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SUPPLIER SELECTION USING A FUZZY MULTI-CRITERIA METHOD

Nazihah Ahmad
School of Quantitative Sciences, College of Arts and Sciences,
Universiti Utara Malaysia, 06010 Sintok, Kedah.
nazihah@uum.edu.my

Maznah Mat Kasim
School of Quantitative Sciences, College of Arts and Sciences,
Universiti Utara Malaysia, 06010 Sintok, Kedah.
maznah@uum.edu.my

Shanmugam Sundram Kalimuthu Rajoo
School of Quantitative Sciences, College of Arts and Sciences,
Universiti Utara Malaysia, 06010 Sintok, Kedah.
shanmugam_krs@yahoo.com

ABSTRACT

Supplier selection is one of the most crucial tasks in managing supply chain. In selecting the best supplier, a firm has to have a systematic, trusted and supportive method to ensure its success especially the ones in the manufacturing sector. The selection process usually involves multiple criteria and vagueness of human judgment. Thus, this paper presents an application of a fuzzy multi-criteria method, the Fuzzy Analytical Hierarchy Process, to evaluate the relative importance or the weights of the criteria and to rank eighteen selected suppliers in an automotive spare part manufacturing company. The results show that quality is the most important criterion, followed by cost, delivery, customer service and technology support. Then, these weights were used in ranking the suppliers by using the weighted sum average method. The results of this study, if implemented would hopefully help the purchasing department in supplier selection decision.

Keywords: Fuzzy Analytical Hierarchy Process, supplier selection

INTRODUCTION

Selecting the best supplier is the responsibility of purchasing managers and this task must be carried out periodically in order to ensure the smoothness of the business flows. A company needs to offer low price but high-quality materials, meets customer satisfaction in order to compete with its competitors. The quality of its end items depends heavily on the quality of the raw materials supplied by the suppliers. Furthermore, in a manufacturing company, the cost of raw materials and components is a major variable that influences the cost of the product, which can be up to 70% of the product cost (Setak et al., 2012). Because of that, it is necessary for the company to find the right supplier with the right quality and quantity at the right price at the right time (Jain et al., 2004). Yahya and Kingsman (1999) also stated that suppliers have varied strengths and weakness which required careful assessment by the purchaser committee before they placed an order. Thus, assessing and selecting the best supplier is crucial in ensuring continuous supply chain improvement, reducing the operational costs and risks towards meeting customer's expectation.

Many approaches such as Multi-Criteria Decision Making (MCDM), mathematical programming and Artificial Intelligence (AI) have been used for solving supplier selection problem (Setak et al., 2012). The MCDM usually involves different criteria and often conflict with each other. There are many multi-criteria models which include Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Analytical Hierarchy Process (AHP), Analytic Network Process (ANP) and Multi-Attribute Utility Technique (MAUT). Data Envelopment Analysis, and mathematical programming method such as linear programming, and nonlinear programming. While examples of AI methods which have been applied include Genetic Algorithm, Artificial Neural Networks, decision tree, and cluster analysis.

The AHP which was introduced by Saaty (1980) is one of the most extensively used approaches for solving supplier selection problem that describes the whole decision system by decomposing a complex problem into a hierarchical multi-level structure. But this classical AHP only deal with deterministic values and is not able to consider human uncertainty in making an evaluation. Zadeh (1965) introduced fuzzy theory to overcome this problem. Thus, in order to incorporate the opinion, expertise, experience and knowledge of the experts, the fuzzy theory has been integrated with AHP namely fuzzy AHP. The Fuzzy AHP has also been successfully applied in many other fields including water management (Srdjevic, 2008), e-commerce (Kong & Liu, 2005; Aydin & Kahraman, 2011), staff selection (Ramadan, 2009), performance evaluation systems (Kilic, 2011) and knowledge sharing (Lin et al., 2009).

In this paper, fuzzy AHP approach was applied to evaluate the relative importance of criteria in selecting the best supplier. Next section reviews various criteria for the supplier selection problem. Then, fuzzy AHP methodology was is briefly explained and applied to the case study in an automotive spare part manufacturing company in Malaysia. Finally, conclusion and suggestion are presented in the last section.

CRITERIA

The suitable criteria to assess the supplier quality performance are very important in ensuring the right performance measuring deployed at suppliers' site. Inappropriate criteria will lead to variance between customer's expectation and supplier's deliverables. Dickson (1966) was known among the first who considered the supplier selection criteria. He identified twenty-

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three criteria for assessing supplier's performance based on responses from 170 managers and purchasing agents. Quality, delivery, price, performance history, technical capability, and finance position are among the top identified criteria. Dickson's 23 supplier criteria have become the main reference in evaluating suppliers as opposed to the traditional approach where supplier selection is solely based on the basis of price for so many years. Examples of studies that focused on supplier's selection criteria in manufacturing industry are Weber et al. (1991), Muslim et al. (2007) and Sun (2010). Weber et al. (1991) reviewed seventy-four papers on vendor selection, revised the criteria and summarized them to eleven criteria. Among the top criteria are quality, delivery, price and technical capability. Muslim et al. (2007) used quality, cost, delivery, service, flexibility and attitude as criteria for evaluating supplier performance. While Sun (2010) used focus group research method to get the evaluation criteria and was able to yield six potential dimensions which are manufacturing capability, supply chain capability, innovation, financial, human resource and service quality capability. Detailed list of recently reviewed criteria can be found in Abdolshah (2013).

FUZZY ANALYTIC HIERARCHY PROCESS

Van Laarhoven and Pedrycz (1983) were the first to perform fuzzy AHP. In fuzzy AHP, the goal, criteria, and sub-criteria had been arranged into a hierarchical structure and evaluated by an expert. The relative importance of each criterion was determined by using linguistic variables which were represented as triangular fuzzy numbers. In this study, the Center of Gravity defuzzification method was used to convert the fuzzy evaluations into their corresponding crisps values. Main steps of procedure conducted in this study are shown as follows:

Step 1: Define the decision-making problem.

Step 2: Decompose the complex problem in a hierarchical structure with decision elements.

In this stage, decision maker determines the goal, criteria and sub-criteria of the problem in the hierarchical form.

Step 3: Establish pairwise comparison matrix of the criteria using Triangular Fuzzy Numbers and calculate the weight of criteria.

A 9-point scale was used to describe the relative importance of criteria with respect to the goal (Tsaur et al., 2002) as shown in Table 1. The weights of criteria are calculated using geometric mean method (Buckley, 1985).

Table 1: Saaty's Crips Scale and Fuzzified Scale for Pairwise Comparison

Saaty's Crips Scale	Judgment Definition	Triangular Fuzzy Scale	Triangular Fuzzy Reciprocal Scale

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1	Equal Importance	(1,1,2)	(1/2,1,1)
2	Least Important	(1,2,3)	(1/3,1/2,1)
3	Weak Importance	(2,3,4)	(1/4,1/3,1/2)
4	Less Strong Importance	(3,4,5)	(1/5,1/4,1/3)
5	Strong Importance	(4,5,6)	(1/6,1/5,1/4)
6	More Strong Importance	(5,6,7)	(1/7,1/6,1/5)
7	Very Strong Importance	(6,7,8)	(1/8,1/7,1/6))
8	Extremely Importance	(7,8,9)	(1/9,1/8,1/7)
9	Very Extremely Importance	(8,9,9)	(1/9,1/9,1/8)

Step 4: *Convert to crisp value.*

Let the fuzzy evaluation for criterion *i be* (l_i, m_i, u_i), where *l* represents lower value, *m* is middle value and *u* is upper value. Each fuzzy evaluation of every criterion has to be converted into crisp value. It was done as in the following step.

The relative weight of all evaluation criteria are still in the form of triangular fuzzy number and need to defuzzify using Center of Gravity (Chou & Chang, 2008)

$$W_i = \frac{(u_i - l_i) + (m_i - l_i)}{3} + l_i \quad (1)$$

Finally, in order to effectively compare the relative importance of the evaluation criteria, the defuzzified priority values are normalized using

$$NW_i = \frac{W_i}{\sum_i^n W_i} \quad (2)$$

Step 5: Consistency check.

Consistency ratio (CR) is required to determine whether the weight assign by the decision maker is correct or not. CR< 0.1 indicates consistent judgment in pairwise comparisons. *CR* is calculated using equation 3, equation 4 and Table 2.

$$CI = \frac{\lambda \max - n}{n-1} \quad (3)$$

$$CR = \frac{CI}{RI} \quad (4)$$

Table 2: Random Consistency index (*CI*)

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

Step 6: Ranking supplier.

Now, both criteria weights and performance of each alternative on each criterion has been assessed and defuzzified.
The overall or final performance of each supplier was calculated by the weighted sum method. Ranking of the suppliers was done based on the final score of the suppliers.

CASE STUDY

The criteria and sub-criteria for evaluating the supplier quality performance using fuzzy AHP in one of the automotive manufacturing sectors in Malaysia are illustrated in Figure 1. Supplier quality performance is done yearly by reviewing the performance of the suppliers based on the established five criteria quality, delivery, cost, customer service and technology support. Quality refers to the ability of products or services that always meet customer's expectation. Delivery depends on the supplier's lead time. Lead time is defined as the time taken into account from the placement of order until the physical part received by the customer. The cost is defined as the price paid by the customer or organization for the product offered by the supplier. Since making a profit is the main aim and intention of the business, a supplier who offered cheaper product stands a better chance to provide service to more customers. In enabling continuous business opportunity from customer, service level of the supplier is crucial in ensuring the minimal gap between customer-supplier relationships. Technology support can be defined as the assistance rendered in leveraging knowledge, products, processes, tools, methods and systems in the creation of goods or in providing services.

Each criterion is then broken down into sub-criteria. There are sixteen sub-criteria as illustrated in Figure 1. For quality, there are four sub-criteria. Supplier corrective action is the first sub-criteria under quality which explains the official notification of customer's dissatisfaction due to a quality issue caused by the supplier. This is done through an official report requesting the supplier to respond to the root cause analysis, corrective action, and preventive action in order not to avoid the repeated problem.

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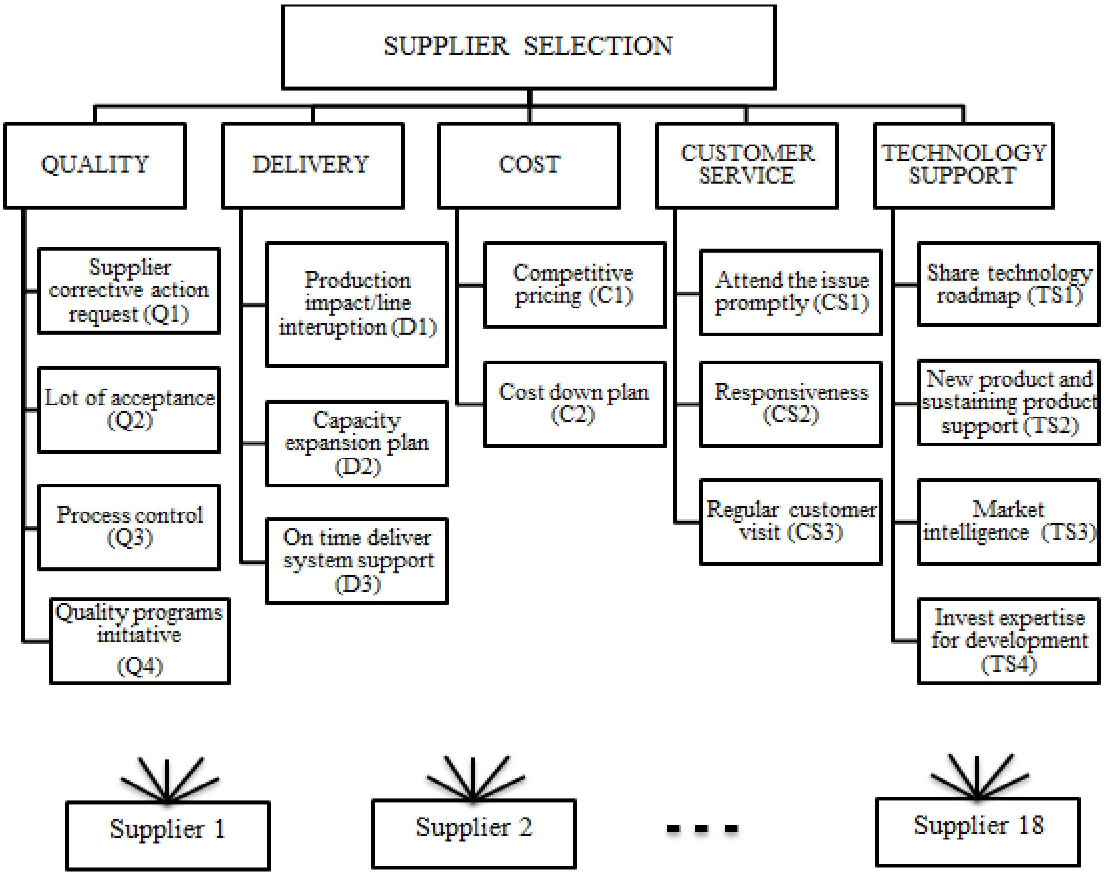

Figure 1: Hierarchy of Supplier Selection

Lot acceptance rate is the percentage of total acceptance lot over delivered lot received by the customer. The third sub-criterion under the quality is process control. Process control defines the supplier's initiative in continuously controlling their specific or critical processes in meeting the defined goal. This is a proactive approach to eliminating the potential problem that might land at customer's site. The last sub-criterion under quality is quality progress initiative. This sub-criterion focuses on the self-initiative and effort taken by the supplier in order to continuously progress and grow in quality without much intervention by the customer.

Under delivery criteria, there are three sub-criteria namely production impact/line interruption, capacity expansion plan and on time delivery support system. Production impact/line interruption is regarded as a serious problem by the customer in which the impact can be sensed by all the customers' in the supplier chain. The second sub-criterion for delivery is capacity expansion plan. This sub-criteria projects the readiness of a supplier if more business opportunity is rendered by the customer and how the supplier could in return support the customer. The last sub-criterion for delivery is on time delivery support system. The customer expects the delivery to be docked at their warehouse as promised and

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committed by the supplier. This sub-criterion will assess the level of on-time delivery support exhibited by the suppliers.

The third criterion is cost. Under cost, there are two sub-criteria; competitive pricing and cost down plan. Price is a global challenge, therefore, the lowest price offered by a supplier is appreciated by many customers without compromising the quality of the product. Competitive pricing assesses the best price offering by the supplier. The second sub-criteria of cost down plan focuses on ongoing support rendered by the supplier in reducing the overall part pricing. The cost down plan could come from the raw material price reduction, reduction in cycle time, alternate material, eliminating unnecessary process and other possible sources.

Fourth criteria focus on customer service. Under customer service, three sub-criteria are listed. The first sub-criterion is attending to issues promptly. Customers expect the supplier to attend to any issue highlighted by customer immediately. Therefore, the responses of the supplier toward customer issues are crucial. The second sub-criterion is responsiveness, which refers to the reply or verbal or written responses to any inquiry from customers. The level of responsiveness determined the customer satisfaction. The third sub-criterion is regular customer visit. The customer's expectation here is to ensure the supplier has a proper face to face meeting with the customer in order to resolve any ongoing issues.

Technology support, the last criteria is supported by four sub-criteria. The first sub-criterion is to share supplier technology roadmap to the customer. It is the duty of the supplier to share with the customer the technology roadmap so that customer would be aware of the latest technology available at supplier's site. This creates an avenue for new business opportunity. The second sub-criterion is a new product and sustaining product group support. Support in terms of sustaining new products is essential for both supplier and customer. Therefore, such a support group is very much needed by the customer in order to work more efficient and effective. The third sub-criterion is market intelligence, reflects the initiative of the supplier in continuously updating latest technology, latest material, latest process and miscellaneous in order to offer the cheapest with fastest cycle time to the customer. The last sub-criterion for technology support is to invest expertise for development. In order for a supplier to be competitive in the global changing market, the content expert's knowledge needs to be updated. So, the initiative and investment put in by the supplier for the company's development carries additional weight and stand a better chance for future business opportunity.
The final portion in evaluating supplier quality performance is alternatives. Each element of the sub-criteria was compared to alternatives and the weights were determined.

Fuzzy comparison matrix of the criteria is given in Table 3, while Table 4 provides an example of fuzzy comparison matrix of sub-criteria which is Quality.

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Table 3: Pairwise Comparison Matrix and Fuzzy Weights of Criteria

	Quality	Delivery	Cost	Customer Service	Technology Support
Quality	(1,1,2)	(6,7,8)	(4,5,6)	(8,9,9)	(8,9,9)
Delivery	(1/8,1/7,1/6)	(1,1,2)	(1/3,1/2,1)	(2,3,4)	(1,2,3)
Cost	(1/6,1/5,1/4)	(1,2,3)	(1,1,2)	(1,2,3)	(1,2,3)
Customer Service	(1/9, 1/9,1/8)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,2)	(1,1,2)
Technology Support	(1/9, 1/9,1/8)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,2)	(1,1,2)

Table 4: Pairwise Comparison Matrix and Fuzzy Weights of Sub-Criteria (Quality)

	Q1	Q2	Q3	Q4
Q1	(1,1,2)	(1,2,3)	(1,2,3)	(3,4,5)
Q2	(1/3,1/2,1)	(1,1,2)	(1,2,3)	(2,3,4)
Q3	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,2)	(2,3,4)
Q4	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,2)

Then, the relative priority weight of each criterion and each sub-criterion were calculated using equation (1) and (2). The results of this analysis are given in Table 5. Quality was the highest weight which indicates the most important criterion in evaluating supplier performance. Then, followed by cost, delivery, technology support and customer service. The highest weight for each sub-criterion was Supplier Corrective Action Request (Q1), Production Impact/Line Interruption (D1), Competitive Pricing (C1), Attend to Issues Promptly (CS1) and New Product and Sustaining Product Support (TS2).

Table 5: Priority of Criteria

Criterion	Final Weight	Sub-Criterion	Final Weight
Quality	0.6129	Q1	0.2528
		Q2	0.1752
		Q3	0.1304
		Q4	0.0546
Delivery	0.1115	D1	0.0575
		D2	0.0062
		D3	0.0478
Cost	0.1400	C1	0.104
		C2	0.036
Customer Service	0.0643	CS1	0.0430
		CS2	0.0146
		CS3	0.0067
Technology Support	0.0713	TS1	0.0189
		TS2	0.0331
		TS3	0.0131
		TS4	0.0062

Then, the consistency ratio for criteria and sub-criteria are checked and satisfied using equation (3) and (4). All values for CR are less than 0.1 which indicate that the weights are consistent.

Finally, the final performance of each supplier was calculated by the Weighted Sum method. Ranking of the suppliers was done based on the final score of the suppliers as shown in Table 6. The result shows that S11 is at the top ranking followed by S9 and S4. Thus, we can see that there is no overlap value in fuzzy AHP analysis which can help the decision maker to select the supplier.

Table 6: Supplier ranking using fuzzy AHP

Rank	Supplier	Total Score
1	S11	0.0852
2	S9	0.0838
3	S4	0.0833
4	S13	0.0779
5	S3	0.0740
6	S2	0.0653
7	S1	0.0527
8	S17	0.0523
9	S5	0.0508
10	S7	0.0470
11	S6	0.0463
12	S12	0.0399
13	S10	0.0396
14	S15	0.0396
15	S14	0.0389
16	S16	0.0382
17	S8	0.0307
18	S18	0.0300

CONCLUSION

In this paper, fuzzy AHP multi-criteria decision making was applied for supplier selection in an automotive spare part manufacturing company in Malaysia. This approach was used to overcome the uncertainty and ambiguity in human decision-making process and thus, help the decision makers in selecting the best supplier with respect to the appropriate criteria and sub-criteria. The results show that the most important criteria in determining supplier selection are quality, followed by cost, delivery, technology support and customer service. The best supplier was identified by ranking the suppliers based on their final scores.

In future work, other multi-criteria approaches such as TOPSIS, ANP and MAUT with integrated fuzzy theory and also a hybrid model which combined several different multi-criteria approaches can be applied and compared. This comparison may help the decision makers to select the most appropriate and suitable supplier.

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