Supplier selection in risk-oriented supply chain: A fuzzy lower and upper boundary approach

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Abstract

Resolving the problem of evaluation and ranking the potential suppliers has become as a key strategic factor for business firms. As competition is growing high in this globalized market, the companies are placing more and more importance on the process of outsourcing suppliers. Supplier selection in interconnected supply chain is fuzzy multi criteria group decision-making FMCDM problem involving multi-risk criteria involving imprecise information's. Increasing emphasis on supply chain vulnerabilities proposes effective mathematical tools for analyzing and understanding appropriate supply chain risks. An algorithm based on fuzzy multi criteria group decision-making FMCDM model analyzing lower and upper boundaries to select the suppliers mitigating risk factors in supply chain. A case study for supplier selection in Electronics industry in which four supplier alternatives are compared using five risk criteria's and ranked accordingly. The paper delineates some approach which industry should adopt to address the risk in supply chain.

Keywords:

Supplier Selection, Supply chain risk, FMCDM, Total performance index.

Introduction

Today's industrialized society depends on integrated supply chain which has cross-boundary multi-suppliers vulnerable to external risks environment. The selection of suppliers of upstream supply chain is based on total production cost, quality of finished product mitigating on-time delivery delay risks. One important factor for Supply chain is effective purchasing function involving buying of raw material and selection of appropriate supplier, since it brings significant savings for the parent organization [1].In this paper we focus in ranking the suppliers alternatives under uncertain risk using Wang's Fuzzy MCDM method based on lower and upper boundaries. A problem of outsourced supplier selection is done to illustrate the method which can help select preferred group ranking outcome.

Bell-man and Zadeh (1970) introduce fuzzy set theory to deal with the inherent imprecision in the human decision. Chen, Lin and Huang (2006) applied fuzzy TOPSIS approach to deal with supplier selection problem in supply chain. Benitez, Martin and Roman (2007) presented fuzzy TOPSIS approach to evaluate the service quality of three hotels in Gran Canaria Island. Extended fuzzy TOPSIS methods are given by Chen (2000) in which extreme values could not stand for max and min values.. In the work of Wang et al (2003) criteria values of ideal and anti-ideal solution may not exist in feasible alternatives. All the above drawbacks are mitigated through Wang (2011) method on FMCDM model based on upper and lower boundaries, applied in this paper for supplier selection.

Electronics product supply chain is complex system consisting of independent upstream and downstream firm's small delivery cycles and massive uncertainty of market. In foundation of investigation and study, we present five supply chain risk attributes, namely, Contract and quality risk, Logistics and inventory risk, Information risk, Environmental risk, and Macro-political risks, in selection of battery supplier's for power product company Microtek.

Preliminaries

Definition 2.1.

Let $S=\{X_1,X_2,\ldots.X_n\}$ indicate a set of composed of triangular fuzzy numbers, where $X_i=(x_i^l,x_i^m,x_i^r), i=1,2,\ldots\ldots,n$. Then normalized fuzzy number $\tilde{X}_i(=(\tilde{x}_i^l,\tilde{x}_i^m,\tilde{x}_i^r)$ of X_i is defined as follows: $\tilde{X}_i=\left(\frac{x_i^-}{x_i^r},\frac{x_i^-}{x_i^m},\frac{x_i^-}{x_i^l}\right)$ as S is the set composed of risk ratings, where $x_i^-=\min_{1\le i\le n}\left(x_i^l\right)$

Definition 2.2. Let $L(\tilde{S})$ and $U(\tilde{S})$ be respectively lower and upper boundaries in a set of normalized fuzzy numbers $\tilde{S}=\{\tilde{X}_1,\tilde{X}_2,\ldots\ldots,\tilde{X}_n\}$ we define $L(\tilde{S})=0$ and $U(\tilde{S})=2$

Definition 2.3. Let $\tilde{X}_i\in\tilde{S}$ be a normalized fuzzy number. The separated value between $\tilde{X}_i$ and lower boundary $L(\tilde{S})$ is defined:

$$Ld(\tilde{X}_i,L(\tilde{S}))=\int_0^1\left((\tilde{X}_i)_\alpha^L-L(S)\right)d\alpha=\int_0^1(\tilde{X}_i)_\alpha^L\,d\alpha$$

also, the separated value between $\tilde{X}_i$ and upper boundary $U(\tilde{S})$

$$Ud\left(\tilde{X}_i,U(\tilde{S})\right)=\int_0^1\left(U(\tilde{S})-(\tilde{X}_i)_\alpha^U\right)d\alpha=\int_0^1(2-(\tilde{X}_i)_\alpha^U)d\alpha\ \tilde{X}_i$$

Definition 2.4. Let $R_{(\tilde{S})}(\tilde{X}_i)$ indicate the relative difference of between lower boundary and upper boundary, for

$$\tilde{S}=\left(\tilde{X}_1,\tilde{X}_2,\ldots\ldots,\tilde{X}_n\right)$$

where

$\tilde{X}_i=(\tilde{x}_i^l,\tilde{x}_i^m,\tilde{x}_i^r),\ i=1,2,\ldots\ldots,n.$ Define

$$R_{(\tilde{S})}(\tilde{X}_i)=\frac{Ld(\tilde{X}_i,L(\tilde{S}))}{Ud(\tilde{X}_i,U(\tilde{S}))}=\frac{\tilde{x}_i^l+\tilde{x}_i^m}{4-\tilde{x}_i^m-\tilde{x}_i^r}$$

Algorithm of FMCDM based On Upper and Lower Boundary

Suppose m alternatives $A_1,A_2,\ldots.,A_m,\ (i=1,2,\ldots\ldots,m)$ are evaluated on n risk criteria $C_1,C_2,\ldots.,C_n,\ (i=1,2,\ldots\ldots,n)$. Let $G_{ij}=(g_{ij}^l,g_{ij}^m,g_{ij}^r)$ indicates the performance rating of A_i on C_j and let W_j indicate the weight of C_j, where j = 1,2,......,n.

Step 1: G_{ij} and W_j are evaluated in linguistic terms, and transferred into triangular fuzzy number $G_{ij}=(g_{ij}^l,g_{ij}^m,g_{ij}^r)$ and $W_j=(w_j^l,w_j^m,w_j^r)$ respectively.

Step 2: G_{ij} and W_j are normalized following Definition 2.1. As G_{ij} belongs to cost criteria,

$$\tilde{G}_{ij}=\left(\frac{g_j^-}{g_j^r},\frac{g_j^-}{g_j^m},\frac{g_j^-}{g_j^l}\right)=\left(\tilde{g}_{ij}^l,\tilde{g}_{ij}^m,\tilde{g}_{ij}^r\right),\ g_j^-=\min_i(g_{ij}^l)$$

&

$$\tilde{W}_j=\left(\frac{w_j^-}{w_j^r},\frac{w_j^-}{w_j^m},\frac{w_j^-}{w_j^l}\right)=\left(\tilde{w}_j^l,\tilde{w}_j^m,\tilde{w}_j^r\right),\ w_j^-=\min_i(w_j^l)$$

where $\tilde{G}_{ij}$ and $\tilde{W}_j$ are normalized values of G_{ij} and W_j respectively.

Step 3: The separated value $Ld(\tilde{G}_{ij},Lb)$ between normalized ratings $\tilde{G}_{ij}$ with lower boundary (Lb) and the separated value *Ud* $(\tilde{G}_{ij}$ *, Ub)* between normalized ratings $\tilde{G}_{ij}$ with upper boundary (Ub) are calculated respectively as

$$Ld(\tilde{G}_{ij},Lb)=\int_0^1\left(\tilde{G}_{ij}\right)_\alpha^L d\alpha=\frac{\tilde{g}_{ij}^l+\tilde{g}_{ij}^m}{2},$$

$$Ud(\tilde{G}_{ij},Ub)=\int_0^1(2-(G_{ij})_\alpha^L)d\alpha=\frac{4-\tilde{g}_{ij}^m-\tilde{g}_{ij}^r}{2}$$

Step4: Calculate the relative difference $d\tilde{G}_{ij}$ of ratings between lower and upper boundaries of the criteria as follows:

$$d\tilde{G}_{ij}=\frac{Ld(\tilde{G}_{ij},Lb)}{Ud(\tilde{G}_{ij},Ub)}=\frac{\int_0^1\left(G_{ij}\right)_\alpha^L d\alpha}{\int_0^1\left(2-\left(G_{ij}\right)_\alpha^L\right)d\alpha}=\frac{\tilde{g}_{ij}^l+\tilde{g}_{ij}^m}{4-\tilde{g}_{ij}^m-\tilde{g}_{ij}^r}$$

Step5: Multiplying relative difference $d\tilde{G}_{ij}$ with relative weight $\tilde{W}_j$, the weighted difference $D\tilde{G}_{ij}$ is presented as follows:

$D\tilde{G}_{ij}=d\tilde{G}_{ij}.W_j\ for\ i=1,2,\ldots.,m;\ j=1,2,\ldots\ldots,n.$

since both $d\tilde{G}_{ij}$ and $\tilde{W}_j$ are in [0, 1].

Step 6: Calculate separated value $D_{\tilde{g}}^-$ between relative difference $d\tilde{G}_{ij}$ with lower boundary on C_j

$$D_{ij}^-=Ld(D\tilde{G}_{ij},Lb)=\sum_0\left(D\tilde{G}_{ij}\right)_\alpha d\alpha=\left(\frac{\tilde{g}_{ij}^l+\tilde{g}_{ij}^m}{4-\tilde{g}_{ij}^m-\tilde{g}_{ij}^r}\right)\left(\frac{w_j^l+w_j^m}{2}\right)$$

Step7: Calculate separated value $D_{\tilde{g}}^-$ between relative difference $d\tilde{G}_{ij}$ with upper boundary as

$$D_{ij}^+=Ud(D\tilde{G}_{ij},Lb)=\int_0^1(2-(D\tilde{G}_{ij})_\alpha^U)d\alpha=\left(2-\frac{\tilde{g}_{ij}^l+\tilde{g}_{ij}^m}{4-\tilde{g}_{ij}^m-\tilde{g}_{ij}^r}\right)\left(\frac{w_j-w_j^m}{2}\right)$$

Step8: Integrating separated value between weighted differences and lower bound on criteria for alternatives A_i, and using Step 6, we get negative separated degree D_i^-

$$D_i^- = \sum_{j=1}^{n} D_{ij}^- = \sum_{j=1}^{n} Ld(D\tilde{G}_{ij}, Db)$$

Step 9: Integrating separated value between weighted differences and upper bound on criteria for alternatives A_i, and using Step 7, we get positive separated degree D_i^+:

$$D_i^+ = \sum_{j=1}^{n} D_{ij}^+ = \sum_{j=1}^{n} UD(D\tilde{G}_{ij}, Ub)$$

Step 10: Calculate the Total Performance Index D_i^* by getting the ratio of D_i^- over D_i^+ as: $D_i^* = \dfrac{D_i^-}{D_i^+}$, $i = 1,2,\ldots\ldots, m$.

Finally the ranking order is calculated on the basis of above steps.

Real Application Based Case Study

Microtek International Pvt. Ltd. is the India's largest power products manufacturer like Line Interactive UPS, online UPS, and Digital & Sine wave Inverters. Microtek has very strong infrastructural Network, presently having 8 manufacturing plants, 305 Service Points, 50 Service Centers, 12000 Distributors and Dealers, 500 exclusive Shoppe spread all across India. Due to economic inflation, steep competition and volatile market nature, Microtek has gone for outsourcing of battery parts from various manufacturing companies like AMARON Batteries, EXIDE India ltd, OKAYA Batteries, AMCO Batteries, PANASONIC Energy ltd & POWER ZONE Battery. Three expert decision-makers in their field, D_1 (Electronics Engineer), D_2 (Marketing Manager), and D_3 (Economics analyst) are engaged in ranking low risk suppliers of Batteries for UPS and Invertors of MICROTEK among four alternatives, Amaron Batteries (A_1), Exide India ltd (A_2), Panasonic Energy India (A_3) and Power zone batteries (A_4) with respect to five risk attributes, namely, Contract and quality risk (C_1), Logistics and inventory risk (C_2), Information risk(C_3), Environmental risk(C_4), and Macro-political risks (C_5).

So, let X be a set of 4 alternative companies, where, X= {A_1, A_2, A_3, A_4} and F be a set of 5 risk criteria's where F= {C_1, C_2, C_3, C_4, C_5}. The linguistic variables for importance weight of each risk criterion and linguistic variables for ratings of alternatives suppliers are given in Table 1. and Table 2. Based on above algorithm, the low risk alternative supplier is calculated and shown through following Tables. The ranking order is $A_2 > A_1 > A_4 > A_3$, based on total performance indices of table 14. So, the low risk based company is A_2 Exide India ltd .

Table 1: Linguistic variables for importance weight of each criteria

Linguistic variables	Triangular fuzzy numbers
Very low (VL)	(0, 0, 0.2)
Low (L)	(0.1, 0.2, 0.3)
Medium Low (ML)	(0.2, 0.35, 0.5)
Medium (M)	(0.4, 0.5, 0.6)
Medium High (MH)	(0.5, 0.65, 0.8)
High (H)	(0.7, 0.8, 0.9)
Very High (VH)	(0.8, 1, 1)

Table 2: Linguistic variables for ratings of alternatives.

Linguistic variables	Triangular fuzzy numbers
Very Poor (VP)	(0, 0, 2)
Poor (P)	(1,2,3)
Medium Poor (MP)	(2, 3.5, 5)
Fair (F)	(4, 5, 6)
Medium Good (MG)	(5, 6.5, 8)
Good (G)	(7, 8, 9)
Very Good (VG)	(8, 10, 10)

Table 3: Importance weight of criteria from three decision-makers

Criteria	Decision -Makers		
	D_1	D_2	D_3
C_1	VH	VH	VH
C_2	H	H	H
C_3	VH	H	VH
C_4	MH	H	MH
C_5	H	MH	H

Table 4: Ratings of the three alternatives by decision-makers under seven criteria

Criteria	Alternatives	Decision-makers		
		D_1	D_2	D_3
C_1	A_1	MG	MG	G
	A_2	G	G	MG
	A_3	G	G	VG
	A_4	VG	G	VG
C_2	A_1	F	F	MG
	A_2	MG	F	MG
	A_3	G	G	G
	A_4	VG	G	MG
C_3	A_1	MG	F	G
	A_2	F	F	MG
	A_3	G	G	F
	A_4	VG	MG	MG
C_4	A_1	G	F	F
	A_2	MG	MG	MG
	A_3	MG	G	VG
	A_4	VG	G	VG
C_5	A_1	F	F	F
	A_2	G	F	F
	A_3	G	G	F
	A_4	F	MG	G

Table- 5 Fuzzy decision matrix and fuzzy weights of four alternatives

	A_1	A_2	A_3	A_4	Weight
C_1	(5, 7, 9)	(5,7.5, 9)	(7, 8.6, 10)	(7, 9.3, 10)	(0.8,1.0,1.0)
C_2	(4, 5.5, 8)	(4, 6, 8)	(7, 8, 9)	(5, 8.1, 10)	(0.7, 0.8, 0.9)
C_3	(4, 6.5, 9)	(4, 5.5, 8)	(4, 7, 9)	(5, 7.6, 10)	(0.7, 0.93,1)
C_4	(4, 6,9)	(5,6.5, 8)	(5, 8.1, 10)	(7, 9.3, 10)	(0.5, 0.7, 0.9)
C_5	(4, 5, 6)	(4, 7, 9)	(4, 7, 9)	(4, 6.5, 9)	(0.5, 0.96, 0.9)

Table- 6 The separated values between normalized ratings $\tilde{G}_{ij}$ and lower boundary (Lb)

$Ld(\tilde{G}_{ij}, Lb)$	A_1	A_2	A_3	A_4
C_1	0.508	0.489	0.433	0.415
C_2	0.614	0.583	0.472	0.447
C_3	0.530	0.614	0.508	0.463
C_4	0.556	0.558	0.447	0.415
C_5	0.733	0.508	0.508	0.530

Table- 7 The separated values between normalized ratings $\tilde{G}_{ij}$ and upper boundary(Ub)

$Ud(\tilde{G}_{ij}, Ub)$	A_1	A_2	A_3	A_4
C_1	1.314	1.333	1.482	1.499
C_2	1.136	1.167	1.464	1.353
C_3	1.192	1.136	1.214	1.337
C_1	1.167	1.292	1.353	1.499
C_5	1.100	1.214	1.214	1.192

Table- 8 The relative differences of ratings of boundaries of five criteria with four suppliers

$d\tilde{G}_{ij}$	A_1	A_2	A_3	A_4
C_1	0.386	0.367	0.292	0.277
C_2	0.540	0.500	0.322	0.333
C_3	0.444	0.540	0.418	0.346
C_4	0.476	0.432	0.333	0.277
C_5	0.667	0.418	0.418	0.444

Table - 9 The weighted differences of three companies on five criteria

$D\tilde{G}_{ij}$	A_1	A_2	A_3	A_4
C_1	(0.19, 0.19, 0.24)	(0.18, 0.18, 0.22)	(0.14, 0.14, 0.18)	(0.13, 0.27, 0.17)
C_2	(0.30, 0.33, 0.38)	(0.45, 0.31, 0.35)	(0.17, 0.20, 0.23)	(0.18, 0.26, 0.23)
C_3	(0.22, 0.23, 0.31)	(0.37, 0.29, 0.27)	(0.20, 0.22, 0.29)	(0.17, 0.32, 0.24)
C_4	(0.26, 0.34, 0.47)	(0.38, 0.30, 0.43)	(0.18, 0.23, 0.33)	(0.15, 0.19, 0.27)
C_5	(0.37, 0.34, 0.66)	(0.37, 0.21, 0.41)	(0.23, 0.21, 0.41)	(0.24, 0.42, 0.44)

Table-10 The separated values between weighted differences and lower boundary on five criteria

D_{ij}^{-}	A_1	A_2	A_3	A_4
C_1	0.193	0.183	0.146	0.208
C_2	0.319	0.381	0.190	0.224
C_3	0.231	0.334	0.217	0.248
C_4	0.302	0.348	0.210	0.174
C_5	0.359	0.297	0.225	0.337

Table- 11 The separated values between weighted differences and upper boundary on five criteria

D_{ij}^{+}	A_1	A_2	A_3	A_4
C_1	1.783	1.794	1.836	1.775
C_2	1.638	1.665	1.784	1.750
C_3	1.722	1.720	1.738	1.715
C_4	1.592	1.630	1.717	1.765
C_5	1.493	1.682	1.682	1.564

Table- 12 The separated degrees of suppliers and boundaries

	D_i	D_i^{+}
A_1	1.404	8.228
A_2	1.544	8.491
A_3	0.988	8.757
A_4	1.190	8.569

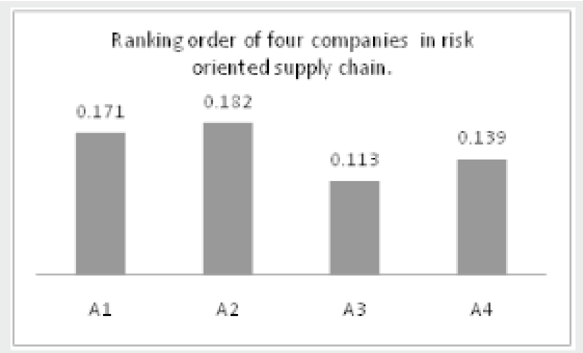
Table- 13 The Total performance indices D_{ij}^{1} of suppliers

	D_{ij}^{1}
A_1	0.171
A_2	0.182
A_3	0.113
A_4	0.139

Result Discussion

Based on the above fuzzy lower and upper boundary approach, the ranking order of the battery manufacturing companies:

Figure- 1 Total performance indices of battery manufacturing companies.



Conclusion and Future Scope of Research

The integrated advantage of this method is that it allow for the vague aspirations of Decision making to set multiple aspiration levels for supplier selection problems. Furthermore, this approach provides a more accurate and systematic decision support tool. By FMCDM model, decision makers can find out alternatives total performance indices, and find the less risk alternative. Some hidden risks can be incorporated into the model and optimal quality risk level can be a supply chain measurement for supplier selection in future. proposed method may be useful for various MCDM problems project management and location selection for warehousing and marketing problems (when available data are inexact, vague, imprecise and uncertain by nature.

References

Haqand, A.N. & Kannan, G. (2006). Fuzzy analytical hierarchy process for evaluating and selecting a vendor in a supply chain model, International Journal of Advanced Manufacturing Technology, 29, 826–835.

Benitez, J.M., Martin, J. & Roman, C. (2007). Using fuzzy number for measuring quality of service in the hotel industry, Tourism Management, 28(2), 544-555.

Chen, C & Huang, S.F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management, International Journal of Production Economics, 102(2), 289-301.

Li, D.F. (2007) Compromise ratio method for fuzzy multi-attribute group decision making, Applied soft computing, 7(3), 807-817.

Chen, C.T. (2000). Extensions to the TOPSIS for group decision-making under fuzzy environment, Fuzzy Sets and Systems, 114, 1-9.

Wang, Y.J., Lee, H.S. & Lin, K. (2003). Fuzzy TOPSIS for multi-criteria decision making, International mathematics journal, 3, 367-379.

Wang, Y.J.(2011). A fuzzy multi-criteria decision-making model based on lower and upper boundaries, Applied Mathematical Modeling, 35, 3213-3224.

R. Bellman & L.A. Zadeh, (1970). Decision-making in a fuzzy environment, Management Science 17,141–164.