or not. The value of *CR* < 0.10 indicates consistent judgment in pairwise comparisons but if *CR* ≥ 0.10, then serious inconsistencies might exist and AHP might not yield meaningful results. The calculation of CR is given by

$$CR = \frac{CI}{RI} \qquad (3),$$

where

$CI = \frac{\lambda \max - n}{n-1}$,

λ max is the maximum eigen value, n is the number of criteria and RI is given in Table 2.

Table 2. Random Index

n	*Random Index*
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

3.2.2 Fuzzy Analysis Hierarchical Process

Step 1: Establish fuzzy pairwise comparison matrices of each criterion

Fuzzy pairwise comparison matrices of each criterion are assigned by the expert using linguistic terms. The linguistics term and its reciprocal scales are represented by triangular fuzzy number as shown in Table 3.

Table 3. Triangular fuzzy and triangular fuzzy reciprocal scale

Fuzzy Number	Triangular Fuzzy Scale	Triangular Fuzzy Reciprocal Scale
$\tilde{1}$	(1,1,2)	(1/2,1,1)
$\tilde{2}$	(1,2,3)	(1/3,1/2,1)
$\tilde{3}$	(2,3,4)	(1/4,1/3,1/2)
$\tilde{4}$	(3,4,5)	(1/5,1/4,1/3)
$\tilde{5}$	(4,5,6)	(1/6,1/5,1/4)
$\tilde{6}$	(5,6,7)	(1/7,1/6,1/5)
$\tilde{7}$	(6,7,8)	(1/8,1/7,1/6))
$\tilde{8}$	(7,8,9)	(1/9,1/8,1/7)
$\tilde{9}$	(8,9,9)	(1/9,1/9,1/8)

Step 2: Calculate the fuzzy relative importance or the fuzzy weights.

The fuzzy relative important or the fuzzy weights of criterion C_i are calculated using geometric mean method [18] given by

$$\tilde{w}_i = \tilde{r}_i \times (\tilde{r}_1 + \tilde{r}_2 + \cdots + \tilde{r}_n)^{-1} \qquad (4)$$

where $\tilde{r}_i = (\tilde{a}_{i1} \times \tilde{a}_{i2} \times \ldots \times \tilde{a}_{in})^{\frac{1}{n}}$.

Step 3: Defuzzify the fuzzy weights

In order to obtain crisp weight, the fuzzy relative weights of all criteria are defuzzified using Center of Gravity method [19], given as follows.

$$dw_i = \frac{(u_i - l_i) + (m_i - l_i)}{3} + l_i \quad (5)$$

Step 4: Normalized the weights.

The weights of criteria obtained in step 3 are normalized by using eq. 6 in order to ensure that the weights are effectively compared.

$$w_i = \frac{dW_i}{\sum_i^n dW_i} \quad (6)$$

Step 3: Consistency check

The step is similar as consistency check in AHP.

3.3 Ranking supplier

Overall performance values are ranked either by AHP, FAHP or VIKOR methods after obtaining the relative important or weights of criteria. Ranking of the suppliers is done based on the final score of the suppliers. The highest score gives the highest rank. Weighted sum method is used in both AHP and FAHP method by taking the sum of product of relative importance or weight of each criterion, sub-criterion and the performance values of each alternative. Meanwhile VIKOR method procedure is given as follows:

Step 1: Finding the positive ideal solution and negative ideal solution for all the criterion function; i=1,2,…,n

$$f_i^+ = \max_j f_{ij} \quad (5)$$

$$f_i^- = \min_j f_{ij} \quad (6)$$

where f_{ij} = the performance rating value of the j^{th} supplier with respect to i^{th} subcriteria, i= 1,…n , j=1,…,m

Step 2: Computing the S_j values and R_j values for $j=1,2,\ldots,m$

$$S_j = \sum_{i=1}^{n} w_i (f_i^+ - f_{ij})/(f_i^+ - f_i^-) \quad (7)$$

$$R_j = \max_i [w_i (f_i^+ - f_{ij})/(f_i^+ - f_i^-)] \quad (8)$$

where w_i = the weight of criteria (expressing their relative performance).

Step 3: Computing the Q_j values for $j=1,2,\ldots,m$

$$Q_j = v\left[\frac{S_j - S^*}{S^- - S^*}\right] + (1-v)\left[\frac{R_j - R^*}{R^- - R^*}\right] \quad (9)$$

where S^* : $\min_j S_j$ S^- : $\max_j S_j$

R^* : $\min_j R_j$ R^- : $\max_j R_j$

v: weight of the strategy of the majority of criteria. The maximum group utility, here v=0.5.

Step 4: Ranking the alternatives, sorting by the values S, R and Q in decreasing order.

Step 5: Proposing a compromise solution

The alternative (a´) which is ranked the best by the measure Q (minimum) if the following two conditions are satisfied:

C1. "Acceptable Advantage"

$Q(a'') - Q(a') \geq \frac{1}{J-1}$

where: (a'') is the alternative with second position in the ranking list by Q

C2. "Acceptable Stability in decision making":
The alternative (a')must also be the best ranked by S or/and R. This compromise solution is stable within a decision making process, which could be the strategy of maximum group utility (when v > 0.5 is needed), or "by consensus" v about 0.5($v \sim 0.5$)), or "with veto" v < 0.5).

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

i. Alternatives (a') and (a'') if only the condition C2 is not satisfied, or
ii. Alternatives $(a'),(a'')$..., (a^M)if the condition C1 is not satisfied; (a^M) is determined by the relation $Q(a^M) - Q(a') < \frac{1}{J-1}$ for maximum M (the positions of these alternatives are "in closeness").

The best alternative ranked by Q, is the one with the minimum value of Q.

4. Result and Discussion

The four methods have been applied to evaluate the performance of eighteen suppliers in an automotive manufacturing industry. The Purchasing and Quality Assurance's had established five key criteria with sixteen sub-criteria as shown in Table 4.

Table 4. Supplier criteria and sub-criteria

Criteria	Sub-Criteria	
Quality, Q	Supplier Corrective Action Request	Q1
	Incoming Lot Acceptance Rate	Q2
	Process Control	Q3
	Quality Programs Initiative	Q4
Delivery, D	Production Line Interruption	D1
	Capacity Expansion Plan	D2
	On Time Delivery System Support	D3
Cost, C	Competitive Pricing	C1
	Cost Down Plan	C2
Customer Service, CS	Attend to Issues promptly	CS1
	Responsiveness	CS2
	Regular Customer Visit	CS3
Technology Support. TS	Share Technology roadmap	TS1
	New product and sustaining product	TS2
	Market Intelligence	TS3
	Invest expertise for development	TS4

Pairwise comparison for each criterion, sub-criterion and alternative is established using AHP and FAHP method. The relative important or weights are given in Table 5.

Table 5. Relative Important weight of criteria, sub-criteria using AHP and FAHP

Criteria	Weight		Sub-Criteria	Weight	
	AHP	FAHP		AHP	FAHP
Q	0.622	0.612	Q1	0.2655	0.2528
			Q2	0.1761	0.1752
			Q3	0.1266	0.1304
			Q4	0.0548	0.0546
D	0.114	0.111	D1	0.0550	0.0575
			D2	0.0064	0.0062
			D3	0.0529	0.0478
C	0.140	0.140	C1	0.1056	0.1040
			C2	0.0352	0.0360
CS	0.059	0.064	CS1	0.0396	0.0430
			CS2	0.0138	0.0146
			CS3	0.0062	0.0067
TS	0.062	0.071	TS1	0.0165	0.0189
			TS2	0.0294	0.0331
			TS3	0.0110	0.0131
			TS4	0.0057	0.0062

Weight ranking resulting from AHP method is similar to results from FAHP method. The absolute weight differences between AHP and FAHP methods for all criteria and sub-criteria are less than 0.01.

The results show that Quality has the highest weight which indicates the most important criterion in evaluating supplier performance. It gained a weight of 62.29% (AHP) and 61.29 % (FAHP) compared to other criteria. Then, followed by cost, delivery, technology support and customer service. The highest weight for each sub-criterion is Q1, D1, C1, CS1 and TS2.

Consistency ratio is checked using step 3 in AHP. All values for CR are satisfied which are less than 0.1 which indicate the weights are consistent. Buckley [18] mentioned that if AHP crisp matrix has low consistency ratio, then FAHP matrix can also be considered of having low consistency ratio.

The overall performances using four methods are given in Table 6. Then, the performances of suppliers were ranked based on the condition in each method.

Table 6. Relative Importance or Weight of Criteria, Sub-criteria Using AHP and FAHP

Supplier	AHP-AHP	AHP-VIKOR	FAHP-FAHP	FAHP-VIKOR
S1	0.0786	0.7856	0.0527	0.8000
S2	0.0897	0.0290	0.0653	0.0000
S3	0.0700	0.2826	0.0740	0.2600
S4	0.0786	0.1480	0.0833	0.0800
S5	0.0483	0.6656	0.0508	0.6400
S6	0.0425	0.7619	0.0463	0.6900
S7	0.0427	0.7552	0.0470	0.6800
S8	0.0301	1.0000	0.0307	1.0000
S9	0.0913	0.0000	0.0838	0.0700
S10	0.0382	0.8893	0.0396	0.9300
S11	0.0877	0.1420	0.0852	0.1800
S12	0.0406	0.8489	0.0399	0.9200
S13	0.0823	0.1388	0.0779	0.2200
S14	0.0389	0.8576	0.0389	0.8400
S15	0.0401	0.8554	0.0396	0.8300
S16	0.0391	0.8835	0.0382	0.9500
S17	0.0534	0.6376	0.0523	0.5300
S18	0.0309	0.9878	0.0300	1.0000

Figure 2 provides the ranking of the eighteen suppliers. The results show that the top ranked supplier is S9 when AHP-AHP and AHP-VIKOR were used, S11 if FAHP-AHP was used, and S2 by using FAHP-VIKOR. Based on overall observation by using all four methods, the most suitable supplier to be selected is S9. While, the worst ranked supplier is S18. Figure 2 shows the graphical performance of all suppliers based on the four combinations of four MCDM methods.

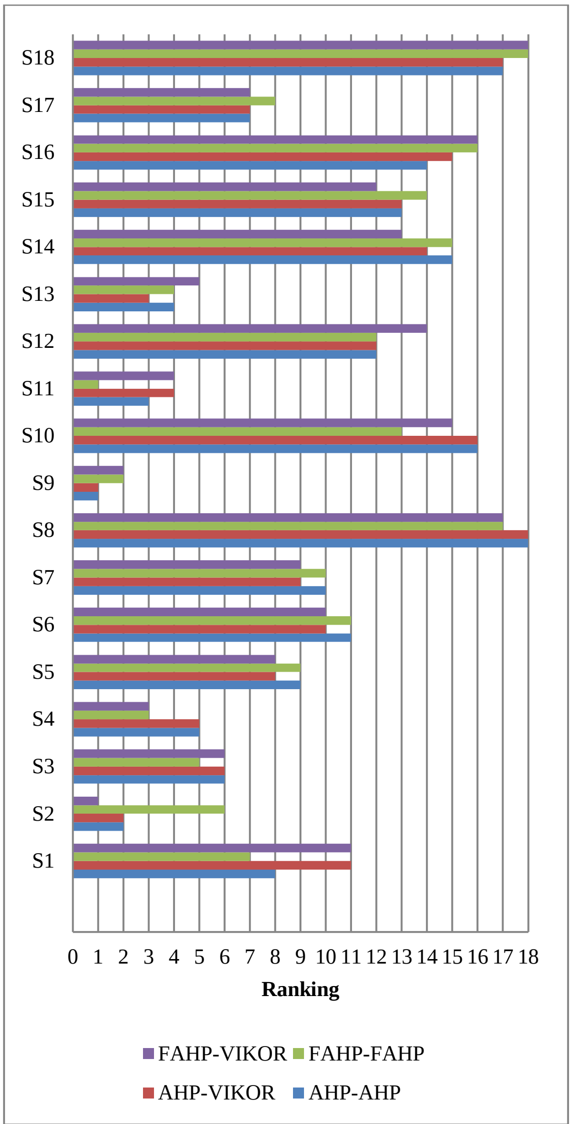

Figure 2: Supplier ranking using Crisp / Fuzzy MCDM

5. Conclusion

Selecting the best suppliers depends on the method used and the predisposition of the decision makers about the criteria. Thus, testing of different MCDM methods would provide more comprehensive decision basis to reflect decision maker evaluations on criteria weights and performance of the suppliers. In this paper four MCDM methods had been applied to select the most suitable supplier for an automotive manufacturing company.

A quite similar result obtained by these four different methods that may help company in making strategic decision as well as in managing the supply base effectively. If the selection between the available multi- criteria methods includes understanding and the acceptability of the method by the decision makers will enable decision makers make a better decision.

These methods can be utilized in any company or service lines that have to rely on suppliers to guarantee their businesses move forward. These models can later be upgraded to become decision support systems which can be part of the whole business process.

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