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Abstract

Supplier selection is the process of finding the right suppliers, at the right price, at the right time, in the right quantities, and with the right quality. The aim of this paper, is supplier selection in the context of supply chain risk management. Thus nine criteria of quality, on time delivery and performance history and six risks in the supply chain including supply risk, demand risk, manufacturing risk, logistics risk, information risk and environmental risk considered for evaluating suppliers. Shannon entropy is used for weighing criteria and fuzzy TOPSIS is applied for ranking suppliers. Findings show that, in the spare parts supplier selection problem, demand risk is the most important factor.

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Keywords: Supply chain management; Supply chain risk; Fuzzy TOPSIS; Shannon entropy.

1. Introduction

Supply chain management is described as the management of a network of interconnected organizations involved with the preparation of product and service packages needed by the end customers in a supply chain (Harland 1996). Supply chain management covers all the movement and storage of raw materials, work-in-process inventory, and finished goods from the point of origin to the point of consumption (Heidarzade et al., 2015). Supply chain management is a holistic and strategic approach to demand, operations, procurement, and logistics process

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management. Ogulin (2003) suggests three distinctive waves of supply chain management in the new economy: operational excellence, supply chain integration and collaboration, and virtual supply chains. Enterprises along the supply chain need to develop organizational, procedural, technical, and strategic capabilities and capacities to respond to four emerging requirements: customer focus, technology adoption, relationships management, and leadership styles (Chow et al., 2008). Business leaders, academics, and policy makers recognize that the management of supply chains is crucial in the highly competitive global business environment, and it has become clear that well managed supply chains provide operational and strategic advantages to organizations, regions, and countries (Silvestre, 2015). In today´s competitive environment, companies are required to optimize business processes and promote the performance of their entire supply chains. Successful operation of a supply chain relies on every single business involved, and an efficient and flexible supply chain allows the firm to choose the right suppliers at the right time for the right materials, not only substantially reducing purchasing cost, but also significantly improving corporate competitiveness (Xia and Wu, 2007). Many factors such as international competitors, demanding customers and rapid technological change profoundly impact the markets. Therefore, successful competition in this environment requires to reduce operational costs and enlarge profit margins. For most industrial firms, the purchasing of raw material and component parts from suppliers constitutes a major expense. Hence, among the various strategic activities involved in the supply chain management, the purchase decision has profound impacts on the overall system (Guo and Li, 2014). Additionally some companies have started to strategically improve their supplier's capabilities. However with a large number of suppliers and limited resources in supplier development, not every supplier in the supply base can be improved. Thus, for a strategic supplier development program, supplier selection decision is very important.

In the context of supply chain management, supplier selection decision is considered as one of the key issues faced by operations and purchasing managers to remain competitive (Bai & Sarkis, 2010). Selecting the right suppliers can influence the overall purchasing cost (the cost of raw materials and component parts), which is responsible for a large percentage of the final product cost (Pazhani et al., 2015). Supplier selection decisions are complicated by the fact that various criteria must be considered in decision making process (Karsak & Dursun, 2015). Dickson (1966) noted that quality, on-time delivery, and performance history are most significant criteria in supplier selection. Selecting the right supplier will result in reducing operational costs, increasing profitability and quality of products, improving competitiveness in the market and responding to customers' demands rapidly (Abdollahi et al., 2015). Moreover, customer satisfaction is also enhanced by determining the best supplier.

Managing risks is a daily issue to supply chain and logistics management. The ability to respond to and mitigate these risk events enables the company to be ahead of its competitors and diminishes the expected long-term damage to its business. The critical drivers for supply chain profitability are responsiveness, efficiency, and reliability (Hendricks and Singhal, 2005). The occurrence of risk events in different stages of the supply chain can put negative influences on supply chain performance. The management of risk events is termed as supply chain risk management (SCRM), which has become a key part of the business strategy. SCRM has got more attention with the movement to global supply chains and the increasing occurrence of internal and external risk events that cause disruptions of supply chain operations (Aqlan & Lam, 2015). In order to select the right supplier, various criteria should be distinguished and evaluated with respect to different suppliers' attributes. Therefore, this problem can be considered as a multiple criteria decision making (MCDM) problem (Yu et al., 2013). When supply chain is faced with risk events, selecting the right suppliers becomes more essential than ever for the business. Several factors such as unquantifiable information, incomplete information, unobtainable information and partial ignorance cause the imprecision in decision making. Since conventional MADM methods cannot effectively handle problems with such imprecise information, therefore fuzzy multiple attribute decision-making methods have been developed owing to the imprecision in assessing the relative importance of attributes and the performance ratings of alternatives with respect to attributes (Kiani Mavi and Kiani Mavi, 2014). One of prevalent MADM methods for weighing criteria is Shannon entropy and for ranking alternatives technique for order preferences by similarity to ideal solution (TOPSIS). Hence, the aim of

this paper is to use Shannon entropy for weighing main criteria in supplier selection and to use fuzzy TOPSIS methods for ranking suppliers in the context of supply chain risk management.

The reminder of this paper is organized as follow. In section 2, literature review of supply chain risk management and supplier selection is presented. In section 3, Shannon entropy and fuzzy TOPSIS methods are explained. Section 4, presents the numerical example. Finally, section 5 concludes the paper.

2. Literature review

2.1 Supply chain risk management (SCRM)

Nowadays supply chains perform in a very volatile environment caused mostly by supply chains globalization where products management is becoming increasingly complex due to market uncertainties and society pressures. Drivers such as sustainability, responsiveness and risk management are today a reality that needs to be accounted for when developing decision supporting tools to inform supply chains activities (Barbosa-Povoa, 2014). Bogataj and Bogataj (2007) defined risk as the potential variation of outcomes that influence the decrease of value added of any activity in a supply chain. The management of risk in operations/supply chains has emerged as one of the key research topics in the recent operations and supply chain management. SCRM is explained as the identification and management of risks for the supply chain through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole (Wieland, 2013). Nooraie and Mellat Parast (2015) defined SCRM as the development and implementation of strategies to manage both day-to-day and exceptional risks along a supply chain, with the objective of reducing vulnerability and ensuring business continuity. Supply Chain Risk Management (SCRM) plays a major role in successfully managing business processes in a proactive manner (Lavastre et al., 2012). Most scholars agree that the main stages of SCRM involve five sequential stages: risk identification, assessment, analysis, treatment and monitoring. Li et al. (2015) identify two relevant joint supply chain risk management (SCRM) practices, namely risk information sharing and risk sharing mechanism. Chopra and Sodhi (2004) point out that there is no distinguished silver-bullet strategy to support organizational supply chains against risks; managers must select the proper mitigation strategy for each risk. Mitigation strategies can be divided into four main categories (Zsidisin and Ritchie, 2009): (1) eliminate the risk, (2) reduce the frequency and consequences of the risk, (3) transfer the risk by means of insurance and sharing, and (4) accept the risk. Managers usually select the proper mitigation strategies based on several factors, such as the nature of the risk, origin of the risk, and company resources.

Supply chain risk comprises any risks for the information, material and product flows from original supplier to the delivery of the final product for the end-user (Shashank & Goldsby, 2009). Reducing supply chain uncertainty leads to enhanced supply chain performance (Punniyamoorthy et al., 2013). Tang (2006) claims that there are two types of risks within a supply chain: operational risks and disruption risks. Operational risks are related to inherent uncertainties such as in products demand, supply and all types of costs. Disruption risks are referred to natural disasters such as earthquakes, floods, hurricanes and also terrorist attacks. Goh et al. (2007 classified supply chain risks into two different types: internal risks that encompass supply, demand and trade credit risks, and external risks that arise from the interactions amongst the supply chain and the environment, including international terrorism and natural disasters.

Hallikas et al. (2004) classified supply chain risks into strategy, operations, supply, customer relations, asset impairment, competition, reputation, financial markets, fiscal and regulatory requirements, and legal. Chopra and Sodhi (2004) propose disruptions, delays, systems, forecasts, intellectual property, procurement, receivables, inventory, and capacity as the nine main sources of supply chain risk. Meanwhile Christopher and Peck (2004) identify process, control, demand, supply, and environment as five risk sources. Kleindorfer and Saad (2005) emphasize three sources that increase disruption risk: operational contingencies (including equipment malfunctions and systemic failures), natural hazards (earthquakes, hurricanes and storms), terrorism and political instability. Kiser and Cantrell (2006) highlight internal risks (risks in manufacturing, business, planning and control, mitigation and contingency) and external risks (risks in demand, supply, environment, business and physical plant). Wagner and Bode (2008)

divide the sources into five distinct classes: demand side; supply side; regulatory, legal and bureaucratic; infrastructure, and catastrophic. Punniyamoorthy et al. (2013) classified risks of supply chain according to their sources as supply side, demand side, manufacturing side, logistics side, information and environment risks. Hantsch and Huchzermeier (2013) classified supply chain management risks as procurement risk, production risk, sales risk, financial market risk, risk specific to the production network, political/legal risk, and other risks. Fazli et al. (2015) developed a taxonomy of supply chain risks and mitigation strategies. Giannakis and Papadopoulos (2015) categorized sustainability-related risk by their endogenous and exogenous nature. Environmental endogenous (Environmental accidents (e.g. fires, explosions), Pollution (air, water, soil) , Non-compliance with sustainability laws, Emission of greenhouse gases, ozone depletion), Energy consumption (unproductive use of energy), Excessive or unnecessary packaging, Product waste) Environmental exogenous (Natural disasters (e.g. hurricanes, floods, earthquakes), Water scarcity, Heat waves, droughts), Social endogenous (Excessive working time; work-life imbalance, Unfair wages, Child labor /forced labor, Discrimination (race, sex, religion, disability, age, political views), Healthy and safe working environment, Exploitative hiring policies (lack of contract, insurance), Unethical treatment of animals), Social exogenous (Pandemic, Social instability, Demographic challenges / Ageing population), Financial / Economic endogenous (Bribery, False claims / Dishonesty, Price fixing accusations, Antitrust claims, Patent infringements, Tax evasion), Financial / Economic exogenous (Boycotts, Litigations, Energy prices volatility, Financial crises).

Yu and Goh (2014) investigate the twin effects of supply chain visibility (SCV) and supply chain risk (SCR) on supply chain performance. They developed a fuzzy multi-objective (SCV maximization, SCR minimization, and cost minimization) decision making approach to model SCV and SCR from an operational perspective. Cardoso et al. (2015) developed a mixed integer linear programming (MILP) model for maximizing the supply chain expected net present value (ENPV), while simultaneously minimizing the associated risk. Qu et al. (2015) extended the proximal point algorithm and applied to a supply chain network risk management problem under bi-criteria considerations. Giannakis and Papadopoulos (2015) by considering risk that is associated with the business decisions and their effect on the biophysical, social and financial ecosystems, adopted a risk management perspective to sustainability. Pazhani et al. (2015) proposed a mixed integer nonlinear programming model to investigate the problem of supplier selection and order quantity allocation in a multi-stage serial supply chain system with multiple suppliers considering inventory replenishment, holding, and transportation costs simultaneously. Aqlan and Lam (2015) developed a multi-objective optimization model and combined it with simulation model for managing risks in supply chains. Mangla et al. (2015) proposed a two stage approach for risk management. In the first phase, six categories of risks and twenty-five specific risks, associated with the green supply chain, were identified. In the second phase, the fuzzy analytic hierarchy process (fuzzy AHP), a qualitative and quantitative analysis was applied to analyze the identified risks for determining of their priority of concern.

2.2 Supplier selection

Selecting suppliers and service providers through competitive bidding processes is a vital activity for most operating organizations and manufacturers (Wood, 2015). In today's competitive markets, companies have understood the importance of selecting proper suppliers who can supply their requirement with their desired quality and in a scheduled time. Therefore, businesses try to measure the performance of their suppliers to select the best supplier to gain supply chain surplus. Consequently, supplier selection is a key factor of the procurement process. Basically, selecting a proper supplier is considered as a non-trivial task. To achieve this goal, the majority of the decision makers empirically evaluate and select suppliers. Supplier selection is a decision approach with the goal of removing the preliminary group of prospective suppliers to the ultimate choices (Rahiminezhad Galankashi et al., 2016). Supplier selection has been identified as a fundamental concern for organizations in maintaining a strategically competitive position due to its direct impact on the cash flow and profitability (Banaeian et al., 2015).

Supplier selection is a decision-making process to evaluate suppliers for making contracts. Supplier selection processes is critically important, since the costs of raw materials and component parts constitute the main cost of a product and most firms need to spend a considerable amount of their revenues on purchasing. Supplier selection is one of the most important decision making problems encompassing both qualitative and quantitative factors to identify

suppliers with the highest potential for meeting the needs consistently with acceptable costs. To meet customer's demand and to minimize internal cost and risk, companies choose appropriate suppliers to offer more competitive products and distribute the products to customers in order to meet a variety of demands (Heidarzade et al., 2015). Some issued must be addressed in supplier selection process for maintaining a strategic and competitive supply chain, such as (Trapp & Sarkis, 2016):

- Which suppliers should be considered for partnering?
- Which suppliers should be part of supplier development initiatives?
- Which suppliers must be removed from the supply base?
- How can weak suppliers improve their performance?
- How can firms effectively allocate resources to supplier development programs?

Different approaches are applied for supplier selection such as data envelopment analysis (DEA) (Hadi-Vencheh & Niazi-Motlagh, 2011), analytical hierarchy process (AHP) (Perić et al., 2013; Chan, 2003), fuzzy analytical hierarchy process (FAHP) (Kilincci & Onal, 2011), analytic network process (ANP) (Lin 2009; Hsu and Hu, 2009), fuzzy QFD (Bevilacqua et al., 2006), technique for order performance by similarity to ideal solution (TOPSIS) (Mokhtarian & Hadi-Vencheh, 2012), preference programming (PP), fuzzy logic (Florez-Lopez, 2007), fuzzy case-based reasoning (CBR) (Faez et al., 2009), simulated annealing (Che, 2012), fuzzy ARAS (Kiani Mavi, 2015), fuzzy VIKOR (Shemshadi et al., 2011), fuzzy AHP and simulation based fuzzy TOPSIS (Zouggari and Benyoucef, 2011), mixed integer non-linear programming (Mendoza and Ventura, 2012), etc.

3. Research methodology

3.1. The Shannon entropy weight method

The entropy weight method was firstly introduced from thermodynamics to information systems (Shannon, 2001). The uncertainty of signals in communication processes is called ''information entropy''. The lower is the information entropy, the higher is the weight. Suppose that there are m alternatives to evaluate and n evaluation criteria, $\boldsymbol{D} = \left(\boldsymbol{x_{ij}}\right)_{m \times n}$ is the initial decision matrix of the evaluation issue.

The decision matrix is normalized as:
$$p_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij} \tag{1}$$
The information entropy for each index is defined as:
$$E_j = -(\ln m)^{-1} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{2}$$
and the weight obtained from information entropy is expressed as follows:
$$w_j = (1 - E_j)/(n - \sum_{j=1}^{n} E_j) \tag{3}$$
where $0 \leq w_j \leq 1$ and $\sum_{j=1}^{n} w_j = 1$.

3.2. Fuzzy TOPSIS

Among many common MCDM techniques, TOPSIS is a practical and useful method for ranking and choosing of a number of possible alternatives through measuring Euclidean distances. It is based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution (PIS), and the farthest from the negative ideal solution (NIS), (Wang and Lee, 2009). It is often difficult for a decision-maker to assign a precise performance rating to an alternative for the attributes under consideration. The merit of a using a Fuzzy approach is to assign the relative importance of the attributes using Fuzzy numbers instead of precise numbers (Sengul et al., 2015).

Based on Sun (2010) fuzzy TOPSIS is carried out by the following steps.
Step 1. Construct the fuzzy performance/decision matrix and choose the appropriate linguistic variables for the alternatives with respect to criteria.

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{21} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}; i=1,2,\ldots,m; \ j=1,2,\ldots,n. \tag{4}$$

$$\tilde{x}_{ij} = \frac{1}{p}\left(\tilde{x}_{ij}^{(1)} \oplus \tilde{x}_{ij}^{(2)} \oplus \ldots \oplus \tilde{x}_{ij}^{(p)}\right) \tag{5}$$

where $\tilde{x}_{ij}$ is the performance rating of alternative A_i with respect to criterion C_j evaluated by k^{th} expert, and $\tilde{x}_{ij}^{(k)} = \left(l_{ij}^{(k)}, m_{ij}^{(k)}, u_{ij}^{(k)}\right).$

Step 2. Normalize the fuzzy-decision matrix. The normalized fuzzy-decision matrix denoted by $\tilde{R}$ is shown as (6).

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{m \times n}, i = 1,2,\ldots,m; \quad j = 1,2,\ldots,n \tag{6}$$

Then, the normalization process can be performed by (7,8).

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}\right); \ u_j^+ = max_i\{u_{ij} : i = 1,2,\ldots,m\} \qquad \text{(for benefit criteria)} \tag{7}$$

$$\tilde{r}_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}}\right); \ l_j^- = min_i\{l_{ij} : i = 1,2,\ldots,m\} \qquad \text{(for cost criteria)} \tag{8}$$

or we can set the best aspired level u_j^+ and j =1,2,..., n is equal one; otherwise, the worst is zero. The normalized $\tilde{r}_{ij}$ is still triangular fuzzy numbers. The weighted fuzzy normalized decision matrix is shown as matrix (9).

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{m \times n}, i = 1,2,\ldots,m; \quad j = 1,2,\ldots,n \tag{9}$$

where

$$\tilde{v}_{ij} = \tilde{v}_{ij} \otimes \tilde{w}_j. \tag{10}$$

Step3. Determine the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS).

According to the weighted normalized fuzzy-decision matrix, we know that the elements $\tilde{v}_{ij}$ are normalized positive TFN and their ranges belong to the closed interval [0, 1]. Then, we can define the FPIS A$^+$ (aspiration levels) and FNIS A$^-$ (the worst levels) as (11), (12):

$$A^+ = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*) \tag{11}$$
$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-) \tag{12}$$

where

$$\tilde{v}_j^* = (1,1,1) \otimes \tilde{w}_j = (lw_j, mw_j, uw_j) \text{ and } \tilde{v}_j^- = (0,0,0); j = 1,2,\ldots,n. \tag{13}$$

Step 4. Calculate the distance of each alternative from FPIS and FNIS. The distances ($\tilde{d}_i^+$ and $\tilde{d}_i^-$) of each alternative from A^+ and A^- can be currently calculated by the area compensation method:

$$d_i^+ = \sum_{j=1}^n d\left(\tilde{v}_{ij}, \tilde{v}_j^*\right), \quad i = 1,2,\ldots,m; \ j = 1,2,\ldots,n \tag{14}$$
$$d_i^- = \sum_{j=1}^n d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right), \quad i = 1,2,\ldots,m; \ j = 1,2,\ldots,n \tag{15}$$

$$d\left(\tilde{A}, \tilde{B}\right) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]} \tag{16}$$

Step 5. Obtain the closeness coefficients (relative gaps-degree) and improve alternatives for achieving aspiration levels in each criterion.

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{17}$$

4. Numerical example

Seven supply chain management experts who have more than 10 years experience in the field participated in this research. Four suppliers who supply the spare parts for a motorcycle manufacturer are investigated. Based on experts' opinion nine criteria are determined for evaluating suppliers. In the today's competitive market, price has not broadly varied among suppliers. Therefore, considered criteria for supplier selection in this study are: quality (C1), on time delivery (C2), performance history (C3), supply risk (C4), demand risk (C5), manufacturing risk (C6), logistics risk (C7), information risk (C8) and environment risk (C9). Linguistic variables for the rating alternatives and

corresponding Triangular fuzzy Numbers (TFN) are extracted from (Chen, 2000) as Table 1. The decision matrix which is the average of experts' opinions about score of alternatives in each criterion is shown in Table 2.

Table 1. Linguistic variables for the importance weight of each criterion

Linguistic Variable	Triangular Fuzzy Number
Very low (VL)	(0.0, 0.0, 0.1)
Low (L)	(0.0, 0.1, 0.3)
Medium low (ML)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Medium high (MH)	(0.5, 0.7, 0.9)
High (H)	(0.7, 0.9, 1.0)
Very high (VH)	(0.9, 1.0, 1.0)

Table 2. Fuzzy decision making matrix

Alternatives	Quality (C1)			On time delivery (C2)			Performance history (C3)			Supply risk (C4)			Demand risk (C5)		
A1	0.74	0.79	0.87	0.54	0.61	0.69	0.53	0.60	0.66	0.19	0.23	0.28	0.24	0.34	0.40
A2	0.52	0.59	0.64	0.64	0.72	0.81	0.73	0.79	0.84	0.17	0.21	0.26	0.16	0.24	0.32
A3	0.67	0.81	0.95	0.74	0.83	0.94	0.84	0.89	0.93	0.21	0.29	0.35	0.31	0.36	0.42
A4	0.68	0.73	0.79	0.81	0.91	1.00	0.71	0.79	0.85	0.23	0.26	0.32	0.23	0.30	0.37

Table 2. (continued) Fuzzy decision making matrix

Alternatives	Manufacturing risk (C6)			Logistics risk (C7)			Information risk (C8)			Environment risk (C9)		
A1	0.13	0.19	0.25	0.17	0.21	0.27	0.23	0.28	0.32	0.25	0.30	0.35
A2	0.18	0.24	0.30	0.18	0.25	0.30	0.21	0.26	0.31	0.25	0.31	0.36
A3	0.21	0.26	0.31	0.11	0.19	0.26	0.27	0.32	0.39	0.28	0.34	0.40
A4	0.17	0.25	0.32	0.20	0.26	0.32	0.22	0.27	0.34	0.22	0.28	0.35

For calculating criteria weights with Shannon entropy, fuzzy data converted into crisp data with centre of area method (Hsieh et al., 2004):

$$x_{ij} = \frac{[(u_{ij} - l_{ij}) + (m_{ij} - l_{ij})]}{3} + l_{ij} \tag{18}$$

Therefore, decision matrix for Shannon entropy is shown in Table 3. Following entropy steps leads to obtaining weights of criteria shown in the last row of Table 3.

Table 3. Weights of supplier selection criteria

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	0.8010	0.6140	0.5957	0.2313	0.3250	0.1893	0.2157	0.2757	0.2977
A2	0.5833	0.7263	0.7860	0.2143	0.2397	0.2430	0.2443	0.2610	0.3073
A3	0.8103	0.8327	0.8873	0.2827	0.3653	0.2607	0.1867	0.3263	0.3380
A4	0.7297	0.9057	0.7823	0.2730	0.3017	0.2467	0.2613	0.2787	0.2840
E_j	0.9942	0.9925	0.9929	0.9953	0.9919	0.9950	0.9943	0.9974	0.9985
w_j	0.1205	0.1565	0.1482	0.0970	0.1681	0.1045	0.1196	0.0543	0.0312

It is clear that, demand risk is the most important criteria in supplier selection problem. The priority order of supplier selection criteria in this study is as follow.

$$C_5 \succ C_2 \succ C_3 \succ C_1 \succ C_7 \succ C_6 \succ C_4 \succ C_8 \succ C_9$$

In step 2, for ranking suppliers, fuzzy TOPSIS method is applied. Based on fuzzy decision matrix (Table 1) and weights of supplier selection criteria (Table 3), weighted normalized fuzzy decision matrix and ranking suppliers are shown in Tables 4-5 respectively.

Table 4. Weighted normalized fuzzy decision matrix

Alternatives	Quality (C1)			On time delivery (C2)			Performance history (C3)			Supply risk (C4)			Demand risk (C5)		
A1	0.09	0.10	0.11	0.09	0.10	0.11	0.08	0.09	0.10	0.09	0.07	0.06	0.11	0.08	0.07
A2	0.07	0.07	0.08	0.10	0.11	0.13	0.12	0.13	0.13	0.10	0.08	0.06	0.17	0.12	0.09
A3	0.08	0.10	0.12	0.12	0.13	0.15	0.13	0.14	0.15	0.08	0.06	0.05	0.09	0.08	0.06
A4	0.09	0.09	0.10	0.13	0.14	0.16	0.11	0.13	0.14	0.07	0.06	0.05	0.12	0.09	0.07

Table 4. (continued) Weighted normalized fuzzy decision matrix

Alternatives	Manufacturing risk (C6)			Logistics risk (C7)			Information risk (C8)			Environment risk (C9)		
A1	0.10	0.07	0.06	0.08	0.06	0.05	0.05	0.04	0.04	0.03	0.02	0.02
A2	0.10	0.07	0.06	0.07	0.05	0.05	0.05	0.04	0.04	0.03	0.02	0.02
A3	0.07	0.05	0.04	0.12	0.07	0.05	0.04	0.04	0.03	0.02	0.02	0.02
A4	0.08	0.06	0.04	0.07	0.05	0.04	0.05	0.04	0.03	0.03	0.02	0.02

Table 5. Ranking of suppliers

Alternatives	d_i^-	d_i^+	CC_i	Rank
A1	5.9235	3.0855	0.6575	3
A2	5.9098	3.1019	0.6558	4
A3	6.0467	2.9641	0.6710	1
A4	6.0229	2.9851	0.6686	2

Findings reveal that final ranking of suppliers is $A_3 \succ A_4 \succ A_1 \succ A_2$.

5. Conclusion

Supplier selection is an important operational and strategic task for supply chain partnership development. Part of supplier selection involves supplier evaluation and ranking across multiple dimensions. With an emphasis on outsourcing initiatives, organizations have become more dependent on suppliers, thus making it critical to choose and evaluate supplier performance. Supplier evaluation and selection requires consideration of multiple objectives and criteria requiring multi-criteria decision-making approaches and analyses. In this study, we have evaluated spare parts suppliers in the context of supply chain risk management. Results show that, demand side risk has the most weight and environmental risk has the least weight in supplier selection problem. Future studies can be devoted on fuzzy Shannon entropy.

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