Supplier selection based on supplier risk: An ANP and fuzzy TOPSIS approach

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Abstract

Typically, supplier selection constitutes one of the most important stages of supply chain management and a variety of basic and hybrid MCDM approaches have been deployed to provide this problem with well-suited solutions. This paper investigates a new novel approach for this problem based on ANP and fuzzy TOPSIS methods while it takes into account the risk factor solely regarding the decision maker's venture strategy. In addition to an ANP model that determines the effects of decision criteria, in the proposed approach, a set of 5 risk categories has been deployed to affect the decision maker's choice by normalizing the weights of risk criteria.

Keywords: Supplier selection, Supplier risk, Analytic network process, Fuzzy TOPSIS.

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1. Introduction

Complexity of the dynamic supply chain in the information era has caused a significant impact on the supply chain management and consequently, on the supply chain risk. Harald et al. (2003) has outlined four factors as the main drivers: product/service complexity, e-business, outsourcing and globalization. The top three drivers of supply chain risk noted by Thun & Hoenig (2009) are globalization, product variants and outsourcing. In the past, risk was easier to manage because most of the manufactures sold products directly to customers, but in today's technology-mediated environment, no firm stands alone.

Supplier selection is the entry point of the supply chain process that starts from purchasing materials to delivering products to the customers. According to AMR research (2007) on risk factors, regardless of industry, supplier failure is the top issue that firms worry about. One of the main concerns of every company is to minimize disruption to its supply chain.

In literature, supplier selection has been treated as a Multiple Criteria Decision Making (MCDM) and a wide range of mathematical methods have been undertaken to provide the problems with sufficient and more accurate solutions (Boer et al., 2001; Ho et al., 2010). Table 1 enlists and categorizes these methods.

Each supplier's reliability depends on the upstream business for supplies and services while, in turn, the reliability of every one of these suppliers relies on upper level suppliers and so on. As a result, a reliability chain exists along supply chains. This means that not only the reliability of suppliers should take into account, but also, the reliability of supplier's suppliers can influence the business indirectly. In other words, today's global firms face "interdependence vulnerabilities", which means that not only must they consider about their own potential risks, but also about the vulnerabilities to their suppliers (Foroughi et al., 2006). For example, the 1995 earthquake in Kobe, Japan, had a widespread impact on the companies such as Eli Lilly, Caterpillar, Texas Instruments, and IBM. It also affected companies like Apple Computer, who had to slow down production of PowerBook computers due to disruption of the production of display monitors in Kobe (Foroughi et al., 2006). Robert Bosch, a German components supplier, delivered its customers with defective high pressure pumps for diesel fuel injection systems in the beginning of 2005 because of the mistake of a sub-supplier (Thun & Hoenig, 2009).

Table 1-Multiple approaches deployed for supplier selection problem

Category	Method	References
Artificial Intelligence & Knowledge Discovery	Genetic Algorithm	Liao & Rittscher (2007); Chen & Wang (2008); Hwang & Rau (2008)
	Artificial Neural Networks	Wei et al. (1997); Wu et al. (2008); Lee & Ou-Yang (2009); Chen et al. (2009)
	Data Mining	Kai et al. (2009)
Mathematical Programming Methods	Data Envelopment Analysis	Wu (2009)
	Linear Programming	Amid et al. (2006); Guneri et al. (2009)
	AHP and Nonlinear Programming	Kokangul & Susuz (2009)
	Rough set theory	Chang et al. (2007)
	Grey system theory	Huixia & Tao (2008)
MCDM and GMCDM	AHP	Xia & Wu (2007); Lee (2009); Chamodrakas et al. (2010)
	ANP	Gencer & Gürpinar (2007); Luo et al. (2009); Razmi et al. (2009)
	TOPSIS	Boran et al. (2009); Rhee et al. (2009)

According to Harland et al. (2003) and Knemeyer et al. (2009), supply chain risk, as showed in the following equation, is the probability of an event, times the business impact or the severity of that event.

Risk = Probability (of an event) × Business Impact (loss) (1)

Oke & Gopalakrishnan (2009), classified risk to three categories: a) High likelihood, low impact b) Medium likelihood, moderate impact c) Low likelihood, High impact. Goankar & Viswanadham (2007) identified three broad forms of risk mentioned as deviation, disruption and disaster that conforms to those classified by Oke & Gopalakrishnan (2009). Tang & Tomlin (2008) described two types of supply risks known as supply cost risks and supply commitment risks. They also mentioned political/social risk in the case of globalization. Harland et al. (2003) introduced eleven types of risks and six types of losses. Another classification of probabilities and impacts provided by Hallikas et al. (2004) extends categorization in Oke & Gopalakrishnan (2009) by adding extra assumptions. Table 2 illustrates the aforementioned classification by Hallikas et al. (2004) and table 3 summarizes the supplier risk factors mentioned in the literature.

Table 2-Business impact and probability of a risk

Impact assessment scale			Probability assessment scale	
Rank	Subjective estimate		Rank	Subjective estimate
1	No impact		1	Very unlikely
2	Minor impact		2	Improbable
3	Medium impact		3	Moderate
4	Serious impact		4	Probable
5	Catastrophic impact		5	Very Probable

Table 3-Supplier risk factors

Reference	Risk factors/Risk classification	Domain
Knemeyer et al. (2009)	Natural accidents (fire, earthquake); Normal accidents (technology failure); Abnormal accidents (ill-will by insides/outsides)	Catastrophic events
Oke & Gopalakrishnan (2009)	Imports; Climate; Man-made disasters; Natural disasters; Socio-economic; Loss of key suppliers	Retail supply chain
Tang & Tomlin (2008)	Supply cost risks; Supply commitment risks; Political/Social risks;	Supply risks
Thun & Hoenig (2009)	Strike; Natural disaster; War; Terrorist attack; Increasing customs duty; Import restriction; Oil crisis; Accident (like fire);	German automotive industry
Chan & Kumar (2007)	Geographical location; Political stability; Economy; Terrorism;	Global supplier selection
Li et al. (2008)	Time delay; Technology; Flexibility; Reliability; Compatibility; Ease of use for product;	Real estate company
Levary (2008)	Supplier reliability; Country risk; Reliability of transportation; Reliability of supplier's suppliers;	Manufacturer ranks foreign suppliers
Micheli et al. (2009)	Capacity constraints; Cost reduction capabilities;	Supplier related risk sources

	Lead time; Environmental performance; Financial health; Failure to meet delivery requirements; Inbound transportation; Information systems compatibility and sophistication Inventory management; Management vision; Process technological changes; Volume and mix requirement changes;	

On the other side, fuzzy set theory, which was introduced by Zadeh (1965) to map linguistic variables to numerical variables, has emerged as a powerful mathematical tool today and has been applied in many applied researches such as (Chen, 2005; Hsiao, 2008). We are going to deploy this theory in our model in order to propose a more applied decision making algorithm.

Reviewing ANP and Fuzzy TOPSIS methods in section 2, we are going to describe the proposed method in section 3. A simple numerical example is provided in section 4, followed by a more complex and more realistic case in section 5.

2. Basic Methods
2.1 ANP
Analytic network process (ANP) was developed by Thomas L. Saaty and is used for multi-criteria decision making (MCDM) problems. ANP is a general framework to deal with decision problems without making assumptions about the independence of the clusters or elements (Saaty, 1999). A sample of an ANP model is shown in figure 1.
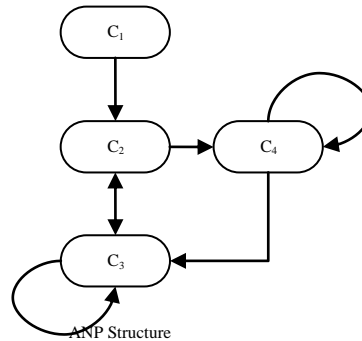

ANP Structure

Figure 1. Sample of ANP model

The network structure of the ANP makes possible the representation of any decision problem without concern for what comes first and what comes next as in a hierarchy.

2.2 Fuzzy TOPSIS
The TOPSIS (technique for order performance by similarity to ideal solution) is a solution to MCDM problem. According to this technique, the best alternative would be the one that is nearest to the positive ideal solution (PIS) and farthest from the negative ideal solution (NIS). The PIS is a solution that maximizes the benefit criteria and minimizes the cost criteria and the NIS is vice versa. This section extends TOPSIS to the fuzzy environment, which was introduced by Zadeh (1965) to map linguistic variables to numerical variables.

Definition 1. Let $\tilde{a} = (a_1, a_2, a_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ be two triangular fuzzy numbers, then the vertex method is defined to calculate the distance between them as equation 2.

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3} \left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2 \right]} \qquad (2)$$

Definition 2. Considering the different importance values for each criterion, the weighted normalized fuzzy decision matrix is constructed as:

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \qquad i = 1,2,\ldots,n \quad j = 1,2,\ldots m$$

where $\tilde{v}_{ij} = \tilde{r}_{ij} \otimes w_i$ (3)

Fuzzy TOPSIS steps can be outlined as follows:

Step 1. Choose the linguistic ratings ($\tilde{x}_{ij} \qquad i = 1,2,\ldots,n \quad j = 1,2,\ldots m$) for alternatives with respect to criteria. To obtain normalized decision matrix R let:

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \qquad \tilde{x}_j^- = (a_j^-, b_j^-, c_j^-) \quad and \quad \tilde{x}_j^* = (a_j^*, b_j^*, c_j^*)$$

then $\tilde{r}_{ij} = \begin{cases} \dfrac{x_{ij}}{\tilde{x}_j^*} = \left(\dfrac{a_{ij}}{a_j^*}, \dfrac{b_{ij}}{b_j^*}, \dfrac{c_{ij}}{c_j^*} \right) \\ \dfrac{\tilde{x}_j^-}{x_{ij}} = \left(\dfrac{a_j^-}{a_{ij}}, \dfrac{b_j^-}{b_{ij}}, \dfrac{c_j^-}{c_{ij}} \right) \end{cases}$ (4)

Step 2. Calculate the weighted normalized fuzzy decision matrix. The weighted normalized value $\tilde{v}_{ij}$ calculated by equation (3).

Step 3. Identify the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS). In this paper our criteria is risk based, so FPIS would be the minimum value and FNIS would be the maximum value.

Step 4. Calculate the distance of each alternative from FPIS and FNIS as mentioned in equations (5) and (6).

$$D_j^* = \sum_{j=1}^{m} (\tilde{v}_{ij}, \tilde{v}_j^*) \qquad j = 1,2,\ldots,m$$ (5)

$$D_j^- = \sum_{j=1}^{m} (\tilde{v}_{ij}, \tilde{v}_j^-) \qquad j = 1,2,\ldots,m$$ (6)

Step 5. Calculate similarities to ideal solution.

$$CC_j = \frac{D_j^-}{D_j^* + D_j^-}$$ (7)

Step 6. Rank alternatives according to CC_j in descending order.

3. The Proposed Model

We have categorized risks into five groups as illustrated in table 4. There are three linguistic values hidden in this categorization known as high, medium and low. Figure 2 shows another view of risk categorization which reveals that this grouping is consists of probability or the likelihood of an event and its impact or loss as in equation (1).

Table 4-Risk categorization

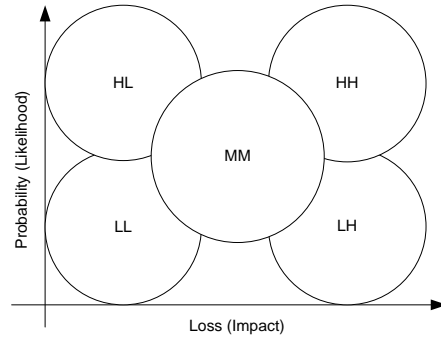| Risk Category	Definition
HH	High likelihood, high impact
MM	Medium likelihood, moderate impact
HL	High likelihood, low impact
LH	Low likelihood, high impact
LL	Low likelihood, low impact

Figure 2. Risk categorization

In our proposed model, we use ANP for comparison of criteria to get the normalized weight of each risk criteria. This part takes the impact factor of the risk into consideration. Then, using a fuzzy TOPSIS approach, we rank the alternatives based on the probability issue and the calculated weights of the criteria. Fuzzy sets theory in this phase helps us to deal with uncertainty of the alternatives evaluation. Figure 3 shows the triangular fuzzy numbers used.
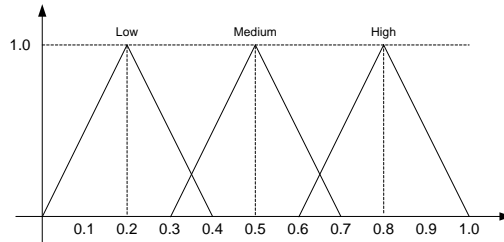

Figure 3. Triangular fuzzy numbers

The proposed approach is illustrated in 9 steps as follows:

Step 1: Identify the potential suppliers.

At the first step we provide a list of known potential suppliers denoted by A_i where $i = (1,2,\ldots,m)$.

Step 2: Identify the risk criteria of the specified business domain.

The risk criteria could be simply denoted by C_j where $j = (1,2,\ldots,n)$.

Step 3: Model the risk criteria as an ANP problem and define the relationships between the clusters and the elements.

Step 4. Weight the criteria using paired comparison as illustrated in ANP

In this step we calculate the normalized weight of each criteria (i.e. risk factor) denoted by W_j where $j = (1,2,\ldots,n)$.

Step 5: Evaluate the alternatives using linguistic variables and convert the linguistic values to their equivalent triangular fuzzy numbers.

Each alternative is evaluated against all risk criterions by the decision maker(s) who merely deploy linguistic terms. Later, the linguistic evaluation results are converted to numerical terms.

Step 6: Determine the weighted decision matrix D.

$$D = [d_{ij}]_{m \times n}$$

$$d_{ij} = (a,b,c)$$

$$d_{ij} = \tilde{r}_{ij} \otimes w_i$$

Step 7: Calculate the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) for every risk factor.

$$PIS_j = (a_j^*, b_j^*, c_j^*)$$

$$NIS_j = (a_j^-, b_j^-, c_j^-)$$

$$a_j^* = \min_i \{a_{ij}\}$$

$$b_j^* = \min_i \{b_{ij}\}$$

$$c_j^* = \min_i \{c_{ij}\}$$

$$a_j^- = \max_i \{a_{ij}\}$$

$$b_j^- = \max_i \{b_{ij}\}$$

$$c_j^- = \max_i \{c_{ij}\}$$

Step 8: Calculate the distance of each alternative from PIS and NIS and determine the closeness coefficient for each alternative.

$$D_j^* = \sqrt{\Delta a_{ij}^{*2} + \Delta b_{ij}^{*2} + \Delta c_{ij}^{*2}}$$

$$D_j^- = \sqrt{\Delta a_{ij}^{-2} + \Delta b_{ij}^{-2} + \Delta c_{ij}^{-2}}$$

$$CC_j = \frac{D_j^-}{D_j^* + D_j^-}$$

Step 9: Rank the alternatives according to their closeness coefficient in a descending order.

4. Numerical example

In this section we are going to clarify our model using a numerical example. There are five risk factors and four alternatives in this example. The goal is to rank the alternatives based on their risks so that the supplier (alternative) with the lowest supply risk can be chosen at the end.

Step 1: There are four suppliers or alternatives known as A1, A2, A3 and A4.

Step 2: Risk criteria of the alternatives considered in this example are defined as follow:

- Country risk (CR)
- Financial risk (FR)
- Natural disasters (ND)
- Technology risk (TR)
- Delivery risk (DR)

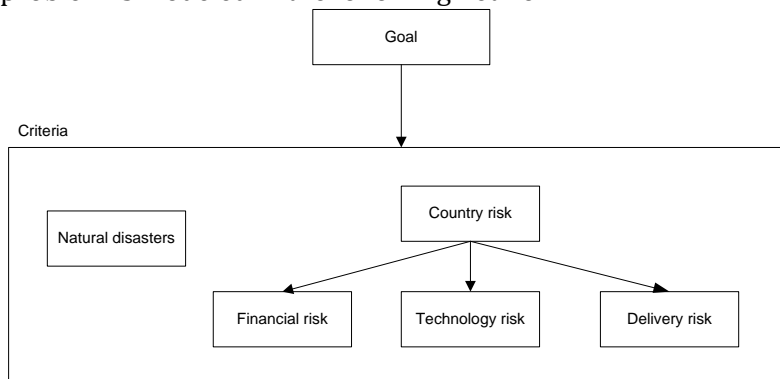Step 3: The ANP problem is modeled in the following network.

Figure 4-Criteria relationships as an ANP diagram

Step 4: We have used Super Decisions software in this step to calculate the weights of the criteria.

$$W = \begin{array}{c} goal \\ criteria \\ alternatives \end{array} \begin{bmatrix} 0 & 0 & 0 \\ W_{11} & W_{12} & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Figure 5 - Super-matrix of the ANP problem

	CR	FR	ND	TR	DR
CR	1	1	1/3	4	3
FR	1	1	1/3	3	5
ND	3	3	1	6	4
TR	1/4	1/3	1/6	1	1/4
DR	1/3	1/5	1/4	4	1

Table 5-Paired comparison of criteria with respect to goal (W$_{11}$)

	FR	TR	DR
FR	1	1	1/3
TR	1	1	1/5
DR	3	5	1

Table 6-Paired comparison of criteria with respect to country risk (W$_{22}$)

Criteria	Weights
Country risk	0.163
Financial risk	0.215
Natural disasters	0.368
Technology risk	0.067
Delivery risk	0.187
Sum	1.000

Table 7-Total weights of criteria (normalized)

Step 5: Evaluating the alternatives using linguistic values. Then, these values have changed to their equivalent fuzzy numbers.

Step 6: Calculate the weighted decision matrix for alternatives.

	CR	FR	ND	TR	DR
A1	(0.098,0.130,0.163)	(0.064,0.107,0.150)	(0.000,0.074,0.147)	(0.020,0.033,0.047)	(0.056,0.093,0.131)
A2	(0.000,0.033,0.065)	(0.064,0.107,0.150)	(0.110,0.184,0.258)	(0.000,0.013,0.029)	(0.112,0.150,0.187)
A3	(0.049,0.081,0.114)	(0.000,0.043,0.086)	(0.221,0.294,0.368)	(0.020,0.033,0.047)	(0.000,0.037,0.075)
A4	(0.000,0.033,0.065)	(0.064,0.107,0.150)	(0.110,0.184,0.258)	(0.040,0.054,0.067)	(0.000,0.037,0.075)

Table 8-Weighted evaluation matrix for alternatives

Step 7: Calculate the PIS and NIS.

	CR	FR	ND	TR	DR
FPIS	$\tilde{v}_1^*=(0,0,0)$	$\tilde{v}_1^*=(0,0,0)$	$\tilde{v}_1^*=(0,0,0)$	$\tilde{v}_1^*=(0,0,0)$	$\tilde{v}_1^*=(0,0,0)$
FNIS	$\tilde{v}_1^-=(1,1,1)$	$\tilde{v}_1^-=(1,1,1)$	$\tilde{v}_1^-=(1,1,1)$	$\tilde{v}_1^-=(1,1,1)$	$\tilde{v}_1^-=(1,1,1)$

Table 9-Fuzzy positive ideal solution and fuzzy negative ideal solution

Step 8: Calculate the distance of each alternative from PIS and NIS and determine the closeness coefficient for each alternative.

Alternatives	D_j^*	D_j^-
A1	1.0852	6.6684
A2	0.8641	6.8098
A3	0.8690	6.8079
A4	0.7567	6.9210

Table 10-Distances of alternatives to PIS and NIS

$$CC_j = \frac{D_j^-}{D_j^* + D_j^-} = \frac{6.6684}{1.0852 + 6.6684} = 0.8600$$

Alternatives	CC_j
A1	0.8600
A2	0.8874
A3	0.8868
A4	0.9014

Table 11-Closeness coefficient value for alternatives

Step 9: Rank the alternatives according to their closeness coefficient in a descending order.

Rank	Alternative
1	A4
2	A2
3	A3
4	A1

The results show that A4 is the best supplier with the lowest supply risk.

5. Conclusion remarks and suggestions

Within the previous pages of this paper we went through a discussion on a hybrid MCDM method based on ANP and Fuzzy TOPSIS to enhance previous solutions for the problem of selecting the best supplier from a set of potential alternatives based on risk factor. The proposed model takes advantage of ANP generally to determine weights and specifically to investigate impact of risk factors on each other. The results are affected by the decision maker's strategy, which in turn denotes company's appeal to decide based on loss or probability of variety of risk categories for each alternative. The final solution is obtained through a few steps based on fuzzy TOPSIS method.

The proposed method takes advantage of conformance with the company's strategy while it is solely based on the risk factor. On the other side, the required preliminary study to model each supplier's risk is a difficult process, thus it is a constraint for this method. Finally a numerical example has been proposed to investigate the properties of the proposed approach. To provide an outline for the next step and develop a more applied approach, the proposed approach could be generalized to take into account non-risk decision making criteria with a broader set of categories and strategic factors. In addition, the proposed method also could be integrated into supply chain management and coordination applications' decision processes such as (Shemshadi et al., 2008; Soroor et al., 2009) and provide them with a well suited supplier selection process.

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