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Application of fuzzy AHP for supplier development prioritization

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ABSTRACT

Supplier development (SD) has been identified as a critical strategy for manufacturing firms in managing and improving the capabilities of suppliers. However, implementing this program necessitates an investment of time, commitment, and finances. The selection of the most beneficial practices to be implemented in order for this program to succeed can ensure a better program output. Therefore, it is crucial for the manufacturing firm to identify which practices should be prioritized and implemented for their SD program. Although SD has been widely researched, the method to evaluate SD practices, particularly in the Malaysian manufacturing industry is virtually non-existent. This paper aims to fill the gap by proposing a method to evaluate the SD practices using the Fuzzy Analytic Hierarchy Process (Fuzzy AHP). Fuzzy AHP is used to rank the practices involved in the program by capturing the evaluation from experts with strong industrial backgrounds in Malaysian Industry. There are five criteria for SD practices: Supplier certification (SC), green capability (GC), investment and resource transfer (IRT), feedback and evaluation (FE), and knowledge transfer (KT), with 30 alternatives identified. The findings of the Fuzzy AHP method, suggest that KT is given the most weight. Thus, the alternatives associated with KT must be prioritized to achieve the objectives of the SD program. The results obtained can be referred to by manufacturing practitioners as guidelines for seeking the opportunity to implement an SD program in enhancing the capabilities of suppliers.

1. Introduction

The manufacturing sector played an important role in the economy's development. However, the pandemic coronavirus put a great challenge to this sector, where the supply chain experienced tremendous disruption (Cai and Luo, 2020; Kumar et al., 2020). Manufacturing firms are working to improve their performance in response to this scenario. They are being challenged to improve their own and their significant suppliers' competencies. They have also become more and more dependent on their suppliers due to outsourcing strategies and environmental pressure (Bai et al., 2019a). Supplier management and development have been recognized as the organization's strategies to remain competitive (Çankaya, 2020; Bai et al., 2019a).

Since the SD program was introduced, researchers have classified SD practices into several categories. Among the categories are evaluative and collaborative (Klassen and Vachon, 2003), direct and indirect (Wagner, 2006), and basic, moderate, and advanced (Sánchez-Rodríguez et al., 2005). Each category has various practices, including communication, knowledge transfer, and investment. Nevertheless, each of these practices serves a distinct purpose and does not contribute equally (Routroy and Pradhan, 2014). These practices must be carefully and wisely identified, which is the most to be implemented so that both the manufacturing firms and suppliers can localize the investment for the SD program (Golmohammadi and Hassini, 2021; Bai and Sarkis, 2016). The wise selection of practices will ensure that the investment in terms of finances, commitment, and time is worthwhile, especially for firms with limited resources (Bai et al., 2016).

While supplier evaluation for selection is widely studied, evaluation of practices for supplier

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development has received little attention (Bai et al., 2019b). The determination of which practices are most beneficial to be implemented may enhance the return of the SD program. The formal model helps identify specific SD practices that benefit firms and suppliers and may justify their SD program inclusion.

This paper's multi-criteria decision-making (MCDM) approach uses the integration of fuzzy and Analytic Hierarchy Process (AHP) methodology. The integration of fuzzy and AHP is capable to capture a human's appraisal of ambiguity when complex MCDM problems are considered (Safari et al., 2013). Furthermore, this method has a strong capability in synthesizing the component of the hierarchy level and the logic algorithm is not too complicated (Tran, 2017). This method incorporates all steps of the indicators selection process, as well as a variety of weighting and ranking approaches.

2. Methodology

A literature review was carried out on practices involved in SD programs within manufacturing supply chains. A survey was conducted across different manufacturing firms, including electrical and electronic, automobile, mechanical, and chemicals in Malaysia, through a formal questionnaire. The respondents were from the top management level, mostly senior engineers, and senior managers from different Malaysian manufacturing firms. To meet the study's aims, which are to provide a priority number for SD practices in improving performance, the method is organized into four phases: planning, AHP operation, fuzzy operation, and ranking as illustrated in Fig. 1.

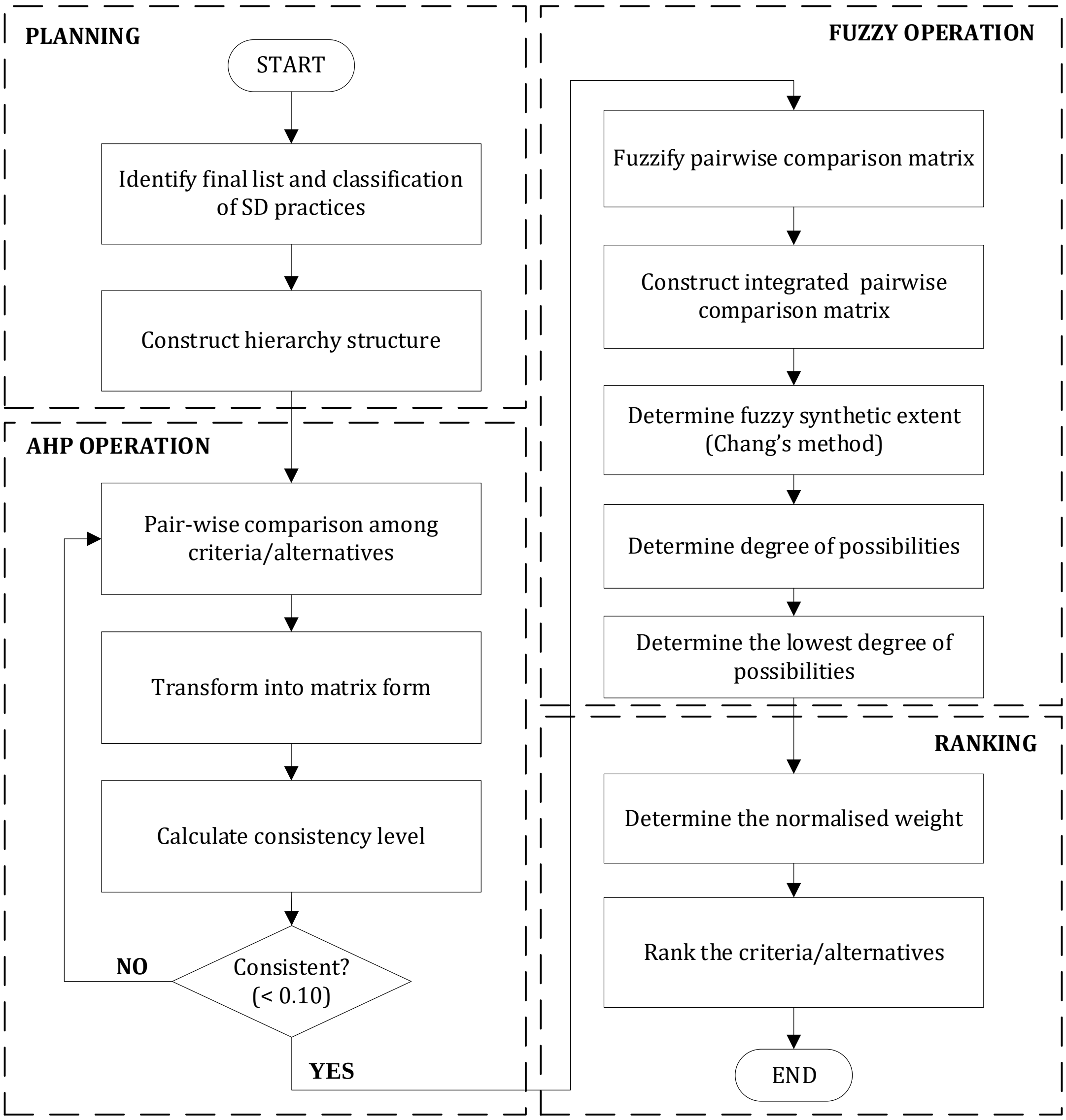

Fig. 1: Methodology flow chart

2.1. Phase 1: Planning

Identifying the priority number for SD practices started with the finalization of the SD practices list and classification resulting from the survey conducted. Thirty-four practices and five criteria were specified for the SD program in the Malaysian context.

However, the relevant and significant practices were extracted using data reduction and factor analysis. The findings were then reformed in a hierarchy structure to visualize SD practice lists in a more understandable manner with five criteria and thirty alternatives. This hierarchy level is used for pair-wise comparison in the next stage.

2.2. Phase 2: AHP operation

A pairwise comparison by experts was used to evaluate the importance level between each SD criteria and among alternatives within the same classification. The evaluations are guided by Saaty's (2008) scale listed in Table 1.

Table 1: The pairwise comparison scale (Saaty, 2008)

Intensity of importance	Description
1	Equally important
3	Moderately important
5	Strongly important
7	Very strongly important
9	Extremely important
2,4,6,8	Intermediate values between two adjacent judgments

The consistency ratio is used to evaluate judgment consistency. Experts' pairwise comparisons are transformed into a matrix format. If i is more important than j, the experts' scale is inserted in rows i and column j. The reciprocal is then used to fill in row j and column i. The eigenvector for every criterion/alternative is calculated as follows:

Stage 1: Total up the number in column j.

$$\sum_{i=1}^{n} a_{ij} \quad \forall i,j \tag{1}$$

Stage 2: Subtract every value by the sum of its columns.

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad \forall i,j \tag{2}$$

Stage 3: Calculate the eigenvector, w, by taking the mean for the rows.

$$w_i = \frac{\sum_{j=1}^{n} a'_{ij}}{n} \tag{3}$$

The eigenvalue, λ_{max} derived from Eq. 4.

$$\lambda_{max} = \sum_{i=1}^{n} \frac{Aw_i}{nw_i} \tag{4}$$

The consistency ratio was then calculated using Eq. 5.

$$CR = \frac{\lambda_{max} - n}{RI(n-1)} \tag{5}$$

where, λ_{max} is the maximum eigenvalue, n is the size of the matrix, and RI is the random indices as shown in Table 2.

If the consistency ratio exceeds 0.10, the expert must re-evaluate the pairwise comparison judgment (Ishizaka and Labib, 2011).

Table 2: Random consistency index

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

2.3. Phase 3: Fuzzy operation

Once the expert judgments pass the consistency test, the method moves on to the fuzzy operation. This procedure specifies fuzziness using a triangular fuzzy number (TFN) as demonstrated in Table 3. The application of TFN in this study is related to its computational efficiency (Moon and Kang, 2001). The fuzzy pairwise comparison of i and j for expert k is represented by $P_{ijk}, Q_{ijk}, R_{ijk}$. It is constructed for all the experts.

Table 3: Characteristic function of fuzzy number

Numeric value	TFN	Reciprocal TFN
1	(1,1,2)	(1/2, 1, 1)
y where y=2, 3,.., 8	(y-1, y, y+1)	(1/y+1, 1/y, 1/y-1)
9	(8,9,9)	(1/9, 1/9, 1/8)

The geometric mean method is used to combine the experts' pairwise comparison matrices to form a single matrix called an integrated fuzzified matrix.

$$\tilde{u}_{ij} = (l_{ij}, m_{ij}, u_{ij}) \tag{6}$$

where,

$$l_{ij} = \left[\prod_{k=1}^{s} P_{ijk}\right]^{\left(\frac{1}{k}\right)} \quad \text{where, } k = 1, 2, \dots\dots, s$$

$$m_{ij} = \left[\prod_{k=1}^{s} Q_{ijk}\right]^{\left(\frac{1}{k}\right)} \quad \text{where, } k = 1, 2, \dots\dots, s$$

$$u_{ij} = \left[\prod_{k=1}^{s} R_{ijk}\right]^{\left(\frac{1}{k}\right)} \quad \text{where, } k = 1, 2, \dots\dots, s$$

The l represents the least likely value, m is the most probable value, and u is the highest possible value. Eq. 7 is applied to calculate the fuzzy synthetic extent value based on the single integrated fuzzified matrix formed.

$$S_i = \sum_{j=1}^{m} \tilde{u}_{ij} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{u}_{ij}\right]^{-1} \tag{7}$$

where,

$$\sum_{j=1}^{m} \tilde{u}_{ij} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right)$$
$$\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{u}_{ij} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right)$$

The fuzzy synthetic extent value for each criterion/alternative is compared to the rest of the criteria/alternatives to obtain the degrees of possibilities using Chang's (1996) method as an Eq. 8.

$$V(S_2 \geq S_1) = \begin{cases} 1 & \text{, if } m_2 \geq m_1 \\ 0 & \text{, if } l_1 \geq u_2 \\ \frac{l_1 - m_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{, otherwise} \end{cases} \tag{8}$$

The relative importance or weight of the criterion/alternative i in relation to the main goal determined by the minimum value among the Degrees of Possibilities, $V(S_i)$ for i.

2.4. Phase 4: Ranking

The normalized weights were derived to identify the significance and the priority of each criterion/alternative. Lastly, the criteria/alternatives are ordered and ranked according to their normalized weight.

3. Result and discussion

3.1. Phase 1: Planning

Fig. 2 depicts the hierarchy structure, which consists of three levels: The goal, criteria, and alternatives.

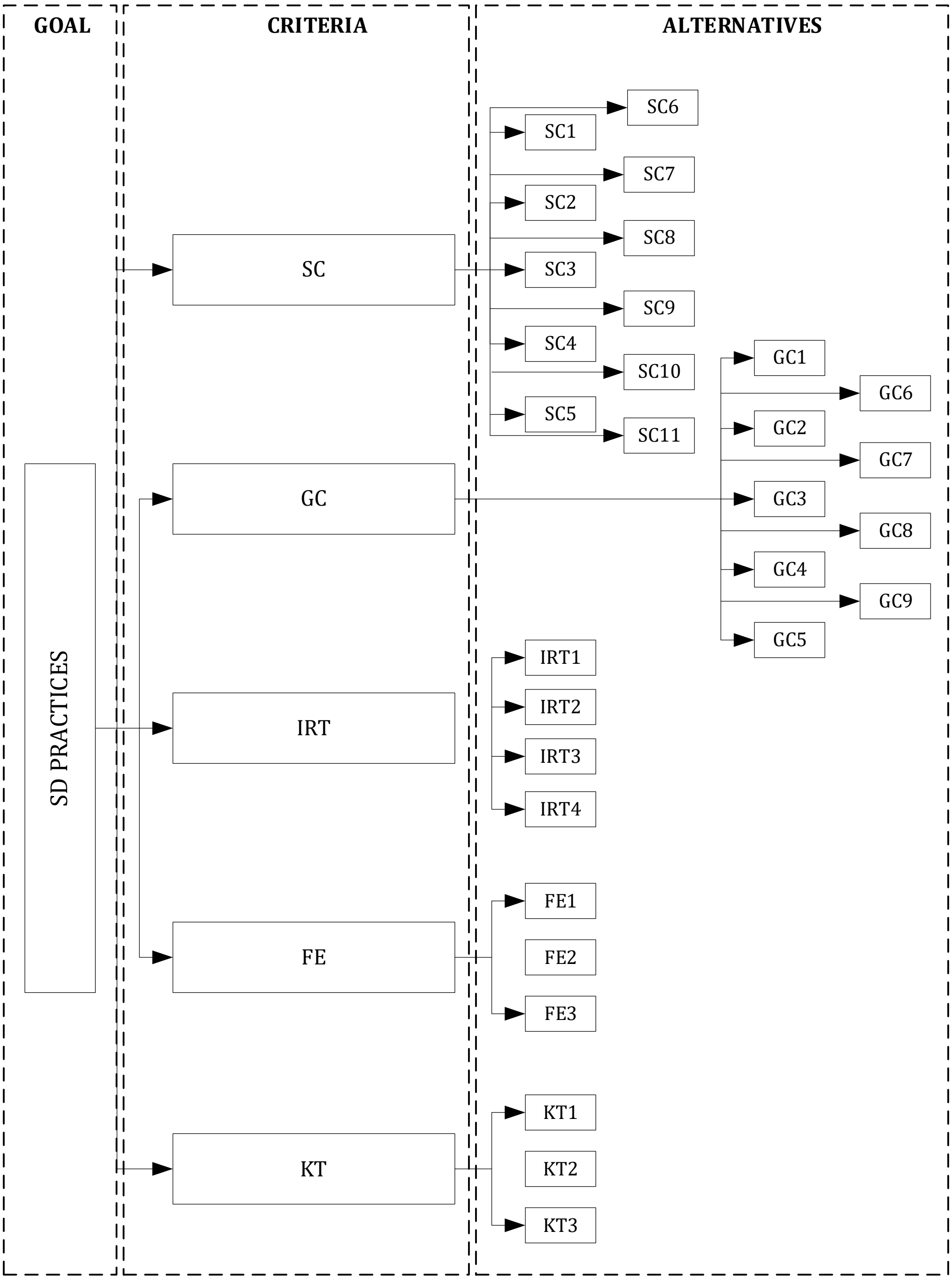

Fig. 2: Supplier development hierarchy structure

3.2. Phase 2: AHP operation

Six Malaysian industry experts were chosen considering their knowledge and dependability in providing accurate responses. According to Ammarapala et al. (2018), 5 to 7 experts are regarded as reliable because too much data complicates data management and increases costs. These six experts were involved in the pairwise comparison development and denoted as experts A, B, C, D, E, and F and worked independently. The responses were then transformed into pairwise comparison matrices. Taking the evaluation of expert A for a criteria level as an example, the pairwise comparison matrix is illustrated in Table 4.

Table 4: The pairwise comparison matrix of expert A evaluation in criteria level

	SC	GC	IRT	FE	KT
SC	1	3	1	3	1
GC	0.33	1	0.33	3	0.33
IRT	1	3	1	3	1
FE	0.33	0.33	0.33	1	0.33
KT	1	3	1	3	1

Eqs. 1, 2, 3, 4, and 5 were used to calculate the reliability of the pairwise comparison matrix in Table 4. Table 5 shows the result of Eq. 1, while Table 6 shows the result of Eqs. 2 and 3.

Table 5: Stage 1 in AHP operation

	SC	GC	IRT	FE	KT
SC	1	3	1	3	1
GC	0.33	1	0.33	3	0.33
IRT	1	3	1	3	1
FE	0.33	0.33	0.33	1	0.33
KT	1	3	1	3	1
	3.66	10.33	3.66	13	3.66

Table 6: Stage 2 and stage 3 in AHP operation

	SC	GC	IRT	FE	KT	sum	*w*
SC	0.27	0.29	0.27	0.23	0.27	1.33	0.266
GC	0.09	0.10	0.09	0.23	0.09	0.60	0.120
IRT	0.27	0.29	0.27	0.23	0.27	1.33	0.266
FE	0.09	0.03	0.09	0.08	0.09	0.38	0.076
KT	0.27	0.29	0.27	0.23	0.27	1.33	0.266

The value of λ_{max} was calculated using Eq. 4 as shown in Table 7.

Table 7: The value of λ_{max}

Aw_i	w	Aw_i/w
1.33	0.266	5.00
0.60	0.120	5.00
1.33	0.266	5.00
0.38	0.076	5.00
1.33	0.266	5.00
	Total	25.00
	λ_{max}	$= \frac{25.00}{5} = 5.00$

Lastly, Eq. 5 was applied to calculate the consistency ratio, CR.

$$\mathrm{CR} = \frac{5.00 - 5}{1.12(5 - 1)} = 0$$

The calculated CR is less than 0.1, indicating that expert A's pairwise comparison evaluation is consistent. Similarly, the level of consistency for other experts is also calculated. In summary, all pairwise comparison matrices have acceptable consistency levels.

3.3. Phase 3: Fuzzy operation

TFN is used to fuzzify expert A's pairwise comparison matrix. Similarly, the remaining five experts' fuzzified comparison pairwise matrices are built from their respective pairwise comparison matrices. Using Eq. 6, the integrated fuzzified pairwise matrix is constructed by integrating all experts' fuzzified comparison pairwise matrices. Table 8 displays the integrated fuzzified pairwise comparison matrix for each hierarchy level.

Table 8: Integrated fuzzified pairwise comparison matrix

Level	Integrated fuzzified matrix										
SD practices (5 criteria)	1.0,1.0,2.0	1.0,1.0,2.0	1.4,1.6,2.7	0.9,1.0,1.7	0.7,0.8,1.3						
	0.5,0.8,1.0	1.0,1.0,2.0	1.1,1.3,2.1	0.9,1.0,1.7	0.5,0.6,1.0						
	0.4,0.6,0.7	0.5,0.8,0.9	1.0,1.0,2.0	0.6,0.7,1.1	0.4,0.4,0.7						
	0.6,1.0,1.1	0.6,1.0,1.1	1.0,1.5,1.7	1.0,1.0,2.0	0.6,0.8,1.3						
	0.8,1.3,1.5	1.0,1.6,1.9	1.0,1.6,1.9	0.8,1.2,1.6	1.0,1.0,2.0						
SC (11 alternatives)	1.0,1.0,2.0	1.0,1.0,2.0	0.9,1.0,1.8	0.5,0.6,1.0	0.8,0.8,1.6	1.8,1.9,3.1	1.8,1.9,3.1	1.0,1.1,1.9	1.0,1.0,2.0	1.3,1.6,2.4	1.3,1.4,2.3
	0.5,1.0,1.0	1.0,1.0,2.0	0.9,1.0,1.8	0.5,0.6,1.0	0.8,0.8,1.6	1.8,1.9,3.1	1.8,1.9,3.1	1.0,1.1,1.9	1.0,1.0,2.0	1.3,1.6,2.4	1.3, 1.4,2.3
	0.6,1.0,1.1	0.6,1.0,1.1	1.0,1.0,2.0	0.5,0.6,1.0	0.8,0.8,1.6	1.9,2.2,3.4	1.9,2.2,3.4	1.0,1.1,1.9	0.9,1.0,1.8	1.3,1.6,2.4	1.4,1.6,2.7
	1.0,1.7,2.0	1.0,1.7,2.0	1.0,1.7,2.0	1.0,1.0,2.0	1.3,1.4,2.5	2.5,3.8,4.4	2.5,3.3,4.4	1.6,1.9,3.0	1.4,1.7,2.8	2.0,2.2,3.5	2.0,2.5,3.6
	0.6,1.2,1.3	0.6,1.2,1.3	0.6,1.2,1.3	0.4,0.7,0.8	1.0,1.0,2.0	2.0,2.3,3.5	2.0,2.3,3.5	1.3,1.3,2.4	1.1,1.2,2.2	1.6,1.9,3.0	1.6,1.7,2.9
	0.3,0.5,0.6	0.3,0.5,0.6	0.3,0.5,0.5	0.2,0.3,0.4	0.3,0.4,0.5	1.0,1.0,2.0	1.0,1.0,2.0	0.6,0.6,1.0	0.5,0.5,0.9	0.7,0.8,1.3	0.6,0.6,1.1
	0.3,0.5,0.6	0.3,0.5,0.6	0.3,0.5,0.5	0.2,0.3,0.4	0.3,0.4,0.5	0.5,1.0,1.0	1.0,1.0,2.0	0.6,0.6,1.0	0.5,0.5,0.9	0.7,0.8,1.3	0.6,0.6,1.1
	0.5,0.9,1.0	0.5, 0.9, 1.0	0.5,0.9,1.0	0.3,0.5,0.6	0.4,0.8,0.8	1.0,1.7,1.8	1.0,1.7,1.8	1.0,1.0,2.0	0.8,0.9,1.6	1.3,1.4,2.5	1.1,1.2,2.2
	0.5,1.0,1.0	0.5, 1.0, 1.0	0.5,1.0,1.1	0.4,0.6,0.7	0.5,0.8,0.9	1.1,1.9,1.9	1.1,1.9,1.9	0.6,1.1,1.2	1.0,1.0,2.0	1.3,1.6,2.4	1.1,1.3,2.1
	0.4,0.6,0.8	0.4,0.6,0.8	0.4,0.6,0.8	0.3,0.5,0.5	0.3,0.5,0.6	0.8,1.2,1.4	0.8,1.2,1.4	0.4,0.7,0.8	0.4,0.6,0.8	1.0,1.0,2.0	0.7,0.8,1.4
	0.4,0.7,0.8	0.4,0.7,0.8	0.4,0.6,0.7	0.3,0.4,0.5	0.4,0.6,0.6	0.9,1.6,1.7	0.9,1.6,1.7	0.5,0.8,0.9	0.5,0.8,0.9	0.7,1.2,1.4	1.0,1.0,2.0
GC (9 alternatives)	1.0,1.0,2.0	1.5,1.7,2.8	1.5,1.7,2.8	1.1,1.3,2.0	1.0,1.1,1.8	1.6,1.8,2.6	1.3,1.4,2.1	1.1,1.3,1.9	1.7,1.8,3.0		
	0.4,0.6,0.7	1.0,1.0,2.0	1.0,1.0,2.0	0.7,0.8,1.4	0.6,0.6,1.1	1.1,1.1,1.8	0.7,0.8,1.4	0.7,0.8,1.3	1.1,1.2,2.2		
	0.4,0.6,0.7	0.5,1.0,1.0	1.0,1.0,2.0	0.7,0.8,1.4	0.6,0.6,1.1	1.1,1.1,1.8	0.7,0.8,1.4	0.7,0.8,1.3	1.1,1.2,2.2		
	0.5,0.8,0.9	1.3,1.4,0.7	0.7,1.3,1.4	1.0,1.0,2.0	0.8,0.8,1.6	1.4,1.4,2.6	1.0,1.1,1.9	1.0,1.1,1.9	1.4,1.6,2.7		
	0.6,0.9,1.0	0.9,1.6,1.7	0.9,1.6,1.7	0.6,1.2,1.3	1.0,1.0,2.0	1.6,1.7,2.9	1.3,1.3,2.4	1.1,1.3,2.1	1.6,1.7,2.9		
	0.4,0.5,0.6	0.6,0.9,1.0	0.6,0.9,1.0	0.4,0.7,0.7	0.4,0.6,0.6	1.0,1.0,2.0	0.6,0.6,1.1	0.6,0.6,1.1	1.0,1.1,2.7		
	0.5,0.7,0.8	0.7,1.2,1.4	0.7,1.2,1.4	0.5,0.9,1.0	0.4,0.8,0.8	0.9,1.6,1.7	1.0,1.0,2.0	0.7,0.8,1.4	1.2,1.3,2.9		
	0.5,0.8,0.9	0.8,1.3,1.4	0.8,1.3,1.4	0.5,1.0,1.1	0.5,0.8,0.9	1.0,1.7,1.8	0.7,1.2,1.4	1.0,1.0,2.0	1.2,1.6,3.0		
	0.3,0.6,0.6	0.5,0.8,0.9	0.5,0.8,0.9	0.4,0.6,0.7	0.4,0.6,0.6	0.6,0.9,1.0	0.5,0.8,0.9	0.4,0.6,0.8	1.0,1.0,2.0		
IRT (4 alternatives)	1.0,1.0,2.0	0.8,0.8,1.6	0.6,0.6,1.0	0.4,0.4,0.7							
	0.6,1.2,1.3	1.0,1.0,2.0	0.6,0.6,1.1	0.5,0.5,0.9							
	1.0,1.7,1.8	0.9,1.6,1.7	1.0,1.0,2.0	0.7,0.8,1.4							
	1.4,2.3,2.7	1.1,1.9,2.1	0.7,1.2,1.4	1.0,1.0,2.0							
FE (3 alternatives)	1.0,1.0,2.0	1.00,1.00,2.00	1.4,1.6,2.7								
	0.4,1.0,0.8	1.00,1.00,2.00	1.4,1.6,2.7								
	0.4,0.6,0.7	0.37,0.64,0.71	1.0,1.0,2.0								
KT (3 alternatives)	1.0,1.0,2.0	1.0, 1.2,2.0	0.8,1.0,1.4								
	0.5,0.8,1.0	1.0,1.0,2.0	0.7,0.9,1.3								
	0.8,1.0,1.3	0.9,1.1,1.6	1.0,1.0,2.0								

The fuzzy synthetic extent is then calculated using Eq. 7. The value of the fuzzy extent is calculated for the criteria level as presented in Table 9.

Table 9: Fuzzy synthetic extent value

	Σl	Σm	Σu	Fuzzy synthetic extent value (Si)
SC	4.97	5.57	9.63	(0.13, 0.22, 0.48)
GC	4.05	4.81	7.81	(0.10, 0.19, 0.39)
IRT	2.81	3.50	5.36	(0.07, 0.14, 0.27)
FE	3.78	5.24	7.20	(0.10, 0.20, 0.36)
KT	4.59	6.64	8.91	(0.12, 0.26, 0.44)
Total	20.20	25.76	38.91	

Eq. 8 is used to calculate the non-fuzzy value. This value represents each criterion/alternative's relative preference over the other criterion/alternative (showing only the relative preference of SC over others in the criteria level).

$V(S_{SC} \geq S_{GC}) = 1.00$
$V(S_{SC} \geq S_{IRT}) = 1.00$
$V(S_{SC} \geq S_{FE}) = 1.00$
$V(S_{SC} \geq S_{KT}) = (0.12\text{-}0.48)/[(0.22\text{-}0.48)\text{-}(0.26\text{-}0.12)]$
$= 0.897$

The minimum value is the relative preference of SC.

$V(S_{SC} \geq S_{GC}, S_{IRT}, S_{FE}, S_{KT}) = \min(1.00, 1.00, 1.00, 0.897)$
$= 0.90$

The relative preference of alternatives is also determined in a similar way.

3.4. Phase 4: Ranking

The non-fuzzy value calculated in phase 3 must be normalized. The ranking of supplier development practices is determined by the normalized weight. The outcome is shown in Table 10.

Table 10: The overall weightage and ranking for supplier development practices

	Criteria/alternative	W(Si)	Overall Wi	Rank
	SC (0.221)			
SC1	Supplier rating scheme	0.131	0.0290	4
SC2	Supplier certification program	0.128	0.0283	5
SC3	Social audit	0.133	0.0294	3
SC4	ISO14001 certification	0.199	0.0440	1
SC5	Environmental audit	0.148	0.0327	2
SC6	Questionnaire to collect information	0.024	0.0053	9
SC7	Supplier reward and incentive	0.010	0.0022	10
SC8	Work with supplier in eco-design	0.094	0.0208	7
SC9	Advice on eco-design product development	0.099	0.0219	6
SC10	Having formal process of SD	0.033	0.0073	8
SC11	Environmental improvement target and performance goal	0.000	0.0000	11
	GC (0.195)			
GC1	Joint effort on reducing waste	0.157	0.1950	1
GC2	Corporate on environmental issue	0.103	0.1285	6
GC3	Long term contract with suppliers	0.098	0.1223	7
GC4	Having supplier environmental assessment program	0.130	0.1615	3
GC5	Joint effort on sustainability, cost and quality improvement	0.150	0.1861	2
GC6	Join supplier in problem solving	0.077	0.0954	8
GC7	Involving suppliers in green procurement and production	0.113	0.1404	5
GC8	Collaborate in developing green innovation and solution	0.124	0.1544	4
GC9	Evaluating environmental management of second tier supplier	0.048	0.0599	9
	IRT (0.135)			
IRT1	Exchanging of expertise personnel	0.183	0.0248	4
IRT2	Providing financial support	0.196	0.0265	3
IRT3	Providing technical and quality expertise and advice	0.283	0.0382	2
IRT4	Having productivity improvement program	0.338	0.0456	1
	FE (0.201)			
FE1	Supplier assessment and evaluation	0.384	0.0773	1
FE2	Formal feedback on supplier performance	0.384	0.0773	1
FE3	Informal feedback/verbal feedback	0.231	0.0465	3
	KT(0.247)			
KT1	Environmental awareness seminar	0.347	0.0856	2
KT2	Training and education programs for suppliers	0.306	0.0755	3
KT3	Sharing information on the environmental topic	0.348	0.0858	1

Each criterion/alternative has a relatively healthy weight, as shown in Table 10. As a result, it can be concluded that all of the criteria/alternatives studied will have an effect on the execution of the SD program. However, because they have various normalized weights and rankings, the degree of influence of each criterion/alternative differs.

The KT has the highest normalized weight of 0.247 and is first on the list of SD practices and activities. In order to successfully implement the SD program, firms must explicitly evaluate, design, and plan the KT concerns in close coordination with suppliers.

Obtaining a competitive advantage requires transferring knowledge through collaboration with other firms and importing their practices (Dyer and Nobeoka, 2000). Furthermore, knowledge transfer through supplier training and education is critical in engaging suppliers, building trust, and sparking innovation, hence enhancing suppliers' skills (Wiratmadja and Tahir, 2021; Zhang et al., 2017).

The SC is placed second, with a normalized weight of 0.221. The findings imply that certification plays an important role in improving organizational effectiveness, especially if the organization is committed to it (Hernandez-Vivanco et al., 2019). Furthermore, accreditation has an impact on ensuring process consistency and, eventually, minimizing the risk of supplier non-conformance (Teli et al., 2013; Wu and Pagell, 2011). The necessity of supplier accreditation is also necessary for providing a demanding approach in the process of selecting appropriate suppliers, stabilizing the supplier connection, and enhancing the firm's economic efficiency (Huang and Wang, 2016).

The FE came in third place with a normalized weight of 0.201. This SD practice is critical for locating competent suppliers and monitoring supplier performance (Arroyo-López et al., 2012). The manufacturer may also use supplier assessment to raise the value of the supplier's operational innovativeness, particularly in the case of knowledge-intensive suppliers. The evaluation not only informs the supplier of the buyer's expectations but also helps the buyer comprehend the provider's capabilities (Azadegan, 2011).

The normalized weights for GC and IRT are 0.195 and 0.135 respectively, thus placed in fourth and fifth. Even though GC and IRT are ranked lower than the others, these two criteria should not be overlooked because they have healthy normalized weights. Nevertheless, Bai and Sarkis (2010) stated that IRT has been shown to have little impact on achieving good environmental and business success. In practice, manufacturers have the choice of improving or eliminating this criterion from the SD program.

SC prioritizes ISO14001 certification for the supplier (SC4) over all other SD practices and initiatives. This result is not surprising given that ISO14001 certification is a reliable sign of high environmental standards (Zobel, 2013). Furthermore, an environmental management system (EMS) is an important first step toward improving environmental performance. The most well-known EMS is the ISO4001 standard, which provides instructions for developing a comprehensive environmental management system. Still, the main goal is to achieve environmental commitment in order to achieve the organization's environmental goals. SC4 is closely related to the second-highest-scoring practice, SC5. This practice is critical for ensuring that environmental management is constantly improved. Furthermore, it serves as a preventive mechanism to ensure that the supplier's activities have the least possible impact on the environment (Yusoff et al., 2016).

GC1 appears to be the highest priority in the C2 process of developing a sustainable supplier. This is because the overall environmental impact of manufacturers is defined not only by the firms' own operations but also by the activities of their suppliers (Darnall et al., 2008). Furthermore, suppliers' raw materials and components account for more than half of the value of a final product. This kind of communication is required to maintain good supply chain management practices. This is a common method used by businesses to eliminate waste in lean production. As a result, working with a supplier to significantly reduce waste benefits both parties.

IRT4 has the highest rank in IRT. Having a productivity improvement program (IRT4) is the highest rating for IRT. Improving production efficiency has always been a complicated subject for organizations due to the added expenditures involved. However, the result will benefit both manufacturers and suppliers. This practice provides "ongoing assistance" to suppliers in the development of efficient operation systems (Abdullah et al., 2008). A second higher priority criterion of IRT is providing technical and quality expertise and advice (IRT3). This practice frequently involved interactions between employees of a manufacturing firm and employees of a supplier. Communication in these interactions contributes to mutual understanding, shared vision, and, ultimately, increased relational capital.

FE1 is the highest priority among the alternatives under FE. In practice, a manufacturer's reliance on its suppliers for materials used in finished products accounts for 50 to 70 percent of production costs. (Lee and Drake, 2010). Manufacturers must be able to assess and evaluate their suppliers' performance in order to verify that their capabilities match their expectations. Manufacturers would be unable to create a high-quality product at a low cost and with timely delivery if this were not done (Sarkis and Dhavale, 2015). FE2 is a practice with the same weight as FE1. FE2 is significant because effective feedback, whether positive or negative, is very useful and vital information in the decision-making process. One of the extrinsic reasons that will drive the supplier to perform better is effective feedback. Evaluating suppliers is even one of the ISO9001: 2015 requirements. According to this requirement, the organization must set requirements for the position, assessment, and re-assessment, as well as maintain records.

For KT, sharing information on the environmental topic (KT3) has the highest priority. The foundation of building and maintaining strategic relationships is the exchange of current information and knowledge with suppliers. In the supply chain, information technology has been widely employed to improve information sharing. Electronic Data Interchanges are used to facilitate information in the supply chain, leading to significant improvements such as cheaper costs, increased efficiency, better outcomes, and better relationships (Tan et al., 2010). KT3 is also critical for controlling a supply chain's long-term consequences (Khan et al., 2016).

In summary, all practices except SC11 have their weight of priority, showing that each of them has its own important contribution to developing a sustainable supplier. SC11 can be considered to have less impact on the SD program. This result is driven by the fact that setting the target must be followed by an assessment to measure the progress of the goal's performance. In addition, the target needs to be re-evaluated according to some factors such as the economy, new product releases from competitors, and other factors that impact the ability to achieve the goal. Lastly, the findings from the fuzzy AHP methodology were sent to three experts for validation purposes. Validation results revealed that experts suggested that KT2 should be given higher priority than KT3 and KT1. It is based on the fact that providing training can reduce workplace accidents and result in fewer disruptions and delays in product delivery, thus improving supplier performance in the form of more reliable supply, shorter lead times, and higher-quality products. Thus, the final graphical presentation on the priority level of criteria/alternatives is presented in Fig. 3.

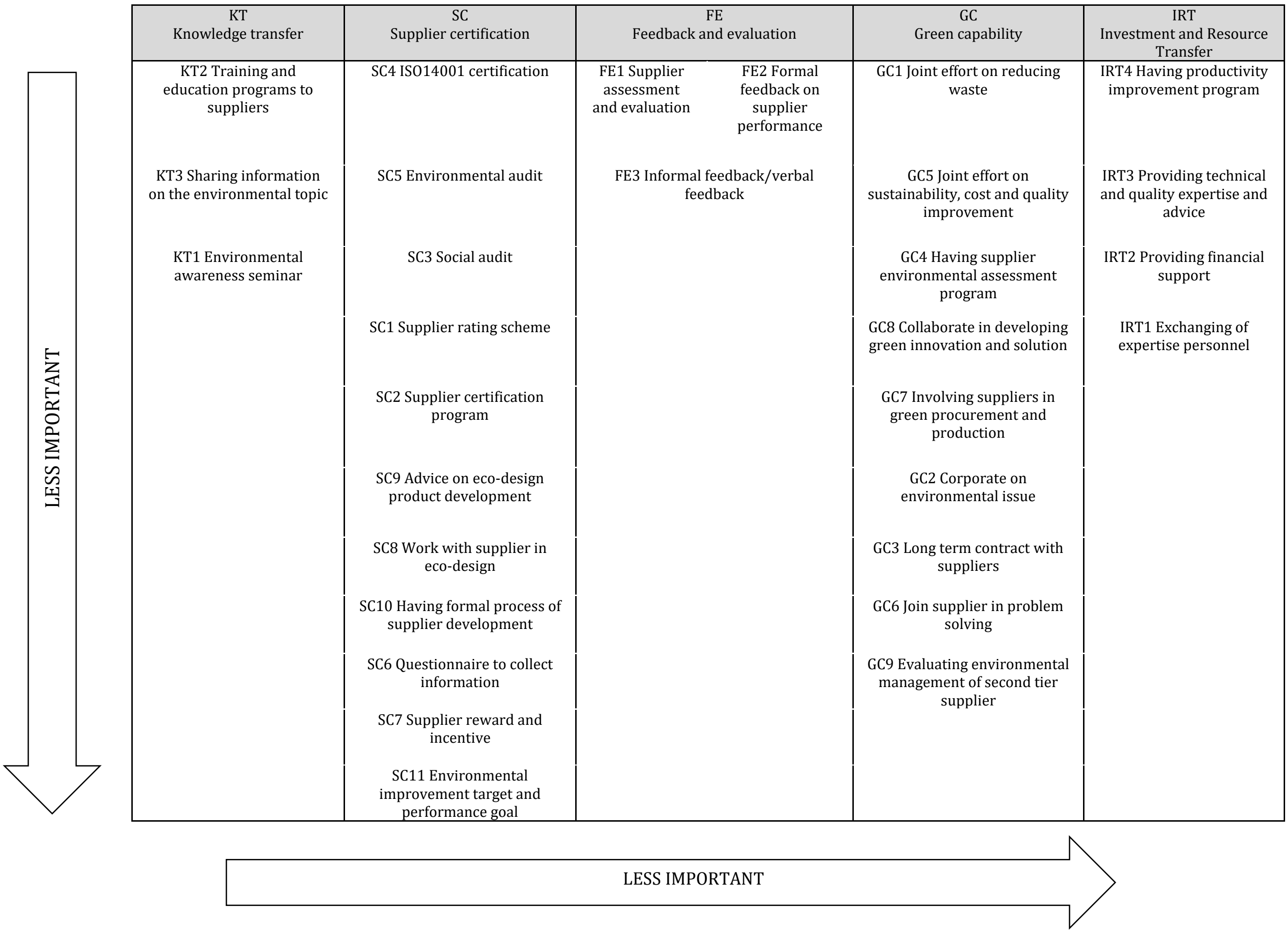

Fig. 3: The priority level of SD practices

The final validated results are in line with Pourjavad and Shahin (2020), who use fuzzy DEMATEL and fuzzy AHP-TOPSIS in evaluating SD practices. They also pointed out that KT2 and SC4 are the best two practices that need to be implemented in developing suppliers. Another application in automobile manufacturing organizations in India using fuzzy NGT-VIKOR by Awasthi and Kannan (2016) also found similar results.

4. Conclusion

Some resources must be allocated for the SD program's execution. The SD program will gain increasing attention and resources as manufacturing firms experience immense pressure to strengthen their supply chains. In this program, however, the identification and administration of SD practices will involve substantial planning and management. Realizing that choosing which practice to implement has become a difficult task, the FAHP technique was employed to identify and organize the implementation process and it helps researchers and practitioners implement, manage, and evaluate these practices. Finally, this study reveals that Knowledge Transfer needs to be emphasized in the SD program's implementation.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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