Evaluation and Selection of 3PL Provider Using Fuzzy AHP and Grey TOPSIS in Group Decision Making

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Abstract. Selection of a 3PL provider is a problem of multi criteria decision making, where the decision maker has to select several 3PL provider alternatives based on several evaluation criteria. A decision maker will have difficulty to express judgments in exact numerical values due to the fact that information is often incomplete and the decision environment is uncertain. This paper presents an integrated fuzzy AHP and Grey TOPSIS for the evaluation and selection of 3PL provider method. Fuzzy AHP is used to determine the importance weight of evaluation criteria. For final selection, grey TOPSIS is used to evaluate the alternatives and obtain the overall performance which is measured as closeness coefficient. This method is applied to solve the selection of 3PL provider at PT. X. Five criterias and twelve sub-criterias were determined and then the best alternative among four 3PL providers was selected by proposed method.

INTRODUCTION

Many companies outsourced their logistic activity to Third Party Logistic (3PL) providers in order to focus on their core competence. Besides, the companies also receive several other benefits such as reduced logistics cost and fixed logistics assets, and improved the service. For those reasons, the suitable 3PL provider should be correctly selected, or otherwise the companies will experience low quality logistic services and non-fulfillment contracts. This may resulted in bad reputation and trust of the company. Therefore the suitable selection of 3PL provider is an important factor that will determine the company's logistic performance.

The evaluation and selection of 3PL providers is Multi-Criteria Decision Making (MCDM) problem whereas a decision maker has to select the best alternative based on several evaluation criteria. At the moment there are many studies performed by researchers and practitioners offering different method and evaluation criteria. A comprehensive study on different methods used in the 3PL provider selection was conducted by [1]. The methods commonly used are Analiytic hierarchy process (AHP) and Fuzzy AHP, Analytic network process (ANP), Technique for order preference by similarity to ideal solution (TOPSIS), and Data envelopment analysis (DEA). On the other side, the evaluation criteria for the selection of 3PL providers have been many times discussed in the previous researches. The relevant criteria for the selection of a provider have been compiled by [2]. Another research provides more detailed 27 criterias covering the general company considerations, quality, client relationship, capabilities, and labor relations in 3PL provider selection on a leading Turkish automotive company. An integrated criteria list (followed by sets of sub-criteria) has been modeled for evaluation and selection of 3PL providers by [4] and [5].

In conventional MCDM, the ratings and weights of criterias are known with their exact numerical value. Decision makers often have difficulty in expressing preferences appropriately. This is due to several factors including incompleteness and uncertainty of information. In recent years, a fuzzy-based approach has been proposed to solve 3PL provider selection under uncertainty. One of method often used is fuzzy AHP [3,4]. In some studies, fuzzy AHP is integrated with TOPSIS or fuzzy TOPSIS to select the best 3PL provider [1, 6, 7]. The usage of fuzzy AHP weights in TOPSIS makes the decisions more realistic and reliable.

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PT. X is one of the company that produces steel pipe and tube. Currently this company is considering the contract with several 3PL providers to handle its inbound and outbound logistics operation. So far the logistic department has not been using any quantitative method to select 3PL provider but instead the selection has already been based on several criteria. In this paper, we propose an integrated fuzzy AHP and Grey TOPSIS to evaluate and select 3PL providers according to a decision making group in PT. X. Grey theory [8] was proposed by Deng in 1982, It is a new method used to solve uncertainty problems with discrete data and incomplete information [9]. Combining fuzzy AHP with Grey TOPSIS will provide more realistic and reasonable judgments for logistic department of PT X.

LITERATURE

Fuzzy analytic hierarchy process (Fuzzy AHP)

The triangular fuzzy numbers are used in the pairwise comparison process to express subjective judgments in fuzzy AHP. It is defined by three real numbers, expressed as (l, m, u). The l, m, and u parameters indicate the smallest possible value, the most promising value, and the largest possible value which describes a fuzzy event. The steps of fuzzy AHP, based on [10] as follows:

Step 1: The value of fuzzy synthetic extent with respect to the i-th object is defined as :

$$s_i = \sum_{j=1}^{m} Mij \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} Mij \right]^{-1} \tag{1}$$

Where

$$\sum_{j=1}^{m} Mij = \left(\sum_{j=1}^{m} 1j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{2}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij} = \left(\sum_{i=1}^{n} 1_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right), and \tag{3}$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij} \right]^{-1} = \left(1 \Big/ \sum_{i=1}^{n} u_i, \; 1 \Big/ \sum_{i=1}^{n} m_i, \; 1 \Big/ \sum_{i=1}^{n} 1_i \right) \tag{4}$$

Step 2: The degree of possibility of $M_1 \geq M_2$ is defined as:

$$V(M_1 \geq M_2) = \sup_{x \geq y} \left\lfloor \min((\mu_{M1}(x)), (\mu_{M2}(y)) \right\rfloor \tag{5}$$

When an (x,y) pair exists such that $x \geq y$ and $\mu_{M_1}(x) = \mu_{M_2}(y) = 1$ then we have $V(M_1 \geq M_2) = 1$. Since M dan M are convex fuzzy number then it become :

$$V(M_1 \geq M_2) = 1 \; if \; m_1 \geq m_2, \quad V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M2}(d), \tag{6}$$

Which d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} (see Fig. 1). When $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ the ordinate of D is given by :

$$V(M_2 \geq M_1) = \frac{1_1 - u_2}{(m_2 - u_2) - (m_1 - 1_1)} \tag{7}$$

To compare M_1 and M_2, both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ are required.

Step 3: The degree possibility for a convex fuzzy number to be greater than *k* convex fuzzy number M_i (i=1, 2,…, k) numbers can be defined by :

$$V(M \geq M_1, M_2, .., M_k) = V\left[(M \geq M_1) \; and \; (M \geq M_2) \; and \; (M \geq M_k) \right] = \min V(M \geq M_i), i = 1,2,..,k \tag{8}$$

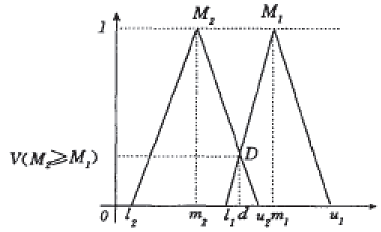

FIGURE 1. The Intersection Between μ_{M1} and μ_{M2}

Step 4: Assume that $d'(A_i) = \min V(S_i \geq S_k)$ for $k = 1,2,...n$; $k \neq i$. Then, the weight vector is given by :

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T \tag{9}$$

Where A_i ($i=1,2,....,n$) are n elements.

Step 5: Via normalization, the normalized weight vectors are :

$$W = (d(A_1), d(A_2), ..., d(A_n))^T \tag{10}$$

Where W is a non-fuzzy number that gives the priority weights of one criterion over another.

B. Grey TOPSIS

A multi-attribute group decision making model under the condition of uncertain information was proposed by [11] using baseline of grey number operations and Minkowski distance function and aggregation technique. Assuming a positive grey number matrix, Dk, be defined as :

$$D^k = \begin{bmatrix} \otimes x_{11}^k & \otimes x_{12}^k & \cdots & \otimes x_{1m}^k \\ \otimes x_{21}^k & \otimes x_{22}^k & \cdots & \otimes x_{2m}^k \\ \cdots & \cdots & \cdots & \cdots \\ \otimes x_{n1}^k & \otimes x_{n2}^k & \cdots & \otimes x_{nm}^k \end{bmatrix} \tag{11}$$

where $\otimes x_{ij}^k$ denotes the grey evaluations of the *i-th* alternative with respect to the *j-th* attribute by decision maker k (k=1,… K); $\otimes x_i^k = (\otimes x_{i1}^k, \otimes x_{i1}^k, ..., \otimes x_{im}^k)$ is the grey number evaluation series of the *i-th* alternative given by decision maker *k*. The proposed model procedure is explained in five steps.

Step 1: Construct the normalized grey decision matrices.

In general, the attribute property can be categorized into two types: (1) the larger-the-better; and (2) the smaller-the-better. The normalization of the larger-the-better type attribute can be written as:

$$\otimes r_{ij}^k = \frac{\otimes x_{ij}^k}{\max(\bar{x}_{ij}^k)} = \left(\frac{\bar{x}_{ij}^k}{\max(\bar{x}_{ij}^k)}, \frac{\bar{x}_{ij}^k}{\max(\bar{x}_{ij}^k)} \right) \tag{12}$$

While the normalization of the smaller-the-better type attribute can be calculated as:

$$\otimes r_{ij}^k = \frac{\otimes x_{ij}^k}{\min(\bar{x}_{ij}^k)} + 2 = \left(\frac{-\bar{x}_{ij}^k}{\min(\bar{x}_{ij}^k)} + 2, \frac{\bar{x}_{ij}^k}{\min(\bar{x}_{ij}^k)} + 2 \right) \tag{13}$$

Step 2: Calculate the positive ideal alternative, A^{k+}, and the negative ideal alternative, A^{k-}, for each decision maker.

$$\begin{aligned} A^{k+} &= \left\{ \left(\max r_{ij}^{-k} \mid j \in J\right), \left(\min r_{-ij}^{k} \mid j \in J'\right) \mid i \in n \right\} \\ &= \left[r_1^{k+}, r_2^{k+}, ..., r_m^{k+} \right] \end{aligned} \tag{14}$$

$$\begin{aligned} A^{k-} &= \left\{ \left(\min r_{-ij}^{k} \mid j \in J\right), \left(\max r_{ij}^{-k} \mid j \in J'\right) \mid i \in n \right\} \\ &= \left[r_1^{k-}, r_2^{k-}, ..., r_m^{k-} \right] \end{aligned} \tag{15}$$

Step 3: There are two sub-steps to be considered in step 3.

Step 3a. Determine the measures from the positive and negative ideal alternatives individually.

For decision maker *k*, the separation measures from the positive ideal alternative, d_i^{k+}, and negative ideal alternative, d_i^{k-}, are computed through weighted grey number minkowski distance as

$$d_i^{k+}=\left\{\frac{1}{2}\sum_{j=1}^{m}w_j\left[|r_j^{k+}-r_{-ij}^{k}|^p+|r_j^{k+}-r_{ij}^{-k}|^p\right]\right\}^{1/p} \tag{16}$$

$$d_i^{k}=\left\{\frac{1}{2}\sum_{j=1}^{m}w_j\left[\left|r_j^{k-}-r_{-ij}^{k}\right|^p+\left|r_j^{k-}-r_{ij}^{-k}\right|^p\right]\right\}^{1/p} \tag{17}$$

Step 3b. Aggregate the measures for the group. The group separation measure of each alternative for all decision makers will be aggregated through an operationn $\oplus$. The aggregation operation may use one of many choices, such as arithmetic mean, geometric mean, or their modification. Geometric mean is selected, and the group measures of each alternative will be

$$d_i^{*+}=\left(\prod_{k=1}^{K}d_i^{k+}\right)^{1/k}, \text{for alternative } i \tag{18}$$

$$d_i^{*-}=\left(\prod_{k=1}^{K}d_i^{k-}\right)^{1/k}, \text{for alternative } i \tag{19}$$

Step 4: Calculate the relative closeness, C_i^{*+}, to the positive ideal alternative for the group. The aggregation of relative closeness for the *i-th* alternative with respect to the positive ideal alternative of the group can be expressed as

$$c_i^{*+}=\frac{d_i^{*-}}{d_i^{*+}+d_i^{*-}} \tag{20}$$

where $0\leq C_i^{*+}\leq 1$.

Step 5: Rank the preference order. A set of alternatives can now be preference ranked by the descending order of the value of C_i^{*+}.

METHODOLOGY

This study integrated fuzzy AHP by [10] and Grey TOPSIS by [11] to solve multi-criteria decision making problem particularly for 3PL provider selection. Fuzzy AHP is used to calculate the importance weight of evaluation criteria. For final selection, grey TOPSIS is used to evaluate the alternatives and obtain the overall performance which is measured as closeness coefficient. Fuzzy AHP is integrated with grey TOPSIS by using the procedure shown in Fig. 2.

We emphasize that this problem follows group decision making. Therefore, the aggregation is strictly needed in order to obtain a single value both for sub-criteria weight and alternative performance. The point should be underlined for the aggregation procedure is there is a difference in aggregating between decision matrix of criteria weight and decision matrix of alternative performance. Using fuzzy AHP, decision matrices of criteria weight by *k* decision makers were aggregated early right before normalization. Whereas, decision matrices of alternative performance constructed using grey TOPSIS were aggregated once the distance measure has been calculated. Arithmetic mean is used for aggregating criteria weight and geometric mean is used for aggregating alternative performance.

RESULT AND DISCUSSION

We implemented fuzzy AHP and Grey TOPSIS to evaluate and select 3PL provider for steel pipe company. There are four 3PL providers to be evaluated under the judgment of two decision makers. Evaluation is performed according to twelve sub-criteria which can be categorized into five criteria (see Table 1).

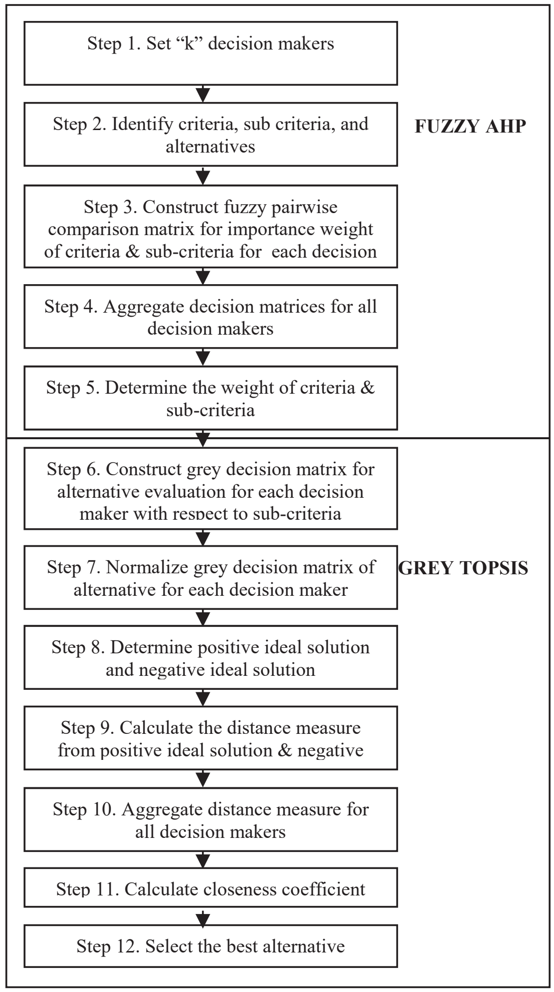

FIGURE 2. Methodology of The Study

TABLE 1. Evaluation Criteria For 3PL Provider

Criteria	Sub-criteria
C1 Financial Performance	SC1 Payment system
	SC2 Financial stability
C2 Service Level	SC3 Flexibility & Responsiveness
	SC4 Reliability
	SC5 Timeliness
C3 Management	SC6 Security & Safety
	SC7 Optimization Capabilities
	SC8 Reputation and experience
C4 Client Relationship	SC9 Long term Relationship
	SC10 Information Sharing
C5 Operational Performance	SC11 IT Capability
	SC12 Size and Quality of fixed asset

The judgment of decision makers for importance weight of criteria and sub criteria are established by using pairwise comparison matrix. We used fuzzy Saaty’s scale in order to express the level of comparison. The transformation of a crisp Saaty's scale into triangular fuzzy number (TFN) is performed in Table 2 [12]. The decision matrix for importance of criteria with respect to triangular fuzzy number is summarized in Table 3. According to consistency ratio (CR), it implied that the decision makers' judgment is assured to fulfill the high consistency.

TABLE 2. Triangular Fuzzy Number For Criteria & Sub Criteria

Saaty's Scale	TFN	Reciprocal TFN
1	1,1,1	1,1,1,
2	1,2,3	1/3,1/2,1
3	1,3,5	1/5,1/3,1
4	2,4,6	1/6,1/4,1/2
5	3,5,7	1/7,1/5,1/3
6	4,6,8	1/8,1/6,1/4
7	5,7,9	1/9,1/7,1/5
8	6,8,9	1/9,1/8,1/6
9	9,9,10	1/10,1/9,1/9

TABLE 3. Triangular Fuzzy Judgment Matrix For Criteria

DM 1*	C1	C2	C3	C4	C5
C1	1,1,1	1/3,1/2,1	2,4,6	3,5,7	1/5,1/3,1
C2	1,2,3	1,1,1	1,3,5	3,5,7	1,1,1
C3	1/6,1/4,1/2	1/5,1/3,1	1,1,1	1,2,3	1/7,1/5,1/3
C4	1/7,1/5,1/3	1/7,1/5,1/3	1/3,1/2,1	1,1,1	1/8,1/6,1/4
C5	1,3,5	1,1,1	3,5,7	4,6,8	1,1,1
DM 2**	**C1**	**C2**	**C3**	**C4**	**C5**
C1	1,1,1	1/5,1/3,1	1/3,1/2,1	1/3,1/2,1	1,1,1
C2	1,3,5	1,1,1	1,3,5	1,1,1	2,4,6
C3	1,2,3	1/5,1/3,1	1,1,1	1/5,1/3,1	1,3,5
C4	1,2,3	1,1,1	1,3,5	1,1,1	4,6,8
C5	1,1,1	1/6,1/4,1/2	1/5,1/3,1	1/8,1/6,1/4	1,1,1

*CONSISTENCY RATIO DM1 (CR) = 0.072, **CR DM 2= 0.069

TABLE 4. Triangular Fuzzy Judgment Matrix For Sub Criteria

DM1*	SC1	SC2	DM 2**	SC1	SC2
SC1	1,1,1	1,2,3	SC1	1,1,1	1/3,1/2,1
SC2	1/3,1/2,1	1,1,1	SC2	1,2,3	1,1,1
*CR = 0.000			**CR= 0.000		

DM 1*	SC3	SC4	SC5	DM 2**	SC3	SC4	SC5
SC3	1,1,1	1,3,5	3,5,7	SC3	1,1,1	1,1,1	1/3,1/2,1
SC4	1/5,1/3,1	1,1,1	1,2,3	SC4	1,1,1	1,1,1	1/9,1/9,1/10
SC5	1/7,1/5,1/3	1/3,1/2,1	1,1,1	SC5	1,2,3	9,9,10	1,1,1
*CR = 0.006				**CR= 0.043			

DM 1*	SC6	SC7	SC8	DM 2**	SC6	SC7	SC8
SC6	1,1,1	1,3,5	3,5,7	SC6	1,1,1	2,4,6	1,1,1
SC7	1/5,1/3,1	1,1,1	1,2,3	SC7	1/6,1/4,1/2	1,1,1	1/5,1/3,1
SC8	1/7,1/5,1/3	1/3,1/2,1	1,1,1	SC8	1,1,1	1,3,5	1,1,1
*CR = 0.006				**CR= 0.011			

DM 1*	SC9	SC10	DM 2**	SC9	SC10
SC9	1,1,1	1,2,3	SC9	1,1,1	1,1,1
SC10	1/3,1/2,1	1,1,1	SC10	1,1,1	1,1,1
*CR = 0.000			**CR= 0.000		

DM 1*	SC11	SC12	DM 2**	SC11	SC12
SC11	1,1,1	1,3,5	SC11	1,1,1	1/3,1/2,1
SC12	1/5,1/3,1	1,1,1	SC12	1,2,3	1,1,1
*CR = 0.000			**CR= 0.000		

Using the fuzzy AHP proposed by [10], we obtained the global weight of sub-criteria. Table 5 shows criteria and sub criteria weight and its ranking.

TABLE 5. Sub Criteria Weight and Ranking

Criteria	Weight	Sub- criteria	Weight	Rank
C1	0.035	SC1	0.017	6
		SC2	0.017	6
C2	0.480	SC3	0.207	2
		SC4	0.066	4
		SC5	0.207	2
C3	0.021	SC6	0.012	7
		SC7	0.004	10
		SC8	0.006	9
C4	0.030	SC9	0.020	5
		SC10	0.009	8
C5	0.434	SC11	0.235	1
		SC12	0.200	3

Then, four 3PL providers are evaluated under those sub-criteria. The evaluation of alternatives is able to incorporate the transition of known-unknown information which most likely can't be declared into a precise form. Therefore, that is going to be unconfident judgment. Using grey number for evaluation is meaningful since it used interval value. Grey TOPSIS was used to relaxing the decision maker's judgment without lack of determination. The linguistic variable for alternative evaluation using Grey TOPSIS is shown in Table 6 [12]. Two decision makers evaluated four 3PL providers for each sub-criteria which are summarized in Table 7.

Because twelve sub-criteria are the larger-the-better type, the alternative evaluation of each decision maker is normalized using (8). In order to measure the overall performance of the alternative, we should ensure the relative distance how close to the best value and how far from the worst value for each sub criteria. The distance measure of alternative with respect to positive ideal solution (d_i^{k+}) and negative ideal solution (d_i^{k-}) are calculated using (12) and (13) with p = 2. The result can be shown in Table 8.

TABLE 6. Linguistic Variable and Corresponding Grey Number

Linguistic Variable	Grey Number	Linguistic Variable	Grey Number
Very Poor (VP)	0-1	Medium Good (MG)	5-6
Poor (P)	1-3	Good (G)	6-9
Medium Poor (MP)	3-4	Very Good (VG)	9-10
Medium (M)	4-5		

TABLE 7. Alternative Evaluation From Two Decision Makers

Sub-criteria	Provider A DM1/DM2	Provider B DM1/DM2	Provider C DM1/DM2	Provider D DM1/DM2
SC1	MG/G	G/G	MG/MG	M/MG
SC2	G/MG	G/G	MG/G	MG/MG
SC3	G/MG	VG/VG	MG/MG	VG/VG
SC4	G/MG	G/G	G/M	G/G
SC5	MG/MG	MG/G	G/M	G/G
SC6	G/MG	MG/MG	M/G	MG/G
SC7	G/MG	G/MG	MG/MG	G/G
SC8	MG/MG	G/G	MG/G	MG/MG
SC9	G/G	VG/VG	MG/MG	MG/M
SC10	MG/MG	G/G	M/M	MG/M
SC11	MG/MG	MG/VG	MG/MG	G/VG
SC12	VG/MG	VG/G	MG/M	MG/G

This problem is a group decision making where there are two decision makers. Thus, we must aggregate the distance measure to obtain single value. Aggregate the evaluation of each d_i^{k+} and d_i^{k-} for k = 1,2 to calculate d_i^{*+} and d_i^{*-} using (14) and (15), respectively, e.g.,

$$d_A^{*+} = (0.599 \text{x} 0.789)^{1/2} = 0.688$$

$$d_A^{*-} = (0.882 \text{x} 0.660)^{1/2} = 0.763$$

TABLE 8. Individual and Aggregation of Distance Measure

Alternatives *i*	DM 1		DM 2		AGGREGATION	
	d_i^{1+}	d_i^{1-}	d_i^{2+}	d_i^{2-}	d_i^{*+}	d_i^{*-}
Provider A	0.599	0.882	0.789	0.660	0.688	0.763
Provider B	0.469	1.052	0.394	1.141	0.430	1.096
Provider C	0.902	0.482	0.856	0.677	0.879	0.571
Provider D	0.738	0.758	0.755	0.834	0.747	0.795

Finally according to aggregated distance measure of d_i^{*+} and d_i^{*-}, we have a relative closeness for each alternative (C_i^+) obtained from the calculation in the following. The relative closeness indicates the closeness from the ideal positive solution. The larger the index value, the better evaluation of alternatives will be with respect to whole sub-criteria.

$$C_A^{*+} = \frac{d_A^{*-}}{d_A^{*+} + d_A^{*-}} = \frac{0.763}{0.688 + 0.763} = 0.526$$

$$C_B^{*+} = \frac{d_B^{*-}}{d_B^{*+} + d_B^{*-}} = \frac{1.096}{0.43 + 1.096} = 0.718$$

$$C_C^{*+} = \frac{d_C^{*-}}{d_C^{*+} + d_C^{*-}} = \frac{0.571}{0.879 + 0.571} = 0.394$$

$$C_D^{*+} = \frac{d_D^{*-}}{d_D^{*+} + d_D^{*-}} = \frac{0.795}{0.747 + 0.795} = 0.516$$

According to the closeness coefficient (C_i^+), it is evident that the most compromised solution is alternative B which means Provider B is selected as the best alternative. The rank order of alternative based on the closeness coefficient for more detail is summarized in Table 9.

TABLE 9. Relative Closeness of Each Alternatives and Alternative Ranking

Ranking	Alternative 3PL Provider	C_i^+
1	Provider B	0.718
2	Provider A	0.526
3	Provider D	0.516
4	Provider C	0.394

CONCLUSION

The decision making problem in accordance with 3PL provider selection can be tackled sophisticatedly by using integration of Fuzzy AHP and Grey TOPSIS. This approach can enhance the unconfident judgment caused by vague and grey information. The triangular fuzzy number represents the vagueness in determination of criteria importance weight. Further, grey number, utilized in TOPSIS, is employed to alternative evaluation when grey information detracts the confidence level of judgmental opinion.

A case study in terms of 3PL provider evaluation is a crucial problem since that activity involving inbound and outbound process can be a direct impact to the long terms existence of the factory. Therefore, 3PL provider should be evaluated thoroughly in order to support the continuity of business process particularly to manage the flow of raw material and product to customer. Evaluation criteria have been identified that are financial performance, service level, management, client relationship and operational performance. Those criteria have been compiled more detail representing sub-criteria. Finally 3PL providers were evaluated under 12 sub-criteria. Considering more criteria in evaluating 3PL providers will be confusing if the inappropriate approach is used. The decision might cause the solution to be inappropriate. This can be overcame by applying a sophisticated decision making approach. Using Fuzzy AHP and Grey TOPSIS offers the most appropriate decision for 3PL provider. The result shows that selected 3PL which is the most compromising alternative can satisfy overall criteria evaluation.

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