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Reducing the Risk of Transportation Disruption in Supply Chain: Integration of FUZZY-AHP and TOPSIS

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ABSTRACT

This research focuses on estimating and understanding the causes of transportation related supply chain disruptions. In-depth interviews with logistics managers were undertaken to investigate how companies perceive transportation related supply chain disruptions and what they are doing to respond and address them. This paper presents an integrated approach for selecting the best solution to reduce the risk of transportation disruption. In this paper key performance indicator (KPI) are criteria and solutions are alternatives. FUZZY-AHP and TOPSIS are used in the integrated approach. FUZZY-AHP is used to determine the fuzzy weights of criteria because it can effectively determine various criteria's weights in a hierarchical structure. TOPSIS aims to rank solutions with respect to the criteria. We apply the integrated approach in real case to demonstrate the application of the proposed method.

1. Introduction

The vulnerability of supply chains has undoubtedly received more attention since the attacks on the World Trade Centers on September 11, 2001, even though supply chains have always been faced with assessing their vulnerabilities and managing risk. Risks faced by supply chains are quite diverse, arising from sources both within and external to the supply chain including natural disasters, transportation failure, labor dispute, terrorism, war, and political instability. These risks may fall into different terms, such as disruptions, uncertainties, and disturbances. SC disruption, particularly, is defined as an event that interrupts the material flows in the SC, resulting in an abrupt cessation of the movement of goods. In recent years, we have come to see many disruption occurrences that have severely affected SCs. For instance, the 1995 earthquake that hit Kobe left vast damage to all of the transportation links in Kobe, and nearly destroyed the world's sixth-largest shipping port The 7.2 scale Richter quake substantially affected Toyota, where an estimated production of 20,000 cars, equivalent to $200 million worth of revenue, was lost due to parts shortages (Sheffi, 2005).

Unlike disruptions in general, a transportation disruption can occur only as a result of a subset of the drivers identified by Chopra and Sodhi (2004), which include natural disasters, labor disputes, terrorist activities and infrastructure failures, for example. This research see transportation disruption. For comparison, consider supplier-related disruptions that could shut down a plant (supplier bankruptcy) or drastically reduce capacity (the fire at Ericsson). These types of disruptions not only stop the flow of goods, but also the production of goods, whereas a transportation disruption stops only the flow of goods and, in that sense, is probably less severe. The uniqueness of a transportation disruption is its specificity, distinctive in that goods in transit have been stopped, although all other operations of the supply chain are intact. For that reason, a transportation disruption arises when the material flow is interrupted between two echelons in a supply chain, temporarily stopping the transit of these goods, regardless of the source of the disruption.

This study estimating and understanding the causes of transportation related supply chain disruptions. In-depth interviews with logistics managers were undertaken to investigate how companies perceive transportation related supply chain disruptions and what they are doing to respond and address them. This paper presents an integrated approach for selecting the best solution to reduce the risk of transportation disruption. In this paper key performance indicators (KPI) are criteria and solutions are alternatives. FUZZY-AHP and TOPSIS are used in the integrated approach. FUZZY-AHP is used to determine the fuzzy weights of criteria because it can effectively determine various criteria's weights in a hierarchical structure. TOPSIS aims to rank solutions with respect to the criteria. We apply the integrated approach in real case to demonstrate the application of the proposed method.

2. Related Works

The concept of disruption management was firstly introduced by Clausen (2001), and applied successfully in the airline operations. Xiao and Yu (2006) investigated the impacts of supply chain disruptions on the evolution of retailers' behaviors in a certain supply chain, where retailers with bounded rationality addressed quantity completion in a duopoly market with homogeneous goods. Not only have Chopra and Sodhi (2004) categorized nine types of risk in order to develop risk mitigation strategies, but also Kleindorfer and Saad (2005), who have identified two categories of risk: risk from coordinating supply and demand, and risks resulting from disruptions to normal activities. The supply chain management literature has addressed many of these risks, discussed how they are interconnected, and analyzed the supply chain response. This is especially evident for studies that fall in the risk category Kleindorfer and Saad described as coordinating supply and demand. Although these studies may not be labeled as ''risk studies,'' they are certainly concerned with managing risk associated with mismatches between supply and demand throughout the supply chain. Examples include research on inventory and capacity planning, demand uncertainty and forecast accuracy, information distortion, purchasing and procurement strategies, and price variation (Lee and Billington, 1992; Levy, 1995; Lee et al., 1997a,b; Sterman, 1989; Chen et al., 2000; Lee, 2002;Cachon, 2004; Zsidisin and Ellram, 2003). These studies have also suggested several methods for mitigating risks, which include information sharing, electronic data interchange, collaborative planning forecasting and replenishment, lead time reductions, consistent low prices, and vendor managed inventory. Tomlin (2006) examines the optimal strategy for a single product system with two suppliers: one that is unreliable and another that is reliable but expensive. Schmitt, Snyder, and Shen (2010) and Chen, Zhao, and Zhou (2012) extend the work of Tomlin(2006)to study the system with stochastic demand. Furthermore Schmitt and Snyder (in-press) conducted a study on the comparison between single period and multiple period settings for an inventory system subject to yield uncertainty and supply disruption. To do this, they extended the paper by Chopra, Reinhardt, and Mohan (2007) which only considered the single period case. Other variations of supply disruptions in stochastic inventory models are also available in literatures (Arreola-Risa & DeCroix, 1998; Li et al., 2004; Mohebbi, 2003; Moinzadeh & Aggarwal, 1997). Snyder et al. (2012) provides an extensive review of supply chain models with disruption. H. Hishamuddin et al. (2012) provide a recovery model for a two-stage production and inventory system with the possibility of transportation disruption. To overcome all these shortcomings of AHP, FAHP was developed for solving the hierarchical problems. Decision makers usually find that it is more confident to give interval judgments than fixed value judgments (Irfan and Nilsen, 2009). There are many fuzzy AHP methods and applications in the literature proposed by various authors. Van Laarhoven and Pedrcyz (1983) proposed the first studies that applied fuzzy logic principle to AHP. Buckley (1985) initiated trapezoidal fuzzy numbers to express the decision maker's evaluation on alternatives with respect to each criterion while Laarhoven and Pedrycz were using triangular fuzzy numbers. Da (1996) introduced a new approach for handling FAHP, with the use of triangular fuzzy numbers for pair-wise comparison scale of FAHP, and the use of the extent analysis method for the synthetic extent values of the pair-wise comparisons. Triantaphyllou and Lin (1996) presented the development of fuzzy multi-attribute decision making methods. These methods are based on AHP, the weighted sum model, the weighted product model and the TOPSIS method. With regard to the shortcoming of Analytical Hierarchy Process, Fuzzy Analytical Hierarchy Process has been used in this research. The concept of TOPSIS is rational and understandable, and the computation involved is uncomplicated. Moreover, the inherent difficulty of assigning reliable subjective preferences to the criteria is worth noting (Shyur, 2006). In the current study, hence, we utilize a multi-criteria decision-making method to determine the importance weights of evaluation criteria, and TOPSIS method to obtain the performance ratings of the feasible alternatives. Therefore, this approach is employed for four reasons: (i) the logic is rational and comprehensible; (ii) the computation processes are straightforward; (iii) the concept permits the pursuit of best alternatives for each criterion described in a simple mathematical form, and (iv) the importance weights are incorporated into the comparison procedures (Wang and Chang, 2007). In this paper, we apply a new integration of techniques (ANP and TOPSIS) that used previously in other area by Cheng-Shiung et al (2010).

3. Evaluation Methods

3.1. FUZZY-AHP

A good decision-making model needs to tolerate vagueness or ambiguity because fuzziness and vagueness are common characteristics in many decision-making problems (Yu, 2002). Since decision- makers often provide uncertain answers rather than precise values, the transformation of qualitative preferences to point estimates may not be sensible. Conventional AHP that requires the selection of arbitrary values in pairwise comparison may not be sufficient and uncertainty should be considered in some or all pairwise comparison values (Yu, 2002). Since the fuzzy linguistic approach can take the optimism/pessimism rating attitude of decision- makers into account, linguistic values, whose membership functions are usually characterized by triangular fuzzy numbers, are recommended to assess preference ratings instead of conventional numerical equivalence method (Liang & Wang, 1994). As a result, the fuzzy-AHP should be more appropriate and effective than conventional AHP in real practice where an uncertain pairwise comparison environment exists (Lee, Chen, & Chang, 2008). There are many fuzzy-AHP methods proposed by various authors (Buckley, 1985; Chang, 1996; Cheng, 1997; Deng, 1999; Leung & Cao, 2000; Mikhailov, 2004; Van Laarhoven & Pedrycz, 1983). These methods are systematic approaches to the alternative selection and justification problem by using the concepts of fuzzy set theory and hierarchical structure analysis. Decision-makers usually find that it is more confident to give interval judgments than fixed value judgments. This is because usually he/she is unable to explicit about his/her preferences due to the fuzzy nature of the comparison process. In this study, we prefer Chang (1996) extent analysis method because the steps of this approach are easier than the other fuzzy-AHP approaches (Fuzzy sets and AHP are not detailed here because of being well-known applications). The steps of Chang (1996) extent analysis approach are as follows: Let X = $\{x_1, x_2, \ldots, x_n\}$ be an object set, and U = $\{u_1, u_2, \ldots, u_m\}$ be a goal set. According to the method of Chang (1996) extent analysis, each object is taken and extent analysis for each goal, g_i, is performed, respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs (Dag˘deviren, Yuksel, & Kurt, in press):

$$\widetilde{M}_{g_i}^{1}, \widetilde{M}_{g_i}^{2}, \ldots, \widetilde{M}_{g_i}^{m}, \; i=1, 2, \ldots, n$$

Where $\widetilde{M}_{g_i}^{j}$ (j=1,2,3,…, m) are all triangular fuzzy numbers. The membership function of the triangular fuzzy number is denoted by $M_{(x)}$. The steps of the Chang's extent analysis can be summarized as follows:

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

$$S_i = \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}\right]^{-1} \quad (1)$$

Where $\otimes$ denotes the extended multiplication of two fuzzy numbers. In order to obtain $\sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}$

We perform the addition of m extent analysis values for a particular matrix such that,

$$\sum_{j=1}^{m} \widetilde{M}_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad (2)$$

and to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}\right]^{-1}$ we perform the fuzzy addition operation of

$\widetilde{M}_{g_i}^{j}$ (j =1,2,…,m) values such that,

$$\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \quad (3)$$

Then, the inverse of the vector is computed as,

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (4)$$

Where u_i, m_i, $l_i > 0$

Finally, to obtain the S_j in Eq. (1), we perform the following multiplication:

$$S_i = \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}\right]^{-1}$$

$$= \left(\sum_{j=1}^{m} l_j \otimes \sum_{i=1}^{n} l_i, \sum_{j=1}^{m} m_j \otimes \sum_{i=1}^{n} m_i, \sum_{j=1}^{m} u_j \otimes \sum_{i=1}^{n} u_i\right) \quad (5)$$

Step 2: The degree of possibility of $\widetilde{M}_2 = (l_2, m_2, u_2) \geq \widetilde{M}_1 = (l_1, m_1, u_1)$ is defined as

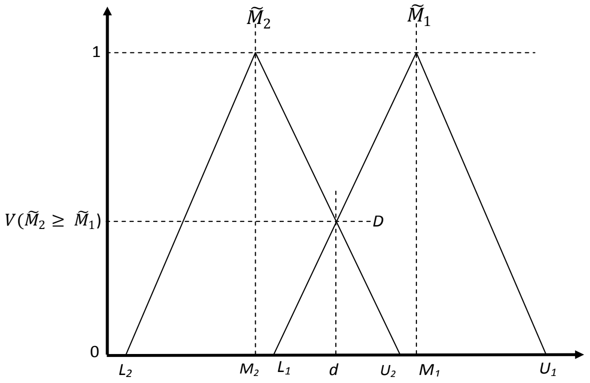


Figure 1. The degree of possibility of $\widetilde{M}_1 \geq \widetilde{M}_2$

$$V(\widetilde{M}_2 \geq \widetilde{M}_1) = sup[\min(\widetilde{M}_1(x), \widetilde{M}_2(y))] \quad (6)$$

This can be equivalently expressed as,

$$V(\widetilde{M}_2 \geq \widetilde{M}_1) = hgt(\widetilde{M}_1 \cap \widetilde{M}_2) = \widetilde{M}_2(d) = \begin{cases} 1 & if m_2 \geq m_1 \\ 0 & if l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \quad (7)$$

Fig. 1 illustrates V ($\widetilde{M}_2 \geq \widetilde{M}_1$) for the case d for the case $M_1 < L_1 < U_2 < M_1$, where d is the abscissa value corresponding to the highest crossover point D between $\widetilde{M}_1$ and $\widetilde{M}_2$,To compare $\widetilde{M}_1$ and $\widetilde{M}_2$, we need both of the values V($\widetilde{M}_1 \geq \widetilde{M}_2$) and V($\widetilde{M}_2 \geq \widetilde{M}_1$).

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

$$V(\widetilde{M} \geq \widetilde{M}_1, \widetilde{M}_2, \ldots, \widetilde{M}_k) = \min V(\widetilde{M} \geq \widetilde{M}_i), \quad I = 1,2,\ldots,k$$

*Step 4:*Finally, W=(min V($s_1 \geq s_k$) min V($s_2 \geq s_k$),….,min V($s_n \geq s_k$))^T, is the weight vector for k = 1,. . .,n

3.2. TOPSIS method

The TOPSIS method is proposed in Chen and Hwang (1992), with reference to Hwang and Yoon (1981). The basic principle is that the chosen alternative should have the shortest distance from the ideal solution that maximizes the benefit and also minimizes the total cost, and the farthest distance from the negative-ideal solution that minimizes the benefit and also maximizes the total cost (Opricovic and Tzeng, 2003).

The TOPSIS method consists of the following steps:

Step 1: Calculate the normalized decision matrix. The normalized value r_{ij} is calculated as

$$r_{ij} = X_{ij} \Big/ \sqrt{\textstyle\sum_{i=1}^{n} X_{ij}^2}, \forall i, j \tag{8}$$

Step 2: Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as

$$v_{ij} = w_j r_{ij}, \forall i,j \tag{9}$$

Where w_j is the weight of the *j*th criterion, and $\sum_{i=1}^{m} w_j = 1$

Step 3: Determine the ideal and negative-ideal solution.

$$A^* = \{v_1^*, \ldots, v_m^*\} = \{(\max_i v_{ij} \mid j \epsilon C_h), (\min_i v_{ij} \mid j \epsilon C_c)\} \tag{10}$$

$$A^- = \{v_1^-, \ldots, v_m^-\} = \{(\min_i v_{ij} \mid j \epsilon C_h), (\max_i v_{ij} \mid j \epsilon C_c)\} \tag{11}$$

where C_b is associated with benefit criteria and C_c is associated with cost criteria.

Step 4: Calculate the separation measures, using the m-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as

$$S_i^* = \sqrt{\textstyle\sum_{j=1}^{m} \left(v_{ij} - v_j^*\right)^2}, \forall i \tag{12}$$

Similarity, the separation from the negative-ideal solution is given as

$$S_i^- = \sqrt{\textstyle\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2}, \forall i \tag{13}$$

Step 5: Calculate the relative closeness to the ideal solution. The relative closeness of the alternative A_i with respect to A^* is defined as

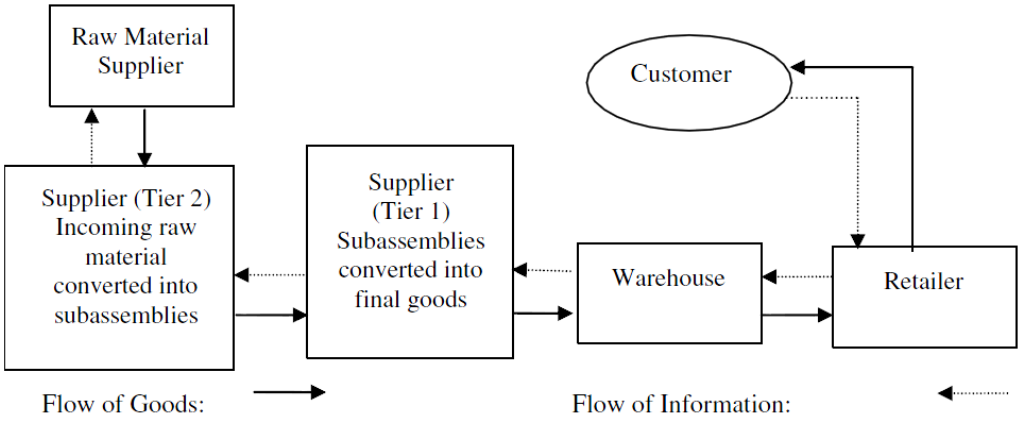
$$RC_I^* = \frac{S_i^-}{S_i^* + S_i^-}, \forall i \tag{14}$$

Step 6: Rank the preference order.

The index values of RC_I^*lie between 0 and 1. The larger index value means the closer to ideal solution for alternatives.

4. Empirical Study and Discussions

As Martha C. Wilson (2007) conclusion the greatest impact occurs when transportation is disrupted between the tier 1 supplier and warehouse.



This research has been conducted in supply chain transportation disruption. The problem is the evaluation and selection of the most appropriate solution to mitigate the risk of transportation disruption. For this reason, first of all, basic fivecriteria are determined. These criteria are key performance indicator (KPI) in supply chain transportation disruption management. Secondly, a two-step fuzzy AHP an TOPSIS methodology is proposed to realize the evaluation. These criteria are Travel time (C1), Inventory level (C2), decreasing time of disruption period due to implementing solution (C3), cost of implementing the solution (C4) and warehouse cost (C5). Six alternatives (solutions) include Establish fire stations (A1), storage locations and capacities to meet post disaster demand in different locations (A2), aim of strengthening the highway network (A3), extra vehicles (A4), extra inventory in focal company (A5) and Allocating fix budget for emergency needs (A6).The weights of criteria are calculated by using fuzzy-AHP, and these calculated weight values are used as Topsis inputs. Then after TOPSIS calculations, evaluation of the alternatives and selection of the most appropriate one is realized. The schematic structure established is shown in Fig 2.

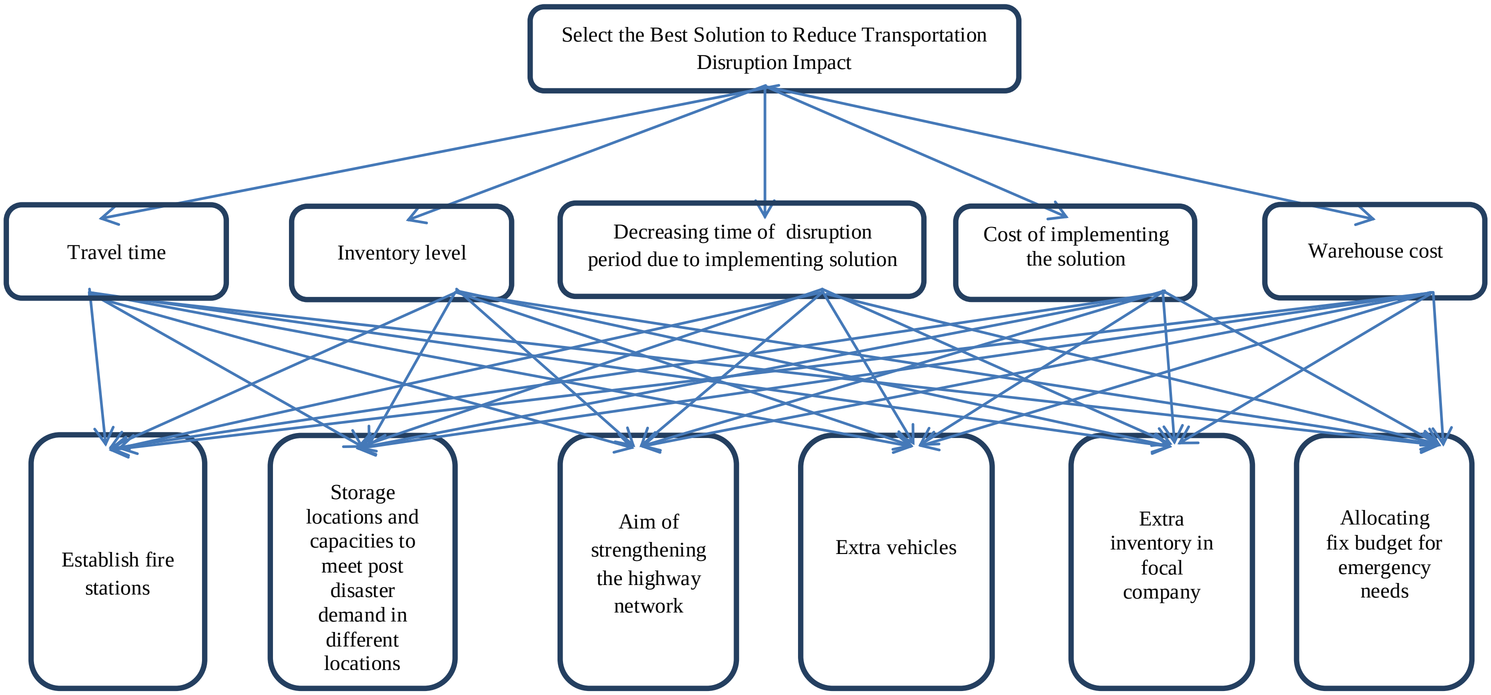


Figure 2. Research framework

firstly,In fuzzy-AHP, there must be linguistic terms and their equivalent fuzzy numbers denoting comparison measures. The linguistic comparison terms and their equivalent fuzzy numbers considered in this paper are shown in Table 1.

Table 1. Fuzzy comparison measures

Linguistic terms	Triangular fuzzy numbers
Perfect	(8, 9,10)
Absolute	(7, 8, 9)
Very good	(6, 7, 8)
Fairly good	(5, 6, 7)
Good	(4, 5, 6)
Preferable	(3, 4, 5)
Not bad	(2, 3, 4)
Weak advantage	(1, 2, 3)
Equal	(1,1,1)

Then, the comparisons the criteria and the weight calculation need to be made. Thus, the evaluation of the criteria according to the main goal must be realized. After all these evaluation procedure, the weights of the criteria can be calculated. Pairwise comparison of criteria can be seen from Table 2.

Table 2. Pairwise comparison of criteria

criteria	C1	C2	…	C4	C5
C1	(0.4,1,1.5)	(0.30,1,0.1.2)	…	(1,2,2.5)	(0.3,0.33,0.50)
C2	(0.5, 0.8, 1.2)	(1,1,1)	…	(6, 6.75, 8)	(3, 4, 5)
⋮	⋮	⋮	⋮	⋮	⋮
C4	(0.33,0.5,1)	(0.125,0.142,0.166)	…	(1,1,1)	(0.33,0.5,1)
C5	(0.5, 1.2, 1.9)	(0.20,0.25,0.33)	…	(1, 2, 3)	(1,1,1)

The criteria weights are calculated as:
W = (0.21, 0.17, 0.22, 0.15, 0.25)

The weights of the criteria are calculated by fuzzy AHP, and then these values can be used in TOPSIS. By following TOPSIS procedure steps and calculations, the ranking of solutions are gained. After developing the weighted normalized decision matrix, the final ranking procedure should determine the ideal solution and negative-ideal solutions by using Eqs. (10) and (11). In particular, the ideal solution and negative-ideal solution are determined as follows:

A^*={0.342, 0.223,0.131,0.095,0.115} and
A^-={0.181,0.074,0.202,0.105,0.045}

The results and final ranking are shown in Table 3.

Table 3. Final evaluation of the alternatives

I	S_i^*	S_i^-	RC_i^*	Ranking
A1	0.63524	0.06524	0.093136	2
A2	0.64745	0.06724	0.094083	1
A3	0.62387	0.05924	0.086721	5
A4	0.63510	0.063254	0.090576	3
A5	0.61290	0.060354	0.089645	4
A6	0.62225	0.058451	0.085869	6

By using Eqs. (12) and (13), the computed distances of each KM strategy from ideal solution (S_i^*) and negative-ideal solution (S_i^-) are presented in Table 3. Based on their relative closeness to the ideal solution obtained by using Eq. (14)

5. Conclusion

Organizations to survive in today's rapid and turbulent environment need to develop coherent long term plans .The issues of environmental pollution accompanying industrial development must be addressed with supply chain disruption management. As pressures for environmental sustainability increase, industries need to adopt strategies to reduce environmental impact and improve products, services and environmental performance (Zhu et al., 2005). So this research focuses on estimating and understanding the causes of transportation related supply chain disruptions. In-depth interviews with logistics managers were undertaken to investigate how companies perceive transportation related supply chain disruptions and what they are doing to respond and address them. For selecting the optimal strategy, this study proposes a strategy decision making process. An appropriate and simple prioritization method for determining the best strategy would be helpful to firms and decision makers. A two-step fuzzy-AHP and TOPSIS methodology is structured here that TOPSIS uses fuzzy-AHP result weights as input weights. Then a real case study is presented to show applicability and performance of the methodology. The usage of fuzzy-AHP weights in TOPSIS makes the application more realistic and reliable. The results of this study show that the most important solution is having storage locations and capacities to meet post disaster demand in different locations.

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