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A Fuzzy TOPSIS Model to Rank Automotive Suppliers

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Abstract

This paper highlights the most significant criteria and sub-criteria in automotive industries for selecting the best supplier from the previous paper. Supplier selection process is one of the key activities of management in a supply chain environment. This paper presents another methodology to select the most suitable supplier in a supply chain system using Fuzzy Technique for Order Performance by Similarity to Ideal Solution (FTOPSIS). Triangular Fuzzy set is applied into the proposed model to handle the vagueness. The interdependencies between criteria are considered. In our FTOPSIS model, the results show that FTOPSIS is remarkably successful in determining the best supplier with stability in the ranking as it relates to the different criteria weights and multiple sub-criteria. The proposed methodology presents a comprehensive multi-criteria approach to find the best ranking among the alternative suppliers. The result shows that supplier A is the best supplier with the Closeness Coefficient of 0.5407. The FTOPSIS model proposed can be apply on other vague multiple criteria decision making problem since it shows good result in the research. Future research may expand the work to another field of study or in a different type of industry.

1. Introduction

Successful organization is the one that enjoys competitive advantage in new environments and can adapt itself. Therefore, agility is to be accountable to clients and monitor the market turbulences [1]. An agile supply chain is able to appropriately respond to the environment and in a situation that market demand for products is fluctuating and changing, agility will improve responsiveness in supply chain by increasing the speed and flexibility in diversity of products, and because the product diversity is vast, its proper utilization will bring high marginal profit. Thus, the agility in supply chain is highly important.

This study focuses on agile supply chain. It aims for promoting and improving supply chain management and identifying supply agility evaluation model. The study finds how the agility of supply chain is in automotive industries and what its weaknesses and strengths are.

Keywords: Fuzzy, Technique for Order Performance by Similarity to Ideal Solution, Supply Chain Management, Automotive Industry, MCDM

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2. Literature review

Agile production concept is well-accepted by manufacturers that are preparing for a considerable jump as a successful strategy [2]. Christopher [3] defines the agility concept as an organization's ability in quickly response to the changes in demand, both in volume and variety. Nejad [4] define agility in supply chain as "the ability of a supply chain to react rapidly to customers' needs and any change in market". Hoek [1] stated that agility is "the effective combination of supply chain that is a close and long term association between consumers and suppliers.

In order to achieve competitive advantage in business environment, besides internal organization, suppliers must align with their customers and demand suppliers to increase their operations efficiency and collaborate with each other to attain an acceptable level of agility [5]. In the literatures on supply chain agility, one aspect of agility has been chosen and developed, e.g. Bal [6] emphasized only on virtual groups to create agility.

Swafford [7] emphasized on the inventory and capacity. Halwog and Tolone [8, 9] stressed the sensitive and responsive role to the current trends in the market and emphasized the flexibility. Power [10] identified the key success factors in an agile supply chain for instance: more customer focused, involvement of suppliers, and using technology to improve productivity [11]. Ambe [12] argued that agile supply chain would be the best supply chain strategy to meet the customer's expectations when demand is unknown.

Another study dealt with the gap of ambiguity surrounding the aspects and definitions of agility to gain an in-depth understanding of agility by revewing multi-disciplinary litrature. The results indicate that supply chain nimbleness of a company consists of five separate dimensions, that is, alertness, accessibility, decisiveness, swiftness, and flexibility [13]. Haoran [14] identified that there is no fuzzy quantitative method was proposed for distributor selection. triangular Fuzzy was used to deal with the vagueness of the selection problem and fuzzy TOPSIS to select the best distributor. Roghanian [15] applied FTOPSIS to improve the supply chain process in the food industries, and the result signify that the method is suitable to select the appropriate suppliers.

Butia and Phipon [16] tried to select the best supplier using both AHP and TOPSIS method. They used AHP to weight the criteria and TOPSIS to rank the supplier. The methodology is simple to understand and give good result in identifying the best supplier. Wang [17] combine Grey Correlation Degree with TOPSIS to select the right supplier, and the method suggested avoided errors caused by subjective factors and the method is effective when only single method is applied.

3. Methodology

To overcome the effects of uncertainty and variation in the expert's preference, a fuzzy set theory is integrated with the TOPSIS method. The qualitative aspects of the decisions are represented by means of linguistic variables, which can be expressed qualitatively by linguistic terms and quantitatively by a fuzzy set in the universe of discourse and respective membership function [20]. Using the five liguistic scales Chen [18], 5 responses from each of the factory were consisdered. The criteria and sub-criteria are taken from previous study [19].

The concepts and operations between the linguistic variables are presented as follows.

A fuzzy set $\tilde{A}$ in X is defined in Eq. (1).

$$\tilde{A} = \{x, \mu_A(x)\}, x \in X \tag{1}$$

Where, $\mu_A(x): X \rightarrow [0, 1]$ is the membership function of $\tilde{A}$ and is the degree of pertinence of x in $\tilde{A}$. If $\mu_A(x) = 0$, x does not belong to the fuzzy set $\tilde{A}$. If $\mu_A(x) = 1$, x completely belongs to the fuzzy set $\tilde{A}$. However, unlike the classical set theory, if $\mu_A(x)$ has a value between zero and 1, x partially belongs to the fuzzy set $\tilde{A}$. That is, the pertinence of x is true with degree of membership given by $\mu_A(x)$ [20, 21]. The triangular fuzzy number is commonly used in decision making due to its intuitive membership function [22, 23] given by Eq. (2).

$$\mu_A(x) = \begin{cases} 0 & \text{for } x < l, \\ \frac{x-1}{m-1} & \text{for } l \le x \le m, \\ \frac{u-x}{x-m} & \text{for } m \le x \le u, \\ 1 & \text{for } x > u, \end{cases} \tag{2}$$

where l, m and u = real numbers and $l < m < u$. Outside the interval $[l, u]$, the pertinence degree is null, and m represents the point in which the pertinence degree is maximum.

Fuzzy TOPSIS method was proposed by Chen [18] to solve multi-criteria decision making problems under uncertainty. Linguistic variables are used by the decision makers, D_r ($r = 1, \ldots, k$), to assess the weights of the criteria and the ratings of the alternatives. Thus, w_r describes the weight of the jthcriterion j ($j = 1, \ldots, m$), given by the rth decision maker. Similarly,x^r describes the rating of the ith alternative, A_i ($i = 1, \ldots, n$), with respect to criterion j, given by the rth decision maker. Given that, the method comprises the following steps:

(i) Aggregate the weights of criteria and ratings of alternatives given by k decision makers, as expressed in Eqs. (3) and (4) respectively.

$$= \frac{1}{k} \left({}^{1}_{1} + {}^{2}_{2} + \cdots + {}^{k}_{k} \right) \quad (3)$$

$$x = \frac{1}{k}\left(x + x + \cdots + x \right) \quad (4)$$

(ii) Assemble the fuzzy decision matrix of the alternatives (Đ) and the criteria (w), according to Eqs. (5) and (6).

$$\text{Đ} = \begin{array}{c|cccc} & C_1 & C_2 & \ldots & C_m \\ A1 & X11 & X12 & \cdots & X1m \\ Ai & \vdots & \vdots & \vdots & \vdots \\ An & Xn1 & Xn2 & Xnj & Xnm \end{array} \quad (5)$$

$$w = {}_1 + {}_2 + \cdots {}_m \quad (6)$$

(iii) Normalize (Đ) using linear scale transformation. The normalized fuzzy decision matrix (R) is given by:

$$R = {}_{m \times n} \quad (7)$$

$$= \frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+} \text{ and } u^+ = \max_i u \text{ (benefit criteria)} \quad (8)$$

$$\frac{l}{ij}, \frac{l}{ij}, \frac{l}{ij}$$

(iv) Compute the weighted normalized decision matrix (V) by multiplying the weights of the evaluation criteria ( ) by the elements ( ) of the normalized fuzzy decision matrix.

$$V = {}_{m \times n} \quad (10)$$

where $=\ \times$

(v) Define the Fuzzy Positive Ideal Solution (FPIS, A^+) and the Fuzzy Negative Ideal Solution (FNIS, A^-), according to Eqs. (21) and (22).

$$A^+ = {}^+_1, {}^+, \cdots, {}^+_m \quad (11)$$

$$A^- = {}_1, \ , \cdots, {}_m \quad (12)$$

where $^+ = (1,1,1)$ and $^- = (0,0,0)$

(vi) Compute the distances d^+ and d^- of each alternative from respectively $^+$ and $^-$ according to Eqs. (13) and (14).

$$d^{+} = \sum_{1}^{n} d(\ ,\ ^{+}) \quad (13)$$

$$d^{-} = \sum_{1}^{n} d(\ ,\ ^{-}) \quad (14)$$

where *d* (x,z) represents the distance between two fuzzy numbers according to the vertex method.
For triangular fuzzy numbers, this is expressed in Eq. (15).

$$d(x,z) = \sqrt{\frac{1}{3}\left[(l_x - l_z)^2 + (m_x - m_z)^2 + (u_x - u_z)^2\right]} \quad (15)$$

(vii) Compute the Closeness Coefficient (CC_i) according to Eq. (16).

$$CC = \frac{d_i}{d_i^{+} + d_i} \quad (16)$$

(viii) Define the ranking of the alternatives according to *CCi* in decreasing order. The best alternative is closest to the FPIS and farthest to the FNIS.

4. Results of the TOPSIS analysis

The linguistic terms used in this study is shown in Table 1.

Table 1. Linguistic scale to evaluate the weights and alternatives.

Fuzzy Number	Alternatives	Weight
(1, 1, 3)	Very Poor (VP)	Very Low (VL)
(1, 3, 5)	Poor (P)	Low (L)
(3, 5, 7)	Fair (F)	Medium (M)
(5, 7, 9)	Good (G)	High (H)
(7, 9, 9)	Very Good (VG)	Very Hight (VH)

The decision matrix of the alternatives and the aggregated weights of the criteria by the five respondents are given in Table 2.

Table 2. Criteria weightage by five experts

Decision maker (D)	C1	C2	C3	C4	C5
D1	H(5, 7, 9)	H(5, 7, 9)	VH(7, 9, 9)	H(5, 7, 9)	M(3, 5, 7)
D2	H(5, 7, 9)	VH(7, 9, 9)	VH(7, 9, 9)	H(5, 7, 9)	H(5, 7, 9)
D3	M(3, 5, 7)	M(3, 5, 7)	M(3, 5, 7)	M(3, 5, 7)	M(3, 5, 7)
D4	M(3, 5, 7)	H(5, 7, 9)	M(3, 5, 7)	M(3, 5, 7)	VH(7, 9, 9)
D5	H(5, 7, 9)	H(5, 7, 9)	H(5, 7, 9)	H(5, 7, 9)	H(5, 7, 9)

The normalized fuzzy decision matrix of the alternatives using the linear transformation scale is given by Table 3.

Table 3. Normalized fuzzy decision matrix for supplier selection

Criteria (C) Suppliers (A, B, C, D)	C1	C2	C3	C4	C5
A	(0.3 , 0.6, 0.8)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.1, 0.3, 0.6)
B	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)
C	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.3 , 0.6, 0.8)	(0.8, 1, 1)	(0.6, 0.8, 1)
D	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)

The weighted normalized decision matrix is shown in Table 4.

Table 4. Weighted normalized fuzzy decision matrix

Criteria (C) Factories	C1	C2	C3	C4	C5
A	(2.7 , 5.4 , 7.2)	(5.4, 7.2, 9)	(5.4, 7.2, 9)	(5.4, 7.2, 9)	(0.9, 2.7, 5.4)
B	(5.4, 7.2, 9)	(7.2, 9, 9)	(5.4, 7.2, 9)	(5.4, 7.2, 9)	(5.4, 7.2, 9)
C	(7.2, 9, 9)	(5.4, 7.2, 9)	(2.7 , 5.4 , 7.2)	(7.2, 9, 9)	(5.4, 7.2, 9)
D	(5.4, 7.2, 9)	(5.4, 7.2, 9)	(5.4, 7.2, 9)	(7.2, 9, 9)	(5.4, 7.2, 9)

Table 5 shows FPIS (A^+) and Table 6 presents FNIS (A^-).

Table 5. The computed d^+

–	C1	C2	C3	C4	C5	d^+
$d(A,A^+)$	4.50	6.37	6.37	6.37	2.72	26.33
$d(B,A^+)$	6.37	7.45	6.37	6.37	6.37	32.93
$d(C,A^+)$	7.45	6.37	4.50	7.45	6.37	32.14
$d(D,A^+)$	6.37	6.37	6.37	7.45	6.37	32.93

Table 6. The computed d^-

–	C1	C2	C3	C4	C5	d^-
$d(A,A^-)$	5.43	7.35	7.35	7.35	3.52	31
$d(B,A^-)$	7.35	8.44	7.35	7.35	7.35	37.84
$d(C,A^-)$	8.44	7.35	5.43	8.44	7.35	37.01
$d(D,A^-)$	7.35	7.35	7.35	8.44	7.35	37.84

Table 7 shows CC of each supplier.

Table 7. Closeness coefficient of supplier

Supplier	CC_i	Rank	Supplier	CC_i	Rank
A	0.5407	1st	C	0.5352	2nd
B	0.5347	3rd	D	0.5347	3rd

5. Conclusion

The best supplier in automotive industries using FTOPSIS methods has been discussed. Responsibility, flexibility, competency, economical optimization and speed were identified as the main criteria and 18 sub-criteria were considered based on four suppliers: A, B, C and D factories. The result from the FTOPSIS analysis shows that Factory A possesses the best supplier in automotive industry, while Factory D is the worst supplier. From the FTOPSIS result it can be concluded that the suppliers need to implement more effective strategies for finding the bottlenecks where there exists malfunction and respond to the rapid changes in the supply chain, in line with business process reengineering. They also can entice their employees to be creative and introduce new ideas and also allure weaker companies in their supply chain to emulate more agile and stronger companies.

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