Prioritization of Supplier Development Practices: A Fuzzy Method

Rahayu Tukimin, Wan Hasrulnizzam Wan Mahmood, Norhafiza Mohamed, Mohd Noor Hanif Mohd Rosdi, Maimunah Mohd Nordin

Abstract*: Today, manufacturing firms are demanding a higher level of performance from their suppliers. Manufacturing firms need to ensure that their suppliers are able to provide the best quality of materials, on time, at the right place and the right level of service. To achieve this objective, manufacturing firms may engage in supplier development (SD) program. However, the number of practices involved in SD is extensive. The management of a manufacturing firm should understand the roles and relationship between these practices, so that it may provide additional information on how to manage them. Thus, this paper proposed a model for evaluating and selecting supplier development practices using an integration of fuzzy logic and Analytical Hierarchy Process (AHP). Experts' decision making is used in the process of developing the model. The result suggested that practices associated with transferring knowledge have the highest priority. The results obtained can be referred by manufacturing practitioners as guidelines of seeking the opportunity to implement SD program in enhancing the capabilities of suppliers who contribute to the movement of a supply chain in achieving the greater performance of manufacturing sustainability and responsiveness.

Keywords*: Fuzzy Analytic Hierarchy Process, Malaysia, manufacturing firm, supplier development.

I. INTRODUCTION

Today, in an increasingly dynamic marketplace, manufacturing firms are expected to change faster to suit the market's demand. They are demanding a higher level of performance from their suppliers. Manufacturing firms need to ensure that their suppliers are able to provide the best quality of materials, on time, at the right place and the right level of service. To achieve this objective, manufacturing firms may engage in supplier development (SD) program. SD is about generating a new capability or competency in suppliers. SD is the collaboration process between buying firms and the suppliers for performance improvement in meeting the short-term and long-term term supply needs[1]. Manufacturing firms can generate a competitive advantage by developing their suppliers. Blome et al., [2] found that SD, specifically green SD not only has a direct positive effect of supplier quality, but can also serve as a significant mediator of the relationship between green procurement initiatives and supplier performance.

SD is important for manufacturing firms that are struggling to achieve world-class performance levels. However, the practices available for SD are extensive. The manufacturing firms should understand the roles and relationship between these practices, so that it may provide additional information on how to manage them. Researchers have classified these SD practices into a number of clusters using a variety of empirical studies and scales [3]-[5]. For example, Bai and Sarkis, [3] categorised SD practices into Green Knowledge Transfer and Communication; Investment and Resource Transfer; Management and Organizational Practices.

Formal modeling tools are needed to aid manufacturing firms on how they should develop and implement their SD. It is very important to aid manufacturing firms to prioritize their investment in the SD program [6]. Unfortunately, the is a very limited number of formal tools and models have been developed in SD [3]. For these reasons, this paper introduces the formal methodology to investigate the importance of organisational SD practices. One of the purposes is to help manufacturing firms prioritise their investments in the SD program. Besides, this model potentially may free up resources that may enhance the return of the SD program while meeting the organisation's performance goal. The formal modeling introduced in this paper is using the integration of fuzzy logic and the Analytic Hierarchy Process.

II. METHODOLOGY

A. Concept of Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a powerful tool in multi-criteria decision making (MCDM), proposed by Saaty T.L., [7]. This tool is used in determining the priority of each criterion, alternatives and determine the overall ranking of these two.

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* Correspondence Author
Rahayu Tukimin*, Kolej Kemahiran Tinggi Mara Kuantan, Pahang, Malaysia. Email: rahayu_tukimin@yahoo.com
Wan Hasrulnizzam Wan Mahmood, Sustainable and Responsive Manufacturing Research Group, Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka, Malaysia; hasrulnizzam@utem.edu.my
Norhafiza Mohamed, Kolej Kemahiran Tinggi Mara Balik Pulau, Penang, Malaysia. Email: norhaifiza_mohamed@yahoo.com
Mohd Noor Hanif Mohd Rosdi, Kolej Kemahiran Tinggi Mara Kuantan, Pahang, Malaysia. Email: noorhanif@kuantan.kktm.edu.my
Maimunah Mohd Nordin, Kolej Kemahiran Tinggi Mara Kuantan, Pahang, Malaysia. Email: maimunah.nordin@kuantan.kktm.edu.my

In the process of determining the ranking, the judgment of decision-makers is required to derive the priority scale. The procedures to employ are as follow:

1. Mapping the decision problem into a hierarchy from the overall goal to the lowest level. The goal will be the top of the hierarchy, followed by the intermediate level that represents criteria and sub-criteria, and the lowest level represents the alternatives.
2. Calculating the relative importance weights of decision criteria in each level of the hierarchy. This process will be using a pair-wise comparisons approach. The decision-maker uses the scale (1 to 9) to assess the priority score for each pair of criteria at the same level.
3. Converting the pairwise comparison to a matrix form. The a_{ij} inside the matrix can be translated as a degree of the preference of the i^{th} criterion over the j^{th} criterion. The pairwise judgment made by the decision-maker will undergo a consistency test to measure the consistency rate of judgment. Next, the average weight for each normalised criterion is calculated.
4. Evaluating decision alternatives will undergo the same procedure as decision criteria. However, the weight of decision criteria needs to be multiplied with the weight of alternatives to obtain the overall score.

B. Fuzzy Analytic Hierarchy Process

Fuzzy Analytic Hierarchy Process (FAHP) integrates the fuzzy theory to basic AHP. A traditional AHP does not include vagueness for personal judgment. To handle the vagueness, fuzzy logic is embedded to provide linguistic variables. The flow of the FAHP algorithm used in this study is shown in Fig. 1.

Basically, this algorithm consists of ten important steps and involving equations (1) to (7). For step 1 and step 2, the procedure is the same as in traditional AHP. After the judgment matrix is passed the consistency check, the matrix then transformed into a fuzzy judgment matrix using a triangular fuzzy number (TFN) to replace the scale of the judgment. The TFN used in the pairwise judgment comparison is represented by three numbers, (b^-, b, b^+) to define the fuzziness, where $b^- < b < b^+$. TFNs numbers used in this present study as per [8] and presented in Table-I.

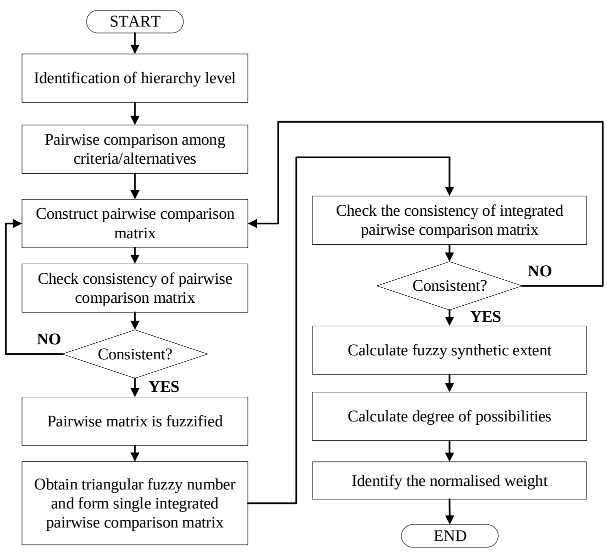

Fig. 1. Fuzzy Analytical Hierarchy Process

Table- I: The scale of relative importance used in the pairwise comparison matrix

Intensity of importance	Linguistic variable	TFN	Reciprocal TFN
1	Equally important	(1, 1, 2)	(1/2, 1, 1)
2	Equally to moderately important	(1, 2, 3)	(1/3, 1/2, 1)
3	Moderately important	(2, 3, 4)	(1/4, 1/3, 1/2)
4	Moderately to strongly important	(3, 4, 5)	(1/5, 1/4, 1/3)
5	Strongly important	(4, 5, 6)	(1/6, 1/5, 1/4)
6	Strongly to very strong important	(5, 6, 7)	(1/7, 1/6, 1/5)
7	Very strong importance	(6, 7, 8)	(1/8, 1/7, 1/6)
8	Very strongly to extremely important	(7, 8, 9)	(1/9, 1/8, 1/7)
9	Extremely important	(8, 8, 9)	(1/8, 1/8, 1/9)

TFNs are used in constructing the pairwise judgment matrix for criteria, sub-criteria, and alternatives as follow:

$$\tilde{A} = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix} \quad (1)$$

where $a_{ij} = (b_{ij}^-, b_{ij}, b_{ij}^+)$ and $a_{ji} = \frac{1}{a_{ij}}$

The pairwise judgment matrix constructed in step 3 then needs to undergo a consistency check to measure the consistency of the judgment. The consistency level is determined using a consistency index that generated from equation (2) and (3):

$$CI = \frac{(\lambda_{max} - N)}{(N-1)} \quad (2)$$

and

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

where

CI = consistency index
N = size of matrix
CR = consistency ratio
RI = random consistency index as per Table- II

Table- II: Random consistency index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

A collected fuzzy judgment matrix then integrated using the fuzzy geometric mean method. The integrated judgment matrix can be determined as (4).

$$b_{ij}^{-} = \left[\prod_{k=1}^{s} P_{ijk}\right]^{\left(\frac{1}{k}\right)}, b_{ij} = \left[\prod_{k=1}^{s} Q_{ijk}\right]^{\left(\frac{1}{k}\right)}, b_{ij}^{+} = \left[\prod_{k=1}^{s} R_{ijk}\right]^{\left(\frac{1}{k}\right)} \quad (4)$$

where $k = 1, 2, \ldots\ldots, s$

The integrated fuzzy judgment matrix is defuzzified [9] to check the consistency as per (5).

$$\bar{b}_{ij} = \frac{(b_{ij}^{-} + 4b_{ij} + b_{ij}^{+})}{6} \quad (5)$$

If the consistency level is not meet, the judgment matrix needs to be revised by the decision-maker. The fuzzy synthetic extent S_i is calculated as (6)

$$S_i = \sum_{j=1}^{m} \bar{b}_{ij} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} \bar{b}_{ij}\right]^{-1} \quad (6)$$

where

$$\sum_{j=1}^{m} \bar{b}_{ij} = \left(\sum_{j=1}^{m} b_j^{-}, \sum_{j=1}^{m} b_j, \sum_{j=1}^{m} b_j^{+}\right)$$

and

$$\sum_{i=1}^{n}\sum_{j=1}^{m} \bar{b}_{ij} = \left(\sum_{i=1}^{n} b_i^{-}, \sum_{i=1}^{n} b_i, \sum_{i=1}^{n} b_i^{+}\right)$$

The non-fuzzy synthetic value that represents the relative preference one criterion over others is then calculated. This value is calculated using Chang's method to identify the degree of possibility using (7) [10].

$$V(S_2 \geq S_1) = \begin{cases} 1 & , \text{if } b_2 \geq b_1 \\ 0 & , \text{if } b_1^{-} \geq b_2^{+} \\ \dfrac{b_1^{-} - b_2^{+}}{(b_2 - b_2^{+}) - (b_1 - b_1^{-})} & , \text{otherwise} \end{cases} \quad (7)$$

The weight of the respective criteria is determined by taking the minimum value among the degree of possibilities. The weight obtained needs to be normalised to determine the priority of each criterion. The ranking is determined based on the normalised weight.

III. RESULT AND DISCUSSION

Within the scope of this study, a FAHP model will be designed for supplier development practices selection in Supply Chain Management. All SD practices and activities are gathered through a literature review, and a questionnaire survey was developed and distributed to ISO14001 certified manufacturing firms as listed in Standard and Industrial Research Institute of Malaysia (SIRIM). The gathered data then undergo the factor analysis to cluster the SD practices and activities. The factor analysis result extracts SD practices and activities into 5 factors; namely supplier certification (SC), Green Capability (GC), Investment and Resource Transfer (IRT), Evaluation and Feedback (EF) and Knowledge Transfer (KT).

In order to apply FAHP, all SD practices and activities initially structured into different hierarchy levels. The best alternative practice must be selected according to 5 criteria. The hierarchical of the problem is illustrated in Fig. 2.

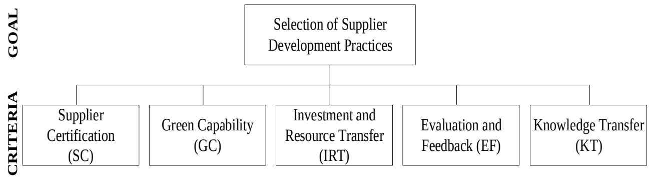

Fig. 2. A hierarchy structure in selecting the supplier development practices and activities.

Pair-wise comparison judgment matrices developed by six decision-makers denoted as decision-makers A, B, C, D, E and F from six different companies. The pair-wise judgment matrix developed by decision-maker A is shown in Table-III. Since the value of CR is less than 0.1, the pairwise judgment matrix by decision-maker A is considered consistent. Similarly, the other 5 matrices developed by 5 decision-makers also undergo the consistency check. If the CR is found to be more than 0.1, the decision-maker needs to rework on his/her judgment. The fuzzified comparison pair-wise matrix of decision-maker A is determined and showed in Table-IV. The fuzzified pair-wise comparison matrices of six decision-makers are then merged to form an integrated fuzzified matrix using the geometric mean method. The result is shown in Table-V.

The integrated fuzzified matrix showed in Table-V, then defuzzified and the result is presented in Table-VI. The value of CR for the integrated defuzzified pair-wise comparison matrix is found to be 0.05 (less than 0.1), indicated that the matrix is consistent. Therefore, the integrated decision-makers' judgment is evaluated and is shown in Table-VII. The fuzzy synthetic extent is calculated and the result as per Table-VIII. The degree of possibilities for all criteria is evaluated and the result is tabulated in Table IX. Finally, the normalized weight and ranking are calculated and the result is showed in Table-X.

From Table- IX, the obtained results indicate that each criterion has a relatively good weight. Therefore, it can be concluded that all criteria considered to have an impact on the SD program. However, the is a difference exist in terms of degree of impact of each criterion since they have different normalised weights and rankings.

Table- III: Pair-wise comparison matrix of decision-maker A

	SC	GC	IRT	EF	KT
SC	1	3	1	3	1
GC	1/3	1	1/3	3	1/3
IRT	1	3	1	3	1
EF	1/3	1/3	1/3	1	1/3
KT	1	3	1	3	1
CI = 0.039	Random CI = 1.12		CR = 0.034		

Table- IV: Fuzzified comparison matrix of decision-maker A

	SC	GC	IRT	EF	KT
SC	(1, 1, 2)	(2, 3, 4)	(1, 1, 2)	(2, 3, 4)	(1, 1, 2)
GC	(1/4, 1/3, 1/2)	(1, 1, 2)	(1/4, 1/3, 1/2)	(2, 3, 4)	(1/4, 1/3, 1/2)
IRT	(1/2, 1, 1)	(2, 3, 4)	(1, 1, 2)	(2, 3, 4)	(1, 1, 2)
EF	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 1, 2)	(1/4, 1/3, 1/2)
KT	(1/2, 1, 1)	(2, 3, 4)	(1/2, 1, 1)	(2, 3, 4)	(1, 1, 2)

Table- V: The integrated fuzzified comparison matrix of six decision-makers

	SC	GC	IRT	EF	KT
SC	(1.00, 1.00, 2.00)	(1.00, 1.00, 2.00)	(1.41, 1.57, 2.70)	(0.90, 1.04, 1.67)	(0.66, 0.76, 1.26)
GC	(0.50, 0.83, 1.00)	(1.00, 1.00, 2.00)	(1.12, 1.31, 2.14)	(0.90, 1.04, 1.67)	(0.53, 0.63, 1.00)
IRT	(0.37, 0.64, 0.71)	(0.47, 0.76, 0.89)	(1.00, 1.00, 2.00)	(0.59, 0.66, 1.05)	(0.37, 0.44, 0.71)
EF	(0.60, 0.96, 1.12)	(0.60, 0.96, 1.12)	(0.95, 1.50, 1.70)	(1.00, 1.00, 2.00)	(0.63, 0.83, 1.26)
KT	(0.79, 1.31, 1.51)	(1.00, 1.57, 1.91)	(1.00, 1.57, 1.91)	(0.79, 1.20, 1.59)	(1.00, 1.00, 2.00)

Table- VI: The integrated defuzzified pair-wise comparison matrix of six decision-makers

	SC	GC	IRT	EF	KT
SC	1.17	1.30	1.73	1.12	0.83
GC	0.80	1.17	1.41	1.12	0.68
IRT	0.60	0.74	1.17	0.72	0.47
EF	0.92	0.92	1.44	1.17	0.87
KT	1.25	1.53	1.53	1.19	1.17
CI = 0.05		Random CI = 1.12		CR = 0.04	

Table- VII: Integrated decision makers' judgement

	$\sum_{j=1}^{n} b^{-}$	$\sum_{j=1}^{n} b$	$\sum_{j=1}^{n} b^{+}$
SC	4.97	5.57	9.63
GC	4.05	4.81	7.81
IRT	2.81	3.50	5.36
EF	3.78	5.24	7.20
KT	4.59	6.64	8.91
Sum	20.20	25.76	38.91

Table- VIII: Fuzzy synthetic extent value of each criterion

Criteria	Fuzzy synthetic extent value		
SC	0.128	0.216	0.477
GC	0.104	0.187	0.387
IRT	0.072	0.136	0.265
EF	0.097	0.204	0.357
KT	0.118	0.258	0.441

Table- IX: Degree of possibilities

	SC	GC	IRT	EF	KT
SC	1	0.897	0.631	0.947	1
GC	1	1	0.760	1	1
IRT	1	1	1	1	1
EF	1	0.945	0.713	1	1
KT	0.897	0.791	0.547	0.815	1

Table- X: Weight and ranking for each criterion

Criteria	Minimum of the degree of possibilities	Normalized weight	Ranking
SC	0.897	0.221	2
GC	0.791	0.195	4
IRT	0.547	0.135	5
EF	0.815	0.201	3
KT	1	0.247	1

The criterion with the highest normalised weight is KT (0.247) and hence stood first in the ranking of SD practices selection. In this case, the manufacturers should cautiously identify, design and plan the different issues relevant to KT in close synchronization with suppliers to make the SD program implementation successful. This result is in line with the finding by Dyer and Nobeoka [11] noting that transferring knowledge by collaborating with other firms as well as importing their practices is crucial to competitive advantages. The criterion with the second-highest normalised weight is SC (0.221). The role of certification is important as it can act as a catalyst in boosting the firm's performance especially if the firm is highly committed to it [12]. In addition, the certification also influential in ensuring process consistency and finally reducing the risk of supplier non-conformance [13],[14].

The criterion with the third-highest normalised weight is FE (0.201). This SD practice is important in identifying qualified suppliers or to control the supplier's performance [15]. FE might also be used by the manufacturer to enhance the value of the operational innovativeness of the supplier, especially in the case of knowledge-intensive suppliers. Besides providing information to the supplier about the buyer's expectations, evaluation also increases the buyer's understanding of the supplier's capabilities [16].

Even though GC and IRT are placed in the fourth and fifth ranking, these two criteria cannot be neglected in implementing the SD program. This is because both of them also have a good normalised weight; 0.195 and 0.135 respectively. In regard to this result, IRT has found to have less influent in producing either good environmental or business performance [3].

IV. CONCLUSION

SD program has proved to have an influential to competitive advantage. However, significant resources need to be allocated to implementing this program. Thus, the selection and management of SD practices need significant arrangements. Therefore, evaluating SD practices needs an appropriate tool to aid the process. This tool is valuable for both researchers and practitioners. This paper uses FAHP in evaluating the criteria in SD practices for implementing the SD program. The results of this study suggested that KT and SC are the two most significant criteria for SD program implementation based on their normalised weight. The finding can be benefitted for a manufacturing firm in Malaysia to maximize the allocation of resources to achieve the maximum benefit from the implementation of the SD program.

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AUTHORS PROFILE

Rahayu Tukimin received a Bachelor in Electrical Engineering from the Universiti Malaya (UM) and finished her Master in Manufacturing System Engineering at Universiti Putra Malaysia (UPM). Currently, she is pursuing her Ph.D. in Manufacturing Engineering at the Technical University of Malaysia Malacca (UTeM). Her research and publication interests include supply chain management, operation strategy, and supplier development. She is also a member of the Board of Engineer Malaysia (BEM) and the Malaysian Institute of Technology (MBOT). She is now a Vocational Training Officer at Majlis Amanah Rakyat.

Associate Professor Ts. Dr. Wan Hasrulnizzam Wan Mahmood holds a Ph.D. in mechanical and material engineering by the Universiti Kebangsaan Malaysia (UKM). He is a senior lecturer in the Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM). The areas of research that he interests and works on are lean manufacturing, operational management, quality management, and production planning.

Norhafiza Mohamed gained her first degree in manufacturing engineering from the Universiti Teknikal Malaysia Melaka (UTeM) in 2008 before pursuing her master's degree in the same field at Universiti Putra Malaysia (UPM). She graduated in 2012 and currently doing her Ph.D. at Universiti Teknikal Malaysia Melaka (UTeM). Her research interest includes supply chain management and operation strategy.

Mohd Noor Hanif Mohd Rosdi awarded his first degree from International Islamic University Malaysia (IIUM) in the year 2007 before gained his master's degree from Universiti Putra Malaysia (UPM) in the year 2012. Currently, he pursuing his Ph.D. at Universiti Teknikal Malaysia Melaka (UTeM). Among his research interests are supply chain management, operation management and manufacturing complexity.

Maimunah Mohd Nordin received her first-degree from Universiti Putra Malaysia in Bachelor of Arts (English Language) and now pursuing her study in Pchychology at Universiti Teknologi Malaysia (UTM).