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An Integrated MCDM Model based on Pythagorean Fuzzy Sets for Green Supplier Development Program

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ABSTRACT

Green supplier development is becoming vital for many industrial firms for effective green supply chain management. Most of the suppliers are willing to invest in many green supplier programs that developed in their firms' performance. The evaluation and selection of an adequate green supplier development program is too complex and challenging as it has multiple criteria and alternatives to be chosen. These criteria involve both qualitative and quantitative information. To select the best alternative of the green supplier development program, it is necessary to settle these problems using multi-criteria decision-making (MCDM) method. This paper proposes the integration of Pythagorean fuzzy AHP and Pythagorean fuzzy VIKOR approach to resolve the green supplier development program selection. The main goal of this study is to present a useful and reliable method to identify the most important criteria and alternatives using Pythagorean fuzzy AHP and Pythagorean fuzzy VIKOR. The first innovation is finding the weight for each criteria using Pythagorean fuzzy AHP. In order to do so, the crisp value evaluated by the decision makers (DMs) are presented in the pair-wise comparison matrix and converted to Pythagorean fuzzy number. The VIKOR is used to rank the alternatives of the green supplier development programs and suggest which program is the best program. Then, the obtained results are compared with the existing VIKOR method in the same case study. The results found the supplier training is the best alternative to select in the green supplier development programs. It is noted that the integration of Pythagorean fuzzy AHP and Pythagorean fuzzy VIKOR is a holistic approach to the MCDM problem.

Keywords: Analytic hierarchy process, Weight, Multi-criteria decision making, Pythagorean fuzzy set and VIKOR.

1. Introduction

Multi-criteria decision-making (MCDM) is a process of making choices by discovering the best option among the feasible alternatives under a finite set of criteria. The problem that regularly occurs in decision making is difficulty in deciding the most desirable alternatives by considering the multiple criteria. The MCDM methods have been extensively employed in many application areas including decision analysis, supply chain management, business organization, pattern recognition and artificial intelligence (Abdullah and Zulkifli (2015)). There are abundant of MCDM methods in the literature to settle the MCDM problems. Among the methods are analytic hierarchy process (AHP) (Buyukozkan and Cifci (2012)), technique for order preference by similarity to ideal solution (TOPSIS) (Krohling and Pacheco (2015)), VIseKriterijumska Optmizacija I Kompromisno Risenje (VIKOR) ((Opricovic, 1998),Opricovic and Tzeng (2004)) and decision-making trial and evaluation laboratory (DEMATEL) (Shieh et al. (2010)).

There is a large volume of literature has been published on the analytic hierarchy process (AHP). The AHP was firstly initiated by Saaty (1980). Instead of using as MCDM tool, AHP can also be used to obtain the weight of criteria. Recently, the crisp AHP is no longer use in determining the weight of criteria because the judgments provided by the DMs are uncertain, imprecise and ill-defined (Torfi et al. (2010)). To tackle this issue, the fuzzy set theory initially introduced by Zadeh (1965) is a powerful tool for decision making problem under the fuzzy environment (Blanco-Mesa et al. (2017)) applied to the AHP (FAHP). Most of the previous studies have applied the FAHP in many applications especially in decision making because its simplicity and popularity. In spite of its popularity, FAHP often being criticized among researchers as it is not efficient when the cases involving the human judgments' subjectivity that need to be assessed. Specifically, it is not practical in some situations as it cannot express the objection evidence simultaneously (Zhu (2014)). Regarding this matter, the Pythagorean fuzzy set (Yager (2014), Yager and Abbasov (2013)) is more adequate and practical to deal with vagueness and uncertainty. PFS is a generalization of intuitionistic fuzzy sets (IFSs). Recently, many scholars have used these sets in solving MCDM problems as it provides the liberty to the DMs in expressing their thinking when it comes to the problems that involving imperfect and uncertain. The PFS is convenient to attain the point because DMs are not required to assign the membership which at least or less than one. Yet, the sum of the squares degree must not be greater than one (Ilbahar et al. (2018)).

Then, another esteemed MCDM method is VIKOR. It is used to find a solution for ranking and selecting the best feasible alternatives that had different unit of measure for criteria. The VIKOR has a simple formulation and a good computational advantage as compared to other MCDM methods which taken into account the closeness to the ideal and anti-ideal alternatives. Previous studies have reported that the VIKOR method is successfully applied in various fields of MCDM problems (Gul et al. (2016)). For example, Wang et al. (2018), Simab et al. (2018) and Baccour (2018). However, little study has focused on Pythagorean fuzzy VIKOR thus far. For example, Chen (2018a) proposed a new model of interval-valued Pythagorean fuzzy set theory (IVPF) and VIKOR technique in selecting the establish PAC service model and Chen (2018b) proposed remoteness index-based Pythagorean fuzzy VIKOR method. Despite that, VIKOR also could be integrated with other methods such as DEMATEL-based ANP and VIKOR (Pineda et al. (2018)), fuzzy ANP and grey VIKOR techniques (Parkouhi and Ghadikolaei (2017)), AHP and VIKOR Babashamsi et al. (2016).

Besides that, the crucial part that needs extra attention to the computational procedure of VIKOR is to find the relative weight of criteria. The weight of criteria is important because it represents the DMs' preference which will influence the final ranking of the evaluation result. Thus, it is necessary to find an appropriate method for the weight of criteria. In the literature, most of the studies employed AHP to determine the subjective weight (Kaya and Kahraman (2010)). Therefore, this paper utilizes the Pythagorean fuzzy AHP (PF-AHP) to determine the weight of criteria. Then, the PF-AHP is integrated into the PF-VIKOR method. The PF-VIKOR method is used to establish the rank and select the best alternatives among of the alternatives.

This paper has been divided into six sections. The second section is preliminaries which include the definition of a Pythagorean fuzzy set. The third section discusses the proposed integrated model. Meanwhile, the fourth section is implementation of the case study: green supplier development program and followed by the comparisons and discussion in the fifth section. The last section assesses the best alternatives, conclude and future work.

2. Preliminaries

Throughout this research study, the definition and notations of the PFSs are introduced.

2.1 Pythagorean Fuzzy Sets (PFSs)

Definition 2.1. *A PFS is an object having the form (Yager (2014), Yager and Abbasov (2013))*

$$D = \left\{ \left\langle m, (\mu_d(m), \mathrm{v}_d(m)\ ) \right\rangle \mid m \in M \right\} \tag{1}$$

where $\mu_d : M \to [0, 1]$ is the membership function while $v_d : M \to [0, 1]$ is the non-membership function of the element $m \in M$ to d and it must be fulfilled the restriction:

$$0 < (\mu_d(m))^2 + (v_d(m))^2 \leq 1 \tag{2}$$

And the degree of hesitancy is presented in the following expression:

$$\pi_m\,(m) = \sqrt{1 - (\mu_d(m))^2 + (v_d(m))^2} \tag{3}$$

3. Proposed Integration Method: An Integration of AHP and VIKOR based on Pythagorean Fuzzy Sets

This section discusses the details of the methodology of the integration model between AHP and VIKOR for selection of green supplier development program under the MCDM environment. This study utilizes Pythagorean fuzzy sets in the process of selection as the human thinking and judgments are imprecise, uncertainty and ill-defined. Pythagorean fuzzy numbers incorporate with AHP is more relevant as compared to the classical AHP.

3.1 The Design of Research Framework

The framework of this study is designed such in Figure 1.

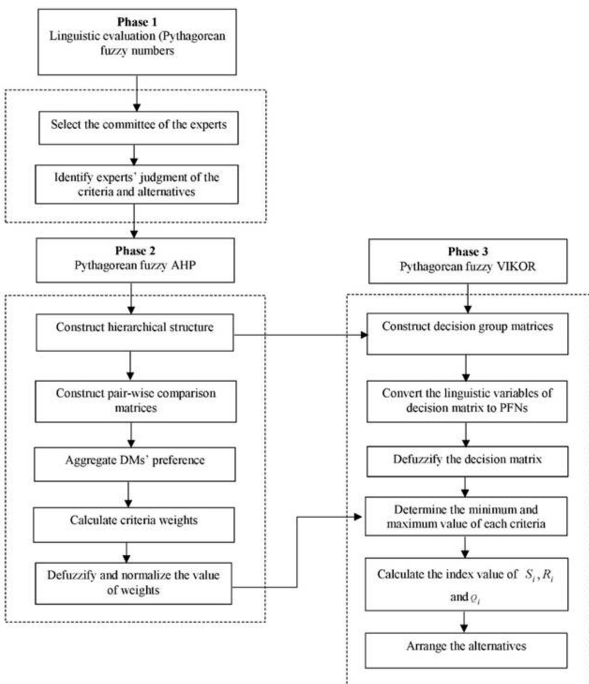

Figure 1: Design of the proposed method

The first activity is to identify the problem. This work consists of the selection of the experts or DMs which are assigned to evaluate the problems. Then, the case study is adapted to test the effectiveness of the method which involves (i) Pythagorean fuzzy AHP and (ii) Pythagorean fuzzy VIKOR.

3.2 An integration of Pythagorean fuzzy AHP and Pythagorean fuzzy VIKOR

The objective of this work is to integrate the AHP and VIKOR under the PFS. There are three phases have been carried out in this study. The details of the procedures are presented as follows:

3.2.1 Phase 1: Linguistic evaluation

This part focused on the assigning of the experts including academicians and industrial organizations. Each of them is required to evaluate the criteria according to the linguistic ratings. Table 1 shows the linguistic scales of AHP and its respective Pythagorean fuzzy numbers (PFNs).

Table 1: The linguistic scale of AHP and PFNs.

Linguistic variables	AHP Scale	PFNs	Reciprocal PFNs
Equally important (EI)	1	(1.0,1.01.0)	(1.0,1.0,1.0)
Intermediate value(IV)	2	(0.5,0.7,0.2)	(1/0.2,1/0.7,1/0.5)
Moderately more important (MMI)	3	(0.3,0.5,0.4)	(1/0.4,1/0.3,1/0.5)
Intermediate value(IV)	4	(0.6,0.7,0.2)	(1/0.2,1/0.7,1/0.6)
Strongly more important (SMI)	5	(0.7,0.2,0.6)	(1/0.6,1/0.2,1/0.7)
Intermediate value(IV)	6	(0.6,0.6,0.4)	(1/0.4,1/0.6,1/0.6)
Very strong more important (VSMI)	7	(0.8,0.3,0.1)	(1/0.1,1/0.3,1/0.8)
Intermediate value(IV)	8	(0.8,0.6,0.1)	(1/0.1,1/0.6,1/0.8)
Extremely more important	9	(0.9,0.7,0.2)	(1/0.2,1/0.7,1/0.9)

3.2.2 Phase 2: Determining the weight of criteria

This study employs Pythagorean fuzzy AHP to fuzzify the pair-wise comparison matrix. The process of implementing AHP is described in detail as below.

Step 1: The problem convert to a hierarchy structure. The first line is the goal, followed by the intermediate line is criteria and the last line is alternatives.

Step 2: The experts required to give their judgments where the judgments present in the pair-wise comparison matrices such that in matrix X.

$$X = \begin{bmatrix} 1 & x_{12} & x_{13} & \dots & x_{1n} \\ x_{21} & 1 & x_{23} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ x_{d1} & x_{d2} & x_{d3} & \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & x_{12} & x_{13} & \dots & x_{1n} \\ \frac{1}{x_{21}} & 1 & x_{23} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{1}{x_{d1}} & x_{d2} & x_{d3} & \dots & 1 \end{bmatrix}$$

Step 3: Use the geometric mean by Buckley (1985) to aggregate the experts' preference which presented in the pair-wise comparison matrices using equation (4).

$$\tilde{c} = \left(\tilde{c}_{ij}^{1} \otimes \tilde{c}_{ij}^{2} \otimes ... \otimes \tilde{c}_{ij}^{n}\right)^{\frac{1}{n}} \tag{4}$$

n is the number of experts.

Step 4: Find the weight of criteria. Each of the matrix of alternative and criteria is constructed by aggregate them using equation (5).

$$\tilde{c}_j = (\tilde{c}_{m1} \otimes \tilde{c}_{m2} \otimes ... \otimes \tilde{c}_{mn})^{\frac{1}{n}} \tag{5}$$

where $j = 1, 2, ..., n$ and m is the PFN. The fuzzy weight can be determined by the equation (6).

$$w_j = \tilde{c}_j \otimes (\tilde{c}_1 \oplus \tilde{c}_2 ... \oplus \tilde{c}_n)^{-1} \tag{6}$$

where $j = 1, 2, ..., n$

Step 5: Defuzzify and normalize the weight of each criterion. The triangular fuzzy number as such in equation (7) is utilized to defuzzify the weight of criteria and alternatives.

$$z = \frac{z_1 + 4z_2 + z_3}{6} \tag{7}$$

3.2.3 Phase 3: Rank alternatives

Step 6: Find the value of the criteria function for the alternative, B_{ij} and decide the best B_j^* and the worst B_j^- values of all criteria.

$$B_j^* = max\left[B_{ij}|i = 1, 2, ..., n\right], B_j^- = min\left[B_{ij}|i = 1, 2, ..., n\right] \tag{8}$$

$$B_j^* = min\left[B_{ij}|i = 1, 2, ..., n\right], B_j^- = max\left[B_{ij}|i = 1, 2, ..., n\right] \tag{9}$$

Step 7: Determine the index of separation measure S_i (utility) and R_i (maximal regret) by the following relations:

$$S_i = \sum_{j=1}^{n} w_j \frac{B_j^* - B_{ij}}{B_j^* - B_j^*} \tag{10}$$

$$R_i = max\left[w_j \frac{B_j^* - B_{ij}}{B_j^* - B_j^*}\right] \tag{11}$$

Step 8: Calculate the VIKOR index,$Q_i, i = 1, 2, ..., n$ by the equation (11).

$$Q_i = v\frac{S_i - S^*}{S - S^*} + (1 - v)\frac{R_i - R^*}{R^- - R^*} \tag{12}$$

$$S^* = minS_i, S^- = maxS_i, R^* = minR_i, R^- = maxR_i \tag{13}$$

Step 9: Rank the best alternatives based on the value of S_i, R_i and Q_i. The minimum value of Q indicates the best alternative though it has to check the following conditions either satisfied or not.

C1: The acceptable advantage:

$$Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq DQ \tag{14}$$

$A^{(1)}$ is referring to the best alternative or first position meanwhile $A^{(2)}$ is referring to the second position of Q. And G denotes the number of alternatives.

$$DQ = \frac{1}{G-1} \tag{15}$$

C2: Acceptable stability in decision making. The alternative $A^{(1)}$ must also be the best ranked by S or/and R .

Alternative with the first position considered as the best. If these alternatives could not satisfied with those conditions, then another set of compromise solutions are offered:

- Alternatives $A^{(1)}$ and $A^{(2)}$ if the condition 2 is not satisfied, or
- Alternatives $A^{(1)}$, $A^{(2)}$,..., $A^{(G)}$ if condition 1 is not satisfied and $A^{(G)}$ is determined by the relation $\mathrm{Q}\big(A^{(G)}\big) - Q\left(A^{(1)}\right) < DQ$.

4. An Application of the Proposed Method to the Green Supplier Development Program

The proposed method is implemented to a case study that retrieved from Awasthi and Kannan (2016). The three experts are assigned to evaluate the opinion.

4.1 Implementation

Step 1: The DMs are asking to rate the three alternatives using linguistic ratings as Table 1. Then the linguistic ratings are converted into Pythagorean fuzzy numbers.

Step 2: The criteria weight is determined using equations (4)-(7) and normalized using equation (7). The minimum and the maximum value of all criteria are obtained using equation (8) and equation (9). The criteria weight for all alternatives shown in Table 2.

Table 2: The best and worst values for all criteria

Criteria weight	Alternatives			B_j^*	B_j^-
	A1	A2	A3		
wC1	0.0038	0.0031	0.0030	0.0030	0.0038
wC2	1.6082	0.0859	0.0071	0.0071	1.6082
wC3	0.0006	0.0008	0.0005	0.0005	0.0008
wC4	0.4661	0.9886	1.3325	0.4661	1.3325
wC5	0.0010	0.0018	0.0022	0.0010	0.0022
wC6	0.0009	0.0074	0.0013	0.0009	0.0074
wC7	0.0060	0.0074	0.0109	0.0060	0.0109
wC8	0.0053	0.0075	0.0170	0.0053	0.0170
wC9	0.5095	0.4818	0.1105	0.1105	0.5095
wC10	0.0470	0.0597	0.0220	0.0220	0.0597
wC11	0.0044	0.0055	0.0301	0.0044	0.0301
wC12	0.0129	0.0133	0.0382	0.0129	0.0382
wC13	0.1939	0.1161	0.0664	0.0664	0.1939
wC14	0.0950	0.0959	0.2058	0.0950	0.2058
wC15	0.0553	0.0432	0.0683	0.0432	0.0683
wC16	0.0205	0.0304	0.0413	0.0205	0.0413

Step 3: Obtain the index values of S_i , R_i and Q_i using equation (10)-(12). The results are presented in Table 3.

Table 3: The values of S_i, R_i and Q_i for alternatives.

	A1	A2	A3
S_i	2.3580	1.0486	2.0396
R_i	1.6082	0.4863	1.5284
Q_i	1.0000	0.0000	0.8429

Step 4: The values of S_i, R_i and Q_i are sorting in ascending order (see Table 4).

Table 4: Ranking of alternatives.

S_i	A2	A3	A1
R_i	A2	A3	A1
Q_i	A2	A3	A1

5. Comparison and Discussion

The results obtained using proposed integrated PF-AHP and PF-VIKOR are compared with the PF-VIKOR and Fuzzy VIKOR (Awasthi and Kannan (2016)). The values of S_i, R_i and Q_i are summarized in Table 5.

Table 5: Comparison between PF-AHP abd PF-VIKOR, PF-VIKOR and Fuzzy VIKOR.

	PF-AHP and PF-VIKOR			PF-VIKOR			Fuzzy VIKOR		
	S_i	R_i	Q_i	S_i	R_i	Q_i	S_i	R_i	Q_i
A1	2.3580	1.6082	1.0000	5.8576	0.6667	1.0000	0.4210	0.0840	0.1860
A2	1.1828	0.5963	0.0000	3.8046	0.6278	0.0000	0.5190	0.1060	1.0000
A3	1.7464	1.3325	0.6036	5.2551	0.6278	0.3533	0.4860	0.0710	0.3320

After that, the alternatives are ranked in ascending order as presented in Table 6.

Table 6: Alternative ranking (ascending order).

	PF-AHP and PF-VIKOR			PF-VIKOR			Fuzzy VIKOR		
	S_i	R_i	Q_i	S_i	R_i	Q_i	S_i	R_i	Q_i
A1	3	3	3	3	3	3	1	2	1
A2	1	1	1	1	1	1	3	3	3
A3	2	2	2	2	2	2	2	1	2

From Table 5, it can be seen that the lowest index for S_i is alternative 1 which is 0.4210 and R_i is the alternative 3 which is 0.0710 in fuzzy VIKOR. Meanwhile, for the index Q_i, the alternative 2 has the lowest value in PF-VIKOR and integrated PF-AHP and PF-VIKOR. In fuzzy VIKOR, the ranking result is A1 $<$ A3 $<$ A2, while A2 $<$ A3 $<$ A1 in PF-VIKOR and PF-AHP and PF-VIKOR. The ranking result is different because the fuzzy set has not taken into consideration of the non-membership degree while Pythagorean fuzzy set considers both membership and non-membership. Despite having the minimum value for S_i and R_i index in fuzzy VIKOR but the final ranking are winning by the PF-VIKOR and PF-AHP and PF-VIKOR. The result obtained may be slightly different because impreciseness and uncertainties imply in the linguistic variables are characterized comprehensively and in PFS considers both degree of membership and non-membership as well (Yager and Abbasov (2013)). When it comes to the fuzzy environment, utterly the PFS is more powerful rather than fuzzy sets to represent the fuzziness, ambiguity and uncertainties of the situation.

In this case, PF-VIKOR and integrated PF-AHP and PF-VIKOR have the similar ranking result. Based on Table 5, we can see that PF-AHP and PF-VIKOR have a minimum value of S_i, R_i and Q_i compared to the PF-VIKOR itself. Therefore, we can say that our proposed integrated model is the best among the rest. In particular, alternative 2 (supplier training) is ranked as the best alternative based on the minimum value of Q_i . However, it has to check the acceptability conditions. Using equation (15), $DQ = \frac{1}{(3-1)} = 0.5$. Then, applying equation (14),

$$Q\left(A^{(3)}\right) - Q\left(A^{(2)}\right) = 0.6036 - 0.0000 = 0.6036 > 0.5$$

Hence, the condition 1 is satisfied. So, it can be concluded that the best alternative for the selection of green supplier development program is alternative 2 (supplier training). It can be said that the proposed model is very sensitive to the changes of criteria weight.

6. Conclusions

The priority in this work is to innovate the traditional VIKOR by integrating AHP with the VIKOR under the PFS. The PF-AHP is employed to find out the weight of criteria whilst the PF-VIKOR is utilized to rank the feasible alternative and decided the most suitable green supplier development program. And, also combining two or more approaches the work is more effective and efficient in solving the real cases. Hence, an integration of PF-AHP and PF-VIKOR in green supplier development program is considered the main contribution in the study as well as in the literature thus far. Up to now, PFS is a more powerful tool in depicting the vagueness, ambiguity and uncertainty yet the proposed integrated method is considered more explicit and applicable to decision-making process as a whole. It is justified that the integrated model can be employed to resolve the complex or other difficult problems in MCDM.

As the future research is considered, we would recommend that the method of determining the weight of criteria is improved as the AHP has its limitation. As far as known, in AHP it is not considered the interrelation among criteria. Specifically, the criteria are assumed to be independent in the proposed model. However, in real situation, the problem is hierarchically structured and it may have a relationship among the criteria. Since the interaction is concerned between the criteria, it is necessary to modify the model so that the model can be adapted to the situation. Furthermore, the weighted geometric is used in information aggregation of the proposed model. But the changes of aggregation operator will be affected the final ranking of the alternatives depending on the type of aggregation operator used. There are a lot of aggregation operators introduced in the literature that could be used in the proposed method such as weighted average, ordered weighted average (Merigó et al. (2018)) harmonic mean and Bonferroni mean (Blanco-Mesa et al. (2018)) in the future research. Eventually, it would be better if the proposed model in here is applied to the other MCDM problems (Yusoff et al. (2018).

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