International Journal of Management and International Business Studies.
ISSN 2277-3177 Volume 4, Number 2 (2014), pp. 159-168

http://www.ripublication.com

A Decision Support System towards Suppliers' Selection in Resilient Supply Chain: Exploration of Fuzzy-TOPSIS

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Abstract

The resilient supplier selection is a complex multi-criteria decision-making problem involving both quantitative and qualitative factors which may be in conflict and may also be uncertain. In this context, a fuzzy based Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method has been proposed to deal with inaccurate, incomplete and imperfect information of expert judgment. A closeness coefficient has been defined to determine appropriate ranking order of alternative suppliers by calculating the distances to both fuzzy positive ideal solution and fuzzy negative ideal solution. A case empirical study has also been provided.

Keywords: Resilient Supplier Selection, Fuzzy Logic, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

1. Introduction: Resilient Supply Chain

From the organizational perspective resilience has been defined in terms of adjustment to capacities or abilities. Definitions that are relevant to this research include [1]:

The capacity to adjust and maintain desirable functions under challenging or straining conditions [2]. It is a dynamic capacity of organizational adaptability that grows and develops overtime and the ability to bounce back from disruptive events or hardship [3, 4]. The ability to recover from disruptive events was also examined by [5]. The authors stated that resilient organizations are proactive and recover better from hardship. However, resilience is more than just recovery; it also implies a certain level of flexibility and ability to adapt to both positive and negative influences of the environment. To summarize, the organizational perspective emphasizes important aspects of resilience such as adapt. A resilient supply chain must be adaptable, as the desired state in many cases is different from the original one. It is stated that resilient processes are flexible and agile and are able to change quickly and the dynamic nature of this adaptive capability allows the supply chain to recover after being disrupted, returning to its original state or achieving a more desirable state of supply chain operations, ability, flexibility, maintenance, and recovery [6].

2. State of Art

In this section, literature survey has been conveyed pertaining to resilient supplier evaluation:

Toni and Tonchia [7] proposed the main objective of supply chain performance measurement is to remain competitive in today's world class market using its values and perceptions. Boer *et al.* [8] proposed the fuzzy set theory as a way for improving the supplier selection process and in addition, to find the supplier with the best overall performance rating among suppliers. Erol *et al.* [9] highlighted the advantages of fuzzy set theory in supplier selection issues. Kumar *et al.* [10] applied a fuzzy goal programming approach for solving the supplier selection problem in supply chain providing a decision method for handling the vagueness and imprecision objectives. Ding and Liang [11] addressed for selecting a suitable partner for strategic alliance applied fuzzy set theory to solving a complex and multi-criteria problem in an MCDM environment. Yang *et al.* [12] explored fuzzy-AHP and employed the ISM method to clarify the interrelationships of intertwined sub-criteria in the complex structural hierarchy in a supplier selection problem. Faeza *et al.* [13] applied an integrated model based on the case-based reasoning method in a fuzzy environment and mathematical programming for a single item supplier selection issue.

According to [14], resilience capability facilitates a supply chain returning to its original state following disruptions; and more specifically, preparing for unexpected events, responding to disruptions, and recovering from them to continue its operation [15]. Pettit *et al.* [16] provided a comprehensive analysis of the need for managers to examine the concept of resiliency in their supply chains. Resiliency refers to a firm’s capacity to survive, adapt and grow in the face of change and uncertainty [17]. It is the capacity of a system to survive, adapt, and grow in the face of change and uncertainty [18] and the ability of the supply chain to return to its former state (before disruption) or to move toward a new state that is more desirable [19]. Regarding resilience, we can refer to conceptual studies that mainly consist of a review of the literature and definitions [13, 20] or guidelines that are based on interesting instances [21]. Provided a framework for supply chain resilience based on vulnerabilities and capabilities [22].

In this work, the assessment of resilient suppler selection has been found fruitful through TOPSIS method, it is known as a classical multiple criteria decision-making (MCDM) method, has been developed by [23] for solving the MCDM problems. The basic principle of the TOPSIS is that the chosen alternative should have the "closer distance "from the positive ideal solution and the "farthest distance "from the negative ideal solution. The TOPSIS introduces two "reference" points, but it does not consider the relative importance of the distances from these points.

Here, we first convert the decision matrix into a fuzzy decision matrix and construct a weighted fuzzy decision matrix once the decision makers' fuzzy ratings have been pooled. The new process of normalization by use of fuzzy distance value and normal fuzzy deviation approach are applied for normalization and detection of the crisp value. According to the concept of TOPSIS, we define the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS). Finally, a closeness coefficient is applied to calculate the ranking order of all alternatives. The higher value of the closeness coefficient indicates that an alternative is closer to FPIS and farther from FNIS, simultaneously.

3. Empirical Research

An automobile part manufacturing company desires to select a suitable material supplier to purchase the key components of new products. After preliminary screening, four alternatives (A_1, A_2, A_3 and A_4) remain for further evaluation. A committee of five decision-makers, D_1, D_2, D_3, D_4 and D_5 has been formed to select the most suitable resilient supplier. Seven benefit criteria are considered:

- Strategic stock , C_1
- Lead time reduction , C_2
- Flexible transportation , C_3
- Optimal use of assets, C_4
- Multiple sourcing , C_5
- Demand aggregation , C_6
- Team work , C_7

The proposed (MCDM-TOPSIS) method is currently applied to solve this problem, the computational procedure of which is summarized as follows:

Step 1: For evaluating priority weight of evaluation indices, a committee of five decision-makers (DMs), has been formed to express their subjective preferences in linguistic terms. In order to provide priority weight against various criteria; the decision-making group has been instructed to use the following linguistic terms: Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH). The five-member linguistic terms and their corresponding fuzzy numbers are shown in Table 1.

Table 1: Five-member linguistic terms and their corresponding fuzzy numbers.

Linguistic terms for weight assignment	**Linguistic terms for ratings**	**Fuzzy numbers**
Very low, VL	Very poor, VP	(0.00, 0.00, 0.25)
Low, L	Poor, P	(0.00, 0.25, 0.50)
Medium, M	Medium, M	(0.25, 0.50, 0.75)
High, H	Satisfactory, S	(0.50, 0.75, 1.00)
Very High, VH	Extremely Satisfactory, ES	(0.75, 1.00, 1.00)

Step 2: Similarly, the decision-making group has also been instructed to use the linguistic scale to express their subjective judgment against performance rating of each evaluation indices of alternatives. The following linguistic scale has been utilized to assign performance appropriateness rating against indices: Very Poor (VP), Poor (P), Medium, (M), Satisfactory (S) and Extremely Satisfactory (ES). The five-member linguistic terms and their corresponding fuzzy numbers are shown in Table 1.

Step 3: After the linguistic variables for assessing the performance ratings and priority weight of different evaluation indices has been accepted by the decision-makers (DMs), the decision-makers have been asked to use aforesaid linguistic scales Table 1 to assess performance rating against each of the alternatives criteria shown in Tables 3-6. Similarly, subjective priority weight evaluation index has been assessed by the DMs and that sown in Table 2.

Table 2: Fuzzy priority weight (in linguistic scale) of indices assigned by DMs.

Performance metrics	Priority weights in linguistic term				
	DM_1	DM_2	DM_3	DM_4	DM_5
C_1	VH	VH	H	H	H
C_2	H	H	H	H	VH
C_3	H	VH	H	VH	H
C_4	VH	VH	VH	VH	VH
C_5	H	M	H	H	H
C_6	VH	VH	H	H	H
C_7	H	H	H	H	VH

Step 4: Then the linguistic values shown in (Table 1) converted into triangular fuzzy numbers to construct the fuzzy decision matrix and determined the fuzzy weight of each criterion as well as its crisps values. In same way we determined the fuzzy rating of each criterion (Tables 3-6) of all alternatives and the appropriateness rating of alternatives as well as its crisps values and constructed a fuzzy multi-criteria group decision making (FMCGDM) matrix; depicted in Table 7.

Table 3: Appropriateness rating (in linguistic scale) of indices assigned by DMs **(Alternative 1)**

Performance metrics	**Ratings in linguistic term (A_1)**				
	DM_1	**DM_2**	**DM_3**	**DM_4**	**DM_5**
C_1	M	S	S	M	M
C_2	S	S	M	M	ES
C_3	S	M	M	M	M
C_4	M	S	S	S	ES
C_5	S	M	M	ES	ES
C_6	M	S	S	M	M
C_7	S	S	M	M	ES

Table 4: Appropriateness rating (in linguistic scale) of indices assigned by DMs **(Alternative 2).**

Performance metrics	**Ratings in linguistic term (A_2)**				
	DM_1	**DM_2**	**DM_3**	**DM_4**	**DM_5**
C_1	M	M	S	M	M
C_2	M	M	S	S	ES
C_3	S	S	S	ES	ES
C_4	S	M	M	M	S
C_5	S	S	ES	ES	ES
C_6	M	M	S	M	M
C_7	M	M	S	S	ES

Table 5: Appropriateness rating (in linguistic scale) of indices assigned by DMs **(Alternative 3).**

Performance metrics	**Ratings in linguistic term(A_3)**				
	DM_1	**DM_2**	**DM_3**	**DM_4**	**DM_5**
C_1	M	S	S	S	S
C_2	S	S	M	ES	ES
C_3	S	S	S	ES	ES
C_4	S	ES	ES	ES	S
C_5	ES	ES	ES	ES	S
C_6	M	S	S	S	S
C_7	S	S	M	ES	ES

Table 6: Appropriateness rating (in linguistic scale) of indices assigned by DMs **(Alternative 4)**

Performance metrics	**Ratings in linguistic term (A_4)**				
	DM_1	**DM_2**	**DM_3**	**DM_4**	**DM_5**
C_1	S	S	M	M	M

C_2	S	S	M	P	P
C_3	M	M	M	P	M
C_4	S	M	M	M	M
C_5	S	S	M	M	P
C_6	S	S	M	M	M
C_7	S	S	M	P	P

Table 7: A fuzzy multi-criteria group decision making (FMCGDM) matrix.

Alternatives	**Criteria**						
	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$
A_1	0.233	0.270	0.220	0.290	0.287	0.233	0.27
A_2	0.214	0.270	0.326	0.233	0.344	0.214	0.27
A_3	0.428	0.497	0.534	0.568	0.603	0.428	0.497
A_4	0.233	0.194	0.175	0.214	0.214	0.233	0.194

Step 5: The normalized fuzzy decision matrix is constructed as in Table 8.

Table 8: Normalized decision matrix.

Alternatives	**Criteria**						
	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$
A1	0.401	0.412	0.321	0.407	0.367	0.401	0.412
A2	0.368	0.412	0.475	0.327	0.440	0.368	0.412
A3	0.737	0.758	0.778	0.798	0.772	0.737	0.758
A4	0.401	0.296	0.255	0.301	0.274	0.401	0.296

Step 6: Weighted normalized fuzzy decision matrix is constructed as in Table 11.

Step 7: Determine FPIS (V_1*^+) and FNIS (V_2*^-) as

V_1*^+ = (0.172, 0.147, 0.136, 0.171, 0.165, 0.172, 0.147) and

V_2*^- = (0.086, 0.056, 0.045, 0.064, 0.059, 0.086, 0.057)

Step 8: Calculate the positive distance ($D*^+$) and negative distance (Distance $D*^-$) of four possible suppliers as

$D*^+$ = (0.205, 0.205, 0.001, 0.244)

$D*^-$ = (0.047, 0.061, 0.249, 0.011)

Step 9: Calculate the closeness coefficient (C*) of each supplier as

$C*_1$ = 0.186 $C*_3$ = 0.997

$C*_2$ = 0.231 $C*_4$ = 0.041

Step 10: According to the closeness coefficients, the ranking order of four suppliers is $\mathbf{A_3 > A_2 > A_1 > A_4}$. Here, the results of ranking order are identical when the different membership functions of linguistic variables are used in the proposed method. Therefore, it can confirm that this proposed method is very effective to deal with the problem of supplier selection. The ranking of alternatives correspond to closeness coefficients are shown in Table 10.

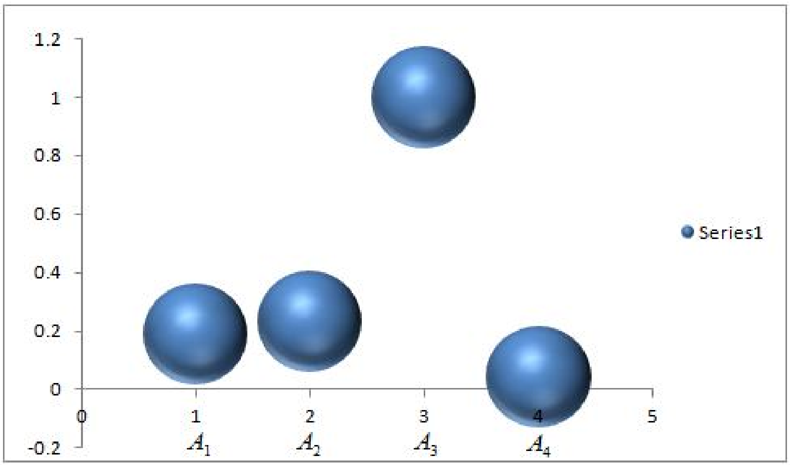

Fig. 1: Bubble chart analysis pointed out the raking order of preferred alternatives derived in descending order.

The fuzzy TOPSIS method is very flexible. According to the closeness coefficient(C*), we can determine not only the ranking order but also the assessment status of all possible suppliers. Significantly, the proposed method provides more objective information for supplier selection and evaluation in supply chain system. Here we finalized the alternative A_3 is best alternative supplier.

Table 9: Weighted normalized decision matrix.

Alternatives	**Criteria**						
	C_1	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**
A_1	0.093	0.080	0.056	0.087	0.079	0.093	0.080
A_2	0.086	0.080	0.083	0.070	0.094	0.086	0.080
A_3	0.172	0.147	0.136	0.171	0.165	0.172	0.147
A_4	0.093	0.057	0.045	0.064	0.059	0.093	0.057

Table 10: The related closeness coefficient and ranking.

Alternatives	**Closeness coefficients(C*)**	**Ranking order**
A_1	0.186	3
A_2	0.231	2
A_3	**0.997**	**1**
A_4	0.041	4

4. Conclusion

In this work, different criteria have been integrated to measure the supplier rating. The effectiveness of the methodology has been demonstrated using a case study of automobile parts manufacturing company where the integration of the TOPSIS and supplier selection index is used to rate and choose the best supplier effective in resilient situation.The major advantages of this work have been summarized as follows:

i. Development and implementation of an efficient decision-making tool to support resilient supplier evaluation.
ii. Concept of fuzzy TOPSIS is used to determine the decision weights using multi-dimensional parameters.
iii. The proposed approach is quite straightforward in the consideration of the different supplier selection factors compared to the conventional approaches for the same and supplier performance measurement.
iv. The appraisement index system has been extended with the capability to search ill performing areas which require future progress.

This method is also simple to understand and permits the pursuit of best alternatives criterion depicted in a simple mathematical calculation. Summarized results from case empirical study of automobile parts manufacturing industry determine that this model could be used for decision making optimization in supplier selection.

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