Application of AHP and FAHP Algorithm for Supplier Development Evaluation

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ARTICLE INFO	ABSTRACT
	Implementation of supplier development (SD) is appropriate for a firm that intends to reduce costs and streamline its operations while minimising defective products. However, the number of practices involved in the SD program is too large, making them difficult to manage. Conventionally, the selection of decisions is based on multicriteria and is often complex and unstructured. Thus, this paper proposed the Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process (FAHP) methodologies to evaluate and select SD practices. Both methods produced the same result. The results obtained can be indicated by the production professionals as guidelines to look for the opportunity to implement the SD program to improve the capabilities of their suppliers.

1. Introduction

Suppliers play an important role in improving the performance of the supply chain. The selection of suppliers becomes a very critical procurement activity because its results significantly impact the quality of goods and the performance of organisations and supply chains [1-2]. However, for the existing suppliers, manufacturing firms need to ensure that suppliers are able to meet their requirements because the default performance of suppliers will cost more money. In response, manufacturing firms can follow one of the three common options practised when faced with default

suppliers. The first option is to look for alternative sources of supply and buy the material from a more competent supplier. However, the first option is possible where another competent supplier and switching do not involve excessively high costs [3]. The second option is the manufacturing firms bring and set up the capacities to produce the product by themselves. But, on the other hand, this choice requires huge investments and may contradict the real intention of firms to focus on their business objectives. The third option is to help the default supplier improve their targeted level capabilities [4-6]. In other words, manufacturing firms should undertake the SD program in response to the competitive market.

In the SD program, numerous practices range from very limited to very extensive efforts practised by the manufacturing firm [7-8]. In today's sustainability challenges, manufacturing firms must consider several aspects of suppliers' performance in implementing the SD program, i.e. economic performance, environmental performance and ethics-related social performance [9]. The impact of individual SD practice may vary and do not contribute equally, and manufacturing firms have a limited resource [9-10]. Therefore, they must carefully and wisely identify the best practices suited to their operational environment to locate their investments to save time, money, and resources [11-12]. As a result, identifying specific SD practices is beneficial in liberating resources that could improve the performance of the SD program while meeting the organisation's performance target.

There is very limited research on the evaluation and selection of SD practices, particularly on the sustainability aspect [13]. Therefore, this study proposed an AHP and FAHP methodology to evaluate and select the SD practices to bridge the gap.

2. Methodology

The essence of AHP is the use of pair-wise comparisons rather than direct weight distribution. This method is widely used in many applications due to its ability to make decisions by making a pair-wise comparison of uncertain, qualitative, and quantitative factors and its ability to model experts' opinions. This method uses a nine-point scale to make an evaluation. However, this conventional AHP presents some deficiencies in terms of the subjectivity of the decision that corresponds to the exact value. The fuzzy set theory is introduced to address the uncertainty of human preference for a more reasonable analysis. Hence, the triangular fuzzy numbers (TFN) for pair-wise comparison scale and the extent analysis method used in this study. The AHP and FAHP methodology is shown in Figure 1.

For AHP, it consists of five steps, while 10 steps are involved for FAHP. Both methods follow the same algorithm up to step 4, checking the consistency of the pair-wise comparison matrix. The difference comes in the fifth step, where step 5a, the priority calculation, is conducted for conventional AHP. The AHP process is completed in step 5. However, for FAHP, the process continues for the extent analysis. The extent analysis is from step 5b until step 10b.

The AHP methodology and the FAHP methodology begin by translating the entire problem into a hierarchical level, including three levels: the objective, the criteria, and the alternatives. The decision-maker makes judgements in terms of pair-wise comparisons at each level using verbal judgements, which will be translated into numbers as presented in Table 1.

The consistency in pair-wise comparison made by decision-makers is confirmed by calculating the consistency ratio [14-15]. The pair-wise comparison was transformed into a matrix form as follow:

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

where $a_{ij} = \left(b_{ij}^{-}, b_{ij}, b_{ij}^{+}\right)$ and $a_{ji} = \frac{1}{a_{ij}}$ for FAHP.
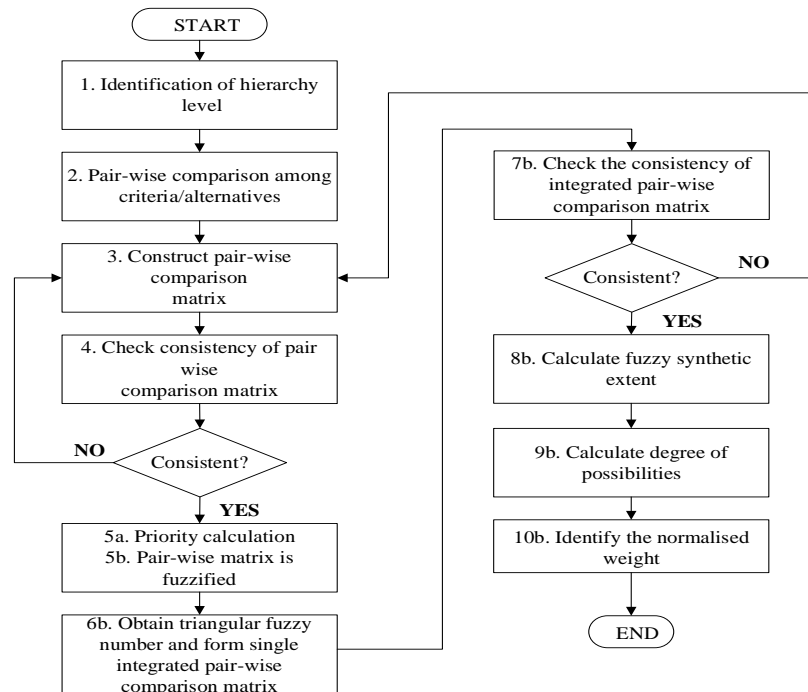
Fig. 1. AHP and FAHP methodology

Table 1
Preference value scale

Preference Value	Numeric Value	TFN (b⁻, b, b⁺)	Reciprocal TFN
Equally important	1	(1,1,2)	(1/2, 1, 1)
Equally to moderately important	2	(1,2,3)	(1/3, 1/2, 1)
Moderately important	3	(2,3,4)	(1/4, 1/3, 1/2)
Moderately to strongly important	4	(3,4,5)	(1/5, 1/4, 1/3)
Strongly important	5	(4,5,6)	(1/6, 1/5, 1/4)
Strongly to very strong important	6	(5,6,7)	(1/7, 1/6, 1/5)
Very strong importance	7	(6,7,8)	(1/8, 1/7, 1/6)
Very strongly to extremely important	8	(7,8,9)	(1/9, 1/8, 1/7)
Extremely important	9	(8,9,9)	(1/8, 1/9, 1/9)

The consistency ratio was determined using Eq. (2) and Eq. (3). The calculated consistency ratio must be less than 10%. If the value is greater than 10%, decision-makers must revise the pair-wise comparison and recalculate the consistency ratio [16]. Once the judgements meet the accepted level of consistency, they can be synthesised to determine the priority ranking.

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

and

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

where

CI	=	consistency index
λ_{max}	=	maximum eigenvalue
n	=	size of matrix
CR	=	consistency ratio
RI	=	random consistency index as Table 2

Table 2
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

In FAHP, the judgment matrix was transformed into a fuzzy judgment matrix using a triangular fuzzy number (TFN) to replace the judgement scale. The TFN used in the pair-wise judgment comparison is defined as three real numbers expressed as (b^-, b, b^+) to define fuzziness. The value of b^- is the smallest possible value, b is the most likely value, and b^+ is the largest possible value, as presented in Table 1.

The fuzzy judgment matrix is defuzzified as Eq. (4) to check the consistency

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

The process of pair-wise comparisons by decision-makers needs to be revised if the consistency level is not met. The fuzzy synthetic extent, S_i is then calculated as follow:

$$S_i = \sum_{j=1}^{m} \bar{b}_{ij} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \bar{b}_{ij}\right]^{-1} \quad (5)$$

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 of one criterion over others is calculated using Chang's method to find the degree of possibility.

$$(S_2 \geq S_1) = \begin{cases} 1 & \text{, if } b_2 \geq b_1 \\ 0 & \text{, if } b_1^- \geq b_2^+ \\ \dfrac{b_1^- - b_2^+}{(b_2 - b_2^+) - (b_1 - b_1^-)} & \text{, otherwise} \end{cases} \qquad (6)$$

The minimum value between the degree of possibilities is the weight obtained for the respective criteria. However, this weighting is normalised to determine the priority for each criterion. The ranking is determined according to the normalised weight.

3. Results

In this study, an AHP and FAHP model was designed for the selection of supplier development practices selection in Supply Chain Management. All SD practices and activities are collected through a literature review. A questionnaire survey has been developed and distributed to ISO14001 certified manufacturing firms as listed in the Standard and Industrial Research Institute of Malaysia (SIRIM). The data collected were then grouped into five criteria based on the result suggested from the factor analysis, namely supplier certification (SC), Green Capability (GC), Investment and Resource Transfer (IRT), Feedback and Evaluation (FE) and Knowledge Transfer (KT).

The pair-wise comparison among the five criteria for SD practices is determined by 6 experts from top management level with at least 10 years of working experience and who possesses extensive knowledge in the manufacturing industry. The geometric mean method was used to aggregate the group decision for the AHP method and the FAHP method.
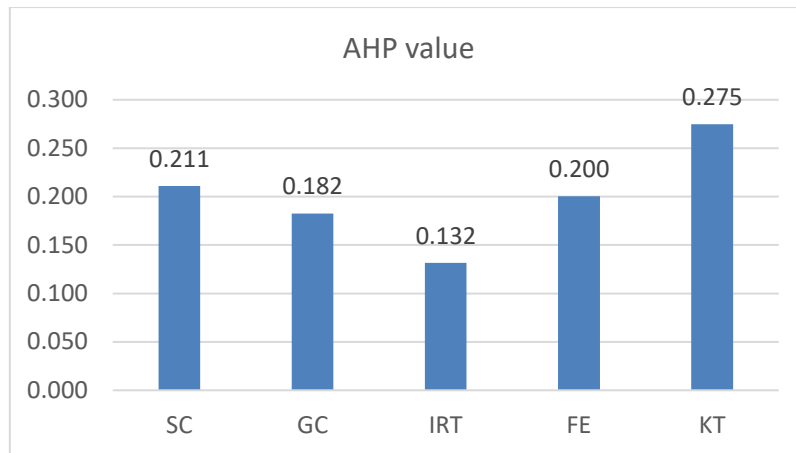
3.1 Determination of priority weight using AHP

The aggregated pair-wise comparison matrix of 5 criteria of SD practices concerning the other relevant SD practices is presented in Table 3.

Table 3
Aggregated pairwise comparison matrix for 5 criteria of SD practices

Criteria	SC	GC	IRT	FE	KT
SC	1.000	1.199	1.570	1.039	0.763
GC	0.830	1.000	1.305	1.039	0.635
IRT	0.636	0.763	1.000	0.662	0.439
FE	0.956	0.956	1.503	1.000	0.829
KT	1.305	1.568	2.265	1.197	1.000

The value of CI is determined, and the value is 0.000048. The results are validated with a consistency check of 0.004% weight. The weight of each criterion shown in Figure 2 indicates that KT is the highest priority with 0.274. SC has been found to be a second priority with 0.211. FE and GC were ranked 3 and 4 with percentages of 0.200 and 0.182. The IRT ranked 5 with 0.132.

Fig. 2. AHP value

3.2 Determination of priority weight using FAHP

The integrated fuzzified comparison matrix of six decision-makers is presented in Table 4, while the integrated defuzzified pair-wise comparison matrix is shown in Table 5.

Table 4
The integrated fuzzified comparison matrix of six decision makers

criteria	SC	GC	IRT	FE	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)
FE	(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 5
The integrated defuzzified pair-wise comparison matrix of six decision makers

criteria	SC	GC	IRT	FE	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
FE	0.92	0.92	1.44	1.17	0.87
KT	1.25	1.53	1.53	1.19	1.17

The results for eigen value of matrix, λ_{max} is 5.19, and the CI is found to be 0.047. The CR value is 0.042, indicated that the matrix is consistent. The fuzzy synthetic extent is calculated, and the result is shown in Table 6. The degree of possibilities for all criteria are evaluated, and the result is tabulated in Table 7. Finally, the normalised weight is calculated, and the result is visualised in Figure 3.
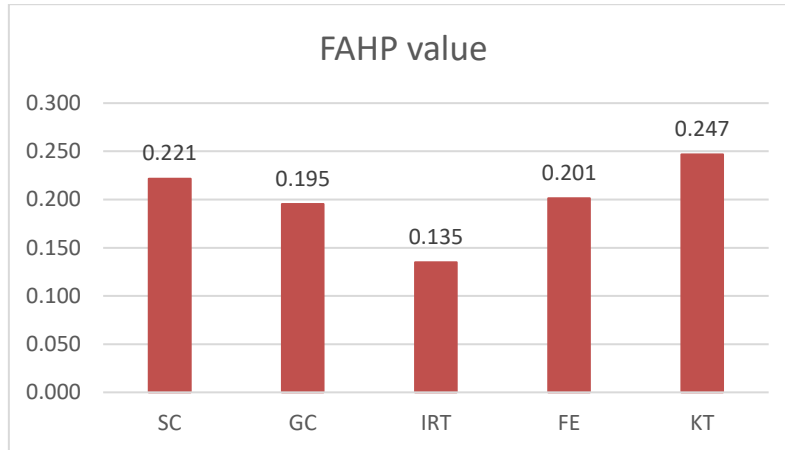
Table 6
Fuzzy synthetic extent value

SC	0.128	0.216	0.477
GC	0.104	0.187	0.387
IRT	0.072	0.136	0.265
FE	0.097	0.204	0.357
KT	0.118	0.258	0.441

Table 7
Degree of possibilities

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

Fig. 3. FAHP value

3.3 Comparison of AHP and FAHP

The comparison between the AHP and FAHP to determine the priority of SD practices is presented in Figure 4. The arrangement according to the priority for both models is KT > SC > FE > GC > IRT. KT has the highest weight and, therefore, occupies first place in the SD practice ranking. This is not surprising because transferring knowledge by collaborating with other firms and importing their practices is essential for competitive advantages [17-18]. In addition, knowledge transfer through providing training and education plays an important role in engaging suppliers, building trust and promoting innovation, thereby enhancing suppliers' capabilities [19-20], thus adding value to the firms [21]. In response to this, manufacturing firms should carefully identify, design, and plan the different issues relevant to KT in close synchronisation with suppliers to implement the SD program successfully.
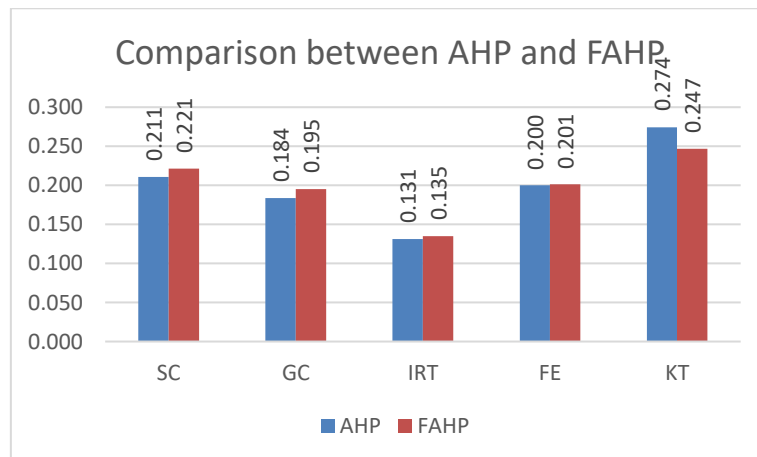
Fig. 4. Comparison of priority weight based on AHP and FAHP

SC has earned second ranking with the normalised priority weight of 0.211 for AHP and 0.221 for FAHP. SC is crucial to boost the firm's performance, especially if the firm is highly committed to it [22]. Besides, SC is also influential in ensuring process consistency and finally reducing the risk of supplier non-conformance [23-24]. The significance of SC is also needed to provide a stringent mechanism in selecting appropriate suppliers, stabilising the supplier connection, and improving the firm's economic efficiency [25].

FE has placed in third place with a normalised priority weight of 0.200 for AHP and 0.201 for FAHP. FE is important to identify qualified suppliers or to control the supplier's performance [26]. The manufacturer might also use supplier evaluation 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, the evaluation also increases the buyer's understanding of the supplier's capabilities [27].

Even though GC and IRT are placed in the fourth and fifth rankings, these two SD criteria cannot be ignored as they have healthy normalised weight. However, IRT has less influence in producing either good environmental or business performance. In this case, manufacturing firms can either improve this criterion or eliminate it from the SD program in practical perspectives [28].

4. Conclusions

In today's business environment, manufacturing firms must have a strategy to remain competitive. They must also properly manage their suppliers so that the deficiencies on the suppliers' side can be improved. The SD program has proven to have an impact on competitive advantage. However, it is necessary to allocate significant resources to the implementation of this programme. Thus, the implementation of the SD program requires significant planning and management. Having an appropriate tool to help evaluate this program is valuable both for researchers and practitioners. This paper uses AHP and FAHP in the evaluation of SD practices. Both methods are capable of considering the relative priorities of available SD practices and demonstrating the best practice. The results achieved in terms of the weight and impact of each criterion on SD can benefit a manufacturing firm, particularly in Malaysia, by optimally allocating resources to maximise the benefits of implementing the SD program. The results obtained show that KT and SC are the two most important criteria for SD practices, as their rank is first and second, respectively. The ranking for SD practices is the same for both models, KT > SC > FE > GC > IRT. However, since the data was collected only in Malaysia, the present study is limited to the scope of Malaysia. Therefore, the results must be interpreted in the context of a developing country. In the future, it is proposed to conduct research to identify and prioritise the critical success factors in SD and the optimal number of suppliers to be developed.

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