ISSN 1816-6075 (Print), 1818-0523 (Online)
Journal of System and Management Sciences
Vol. 2 (2012) No. 4, pp. 37-43

Supply chain risks evaluation model in fuzzy environment

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Abstract: In this paper, we analyzed the classification of supply chain risk (SCR), and put forward its index systems on the basis of its many results. According to its characteristics, we established the general assessment model of SCR in fuzzy environment. Then, we proposed its improved model by the fuzzy information measurement system with the interpretation and synthetic effect. Finally, we specified numerical example to analyze the model, the results indicate that the method is not only accommodates the existing fuzzy decision-making methods, but also successfully incorporates the decision preference into the optimization process. Therefore, the fuzzy analysis technique can be widely used in many fields of fuzzy risk assessment.

Keywords: Supply Chain Risk, Evaluation Index System, Evaluation Model, Fuzzy Number, Synthetic Effect

1. Introduction

With the deepening of supply chain management (SCM) in enterprises and inter-enterprises, its application has been more widely in the actual manufacturing operations, and has brought more profit to the enterprise, however, bringing the more profitable at the same time, its risks have been revealed, and have caused some negative impact because managers or decision-makers were not enough to prevent and manage risk and were even ill-prepared (Zsidisin, 2003). Such as the rupture of relations between the node enterprises in supply chain, the business failure of a node enterprise passed to the entire supply chain network, which leads to more complex supply chain risks. Therefore, the SCR management has been more and more the attention by the experts and enterprise. These risks are objective reality and have consequential, If they could ignored or handled properly, these risks could led to the failure of the supply chain cooperation, and caused losses to enterprises and the whole supply chain. So, taking SCR and its sources, clear its state, these can not only help supply chain companies to effectively control and deal with risks, but also to provide support for the efficient operation and science management of the supply chain.

In recent years, it has become an important aspect of SCM with the deepening of research on SCR management; especially in SCR evaluations, a number of SCM researchers have been focus on its risk evaluations (Zhu, et al., 2006).SCR evaluation is about the measurement of SCR, major identification methods include Delphi, the flow chart, decomposition analysis, fault tree analysis, risk questionnaires, scenario analysis, Etc. It is worth noting that some scholars have begun to study quantitative methods and constructed the model to evaluate SCR, includes: fuzzy risk factors analysis method, AHP, Mean-Variance Model, CVaR, Multiple Attribute Decision Making, risk diffusion model Etc., but these methods and models have their advantages and disadvantages.

In this paper, we consider many factors of the SCR, and establish a generalization model for risk assessment based on fuzzy theory. We put forward the concept of level effect function for describing fuzzy information processing, and establish concentrated quantification method of fuzzy information with wide application. Further, we establish a fuzzy information comparison method based on synthesizing effect and the improved model of the fuzzy risk model. Finally, we specified cases to analyze the characteristics of the model, These work laid a foundation for establishing different risk evaluation, and systematically enrich information processing and comprehensive evaluation theories, they can not only realize the transformation between qualitative depiction and quantitative description, but effectively merge decision preference into decision process. Therefore, the discussions have important guiding significance for uncertain decision problems.

2. SCR evaluation model in fuzzy environment

2. 1 Fuzzy number and operations

In the following, let R be the real number field, $F(R)$ the family of all fuzzy sets over R. For any $A \in F(R)$, the membership function of A is written as $A(x)$, the λ-cuts of A as $A_\lambda = \{x \mid A(x) \geq \lambda\}$ and the support set of A as supp$A = \{x \mid A(x)\ 0\}$.

In what following, we introduce the definition of fuzzy number and its basic operation properties.

Definition 1(Goetschel & Voxman, 1983**)** $A \in F(R)$ is called a fuzzy number if it satisfies the following conditions:

1) For any given $\lambda \in (0, 1]$, A_λ are closed intervals; 2) $A_1=\{x \mid A(x)=1\} \neq \phi$; 3) supp$A$ is bounded. The class of all fuzzy numbers is called fuzzy number space, which is denoted by E^1. In particular, if there exists a, b, $c \in R$ $A(x) = (x-a)/(b-a)$ such that $x \in [a, b)$, $A(b) =1$, $A(x) = (x-c)/(b-c)$ for each $x \in (b, c]$, and $A(x) =0$ for each $x \in (-\infty, a) \cup (c, +\infty)$, then we say that A is a triangular fuzzy number, and written as $A = (a, b, c)$ for short.

For $A \in E^1$, it is easily to see that the closure of suppA is closed interval, in what follows we denote the closure of suppA by A_0. By Definition 1, we can prove that $A_\lambda = [a + (b-a)\lambda, c-(c-b)\lambda]$ for any $A = (a, b, c)$ and $\lambda \in [0, 1]$.

Theorem 1(Diamond & Kloeden, 1994) *Let* A, $B \in E^1$, $k \in R$, $f(x, y)$ be a continuous binary function,
A_λ, B_λ be the λ - cuts of A and B, respectively. Then $f(A, B) \in E^1$, and $(f(A,B))_\lambda = (A_\lambda, B_\lambda)$ for any $\lambda \in (0, 1]$. In particular, we have: 1) $A+B= B+A$, $A \cdot B=B \cdot A$, $k(A \pm B)=kA \pm kB$; 2) For $A=(a_1, b_1, c_1)$, $B=(a_2, b_2, c_2)$, $A+B=(a_1+a_2, b_1+b_2, c_1+c_2)$, $A-B=(a_1-c_2, b_1-b_2, c_1-c_2)$, $kA=(ka_1, kb_1, kc_1)$ for any $k<0$, and $kA=(kc_1, kb_1, ka_1)$ for any k<0. Here, $f(A_\lambda, B_\lambda)=\{f(x, y) \mid x \in A_\lambda, y \in B_\lambda\}$.

2. 2 the ranking methods of fuzzy number about synthesis effect

Ordering fuzzy numbers, a main part of the theory of fuzzy numbers, is the key to fuzzy optimization problems. Up to now, the usually procedure is to map fuzzy numbers by an appropriate transformation into a real number and thus realize a comparison and ordering of fuzzy numbers. To establish a general quantification of fuzzy information, we introduce the following definition (Li, et al., 2012).

Definition 2 We call $L(\lambda) : [0, 1] \to [a, b] \subset [0, \infty)$ a level effect function, if $L(\lambda)$ is piecewise continuous and monotone non-decreasing. For $A \in E^1$, let

$$I_L(A) = \frac{1}{2L^*}\int_0^1 L(\lambda)\left(\overline{a}(\lambda) + \underline{a}(\lambda)\right)d\lambda, U_L(A) = \frac{1}{2L^*}\int_0^1 L(\lambda)\left(\overline{a}(\lambda) - \underline{a}(\lambda)\right)d\lambda \quad (1)$$

Then $I_L(A)$ is called the centralized quantification principle value of A, and $U_L(A)$ is the dispersion of A. When $L^*=0$, we define $I_L = \left[\underline{a}(1) + \underline{a}(1)\right]/2$, and $U_L(A) = \overline{a}(1) - \underline{a}(1)$. Here, $A_\lambda = [\underline{a}(\lambda), \overline{a}(\lambda)]$ is the λ-cuts of A,
$L^* = \int_0^1 L(\lambda)d\lambda$.

Theorem 2 Let *A*, *B* $\in E^1$, *a*, *k* $\in R$. Then: 1) $I_L(A \underline{+} B) = I_L(A) \underline{+} I_L(B)$, $U_L(A \underline{+} B) = U_L(A) \underline{+} U_L(B)$; 2) $\mathrm{I_L(kA) = kI_L(A), U_L(kA) = |k| U_L(A)}$; 3) $I_L(a + A) = a + I_L(A)$, $U_L(a + A) = U_L(A)$.

Theorem 3 For $A = (a, b, c)$, $\alpha \in [0, \infty)$, when $\mathrm{L}(\lambda) = \lambda^\alpha$, we have

$$I_L(A) = \frac{a+2\alpha b+c}{2(\alpha+2)}, U_L(A) = \frac{c-a}{(\alpha+1)(\alpha+2)}. \tag{2}$$

Definition 3 A continuous function $S(x, y)(-\infty,+\infty)\times[0,+\infty)\rightarrow(-\infty,+\infty)$ is called a maximum synthesizing effect function, if it satisfies: 1) $S(x, y)$ is monotone non-decreasing on x for any $y \geq 0$; 2) $S(x, y)$ is monotone non-decreasing on y for any $x \in (-\infty,\infty)$; 3) $S(x, y) \leq x$, $S(x,0)=x$.

If we regard x and y as $I_L(A)$ and $U_L(A)$ of A respectively, then

$$S_L(A) = \mathrm{S}(I_L(A), U_L(A)) \tag{3}$$

is a compound quantification method of fuzzy information considering both I_L-metric and U_L-dispersion. And this method not only contains I_L-metric, but it has better interpretability. In practical problems, we can choose different synthesizing effect function to embody different uncertainty conscious in the decision process.

2.3 The evaluation model of SRC based on synthesis effect

Based on the collation of relevant knowledge about fuzzy numbers, complex quantitative methods and their synthetic effect in the section 2.1 and section 2.2, we construct the assessment model of SCR under fuzzy environment as follows:

$$OptR^*(P_i) = S(I_L(R(P_i)), U_L(R(P_i)))$$

$$(\mathrm{PI}) \qquad s.t \begin{cases} R(\mathrm{P}_i) = \sum_j^m w_j \tilde{r}_{ij} \\ \tilde{r}_{ij} = f(\mathrm{P}_i, u_j), i = 1, 2, \cdots, n, \ j = 1, 2, \cdots, m \\ P_i \in RP_I \\ u = \{u_1, u_2, \cdots, u_m\} \\ \sum_i^m w_j = 1, w_j \in [0,1] \end{cases} \tag{4}$$

Here, $\boldsymbol{R}^*(\boldsymbol{P_i})$ is the objective function and SCR evaluation result, it can not only be denoted a sort of risk values, but also be denoted the maximum risk value. $RP_I = \{\mathrm{P}_1, \mathrm{P}_2, \cdots, \mathrm{P}_n\}$ denotes all the node enterprises of SC Network (Number n); $u=\{u_1,u_2,\ldots,u_m\}$ is the risk index systems sets of SCR; $\tilde{r}_{ij} = f(\mathrm{P}_i, u_j)$ is the fuzzy evaluation result of P_i on the jth risk index u_j; $w = \{w_1, w_2, \cdots, w_m\}$ denotes the degree of importance of risk index, and $\sum_i^m w_j = 1$, $w_j \in [0,1]$; $I_L(A)$ is the I_L-metric of $R(P_i)$, $U_L(A)$ is the U_L-dispersion of $R(P_i)$, $S(x, y)$ is the maximum synthesizing effect function.

3. Numerical examples

In this paper, we selected the conglomerates supply chain including suppliers, manufacturers, distributors, retailers and 3PLs, took into account it's the various risk factors, selected expert system such as shown in Schedule1., and obtained their fuzzy evaluation value for indicators by the questionnaires(shown schedule1). Then, Given $L(\lambda)=\lambda$ or $L(\lambda)=\lambda^{\tau}$, synthetic effect function $S(x, y)= x((1+ay)^{-b})$, and different parameter values, we dealt with the data of the conglomerates SRC with utilizing model(PI) in Part 3 . Finally, we calculated evaluation values and obtained the sorting results for SRC various values, shown in Table1.

Table1. The various sorting results for SRC values in different parameters

parameters	a=5,b=1		a=0.5,b=1		a=0.5,b=0.005		a=5,b=0.005	
$L(\lambda)=\lambda$	RV	RS	RV	RS	RV	RS	RV	RS
Suppliers	1.2076	5	9.3106	5	37.2084	3	36.8292	3
Manufacturers	1.3822	3	10.2275	4	37.1550	5	36.7820	5
Distributors	1.5351	1	11.2797	1	39.2015	1	38.8108	1
Retailers	1.3696	4	10.2771	3	37.1965	4	36.8230	4
3PLS	1.4738	2	10.9092	2	38.7401	2	38.3525	2
a=0.5,b=1	τ =0.5		τ = 1		τ =2		τ =3	
$L(\lambda)=\lambda^{\tau}$	RV	RS	RV	RS	RV	RS	RV	RS
Suppliers	5.8391	5	9.3106	5	16.5810	5	23.1595	5
Manufacturers	6.4227	4	10.2275	4	18.0177	3	24.8893	3
Distributors	7.1520	1	11.2797	1	19.5956	1	26.7860	1
Retailers	6.5250	3	10.2771	3	17.9075	4	24.5702	4
3PLS	6.9681	2	10.9092	2	18.8573	2	25.7535	2

Note: RV (Risk value); RS (Risk sort)

From Table1, we can see each node enterprise in supply chain that the evaluation values of the Distributors' risk are the highest, and the followed 3PLS, and the Suppliers' risk values are the lowest; we obtained the evaluation value of each node enterprise, as well as the difference results of the risk value sort by setting different parameters. Overall, little change especially in high-risk value. In short, these results indicate that the model (PI) is integration into the artificial sense in the decision-making process, and fully reflects the good characteristics, which we used the synthetic effect function to deal with fuzzy information.

4. Conclusion

In this paper, according to supply chain risk characteristics and the researched results of its assessment methods, we investigated the scheduling problem of the SRC value, the main conclusions:① Based on the induction of the previous work, and Combining with the basic principles of SCR indicators and data integration, we proposed SCR index system; ② By combining fuzzy characteristic in SRC indicators, we establish a fuzzy information comparison method based on synthesizing effect, and SCR assessment model; ③ Combining with numerical examples, we analyzed and discussed for SRC evaluation values. The results indicate that the method is not only accommodates the existing fuzzy decision-making methods, but also successfully incorporates the decision preference into the optimization process. Therefore, the fuzzy analysis technique can be widely used in many fields of fuzzy risk assessment.

Acknowledgments

This paper is supported by the project from National Key Technologies R & D Program of China (2012BAH20B03), and Supported by the National Natural Science Foundation of China (71071049,71173129),and Supported by the National Social Science Fund(11AZD011),and Supported by Hebei University of Science and Technology Foundation (XL200761).

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Schedule 1. The SCR evaluation index systems

Target	L index	T index	Weight	Suppliers			Manufacturers			Distributors			Retailers			3PL		
SCR	Environmental risks (0.2039)	natural risks	0.1927	34	59	80	41	50	81	22	44	82	34	56	74	37	46	69
		social risks	0.1726	27	39	62	20	56	77	37	50	70	44	56	79	38	43	69
		policy risks	0.3256	44	62	84	55	66	81	44	66	81	50	74	88	39	46	73
		market risks	0.2124	46	62	84	51	70	85	45	59	82	44	54	70	30	42	64
		logistics risks	0.0966	30	43	64	37	53	69	31	38	60	34	44	64	36	52	68
	Financial Risks (0.1407)	financing risks	0.3802	47	62	83	35	55	77	44	63	75	59	61	75	47	59	68
		Investment risk	0.3703	35	59	73	30	57	74	41	59	81	43	67	86	33	47	59
		cost risks	0.2495	31	44	61	25	39	58	31	54	66	41	56	65	31	50	57
	Coordinate risks (0.3638)	credit risks	0.1803	49	65	84	51	74	82	52	63	78	47	66	75	46	57	73
		cooperation interrupt risks	0.1603	40	59	75	47	51	79	54	66	74	46	66	76	36	47	68
		Communication delay risks	0.1877	55	59	75	49	63	83	54	69	90	37	51	83	38	54	76
		Leakage risks	0.2056	49	59	80	44	60	76	50	63	74	52	65	88	46	65	83
		conflict risks	0.0682	34	40	64	35	50	79	38	61	70	44	54	72	30	47	68
		Information risks	0.1138	34	45	61	31	43	64	38	50	66	30	57	75	29	59	67
		Compliance delay risks	0.0841	20	36	54	28	40	59	33	47	64	38	50	68	36	58	69
	Competitive risks (0.1158)	Alternatives risks	0.2192	35	39	61	31	46	61	32	43	67	33	41	67	36	50	68
		Intraindustry competition risks	0.2157	24	35	54	37	52	66	33	46	59	35	44	61	32	50	65
		Technology steal and imitate	0.5643	55	64	84	51	66	80	47	57	84	51	61	88	48	66	79
	Systemic Risks (0.1758)	market lemons risks	0.4790	55	64	84	49	62	81	54	63	84	56	61	85	48	66	87
		governance risks	0.2702	47	53	67	38	54	77	52	60	84	44	54	71	25	52	69
		Market cycle risks	0.1354	39	49	67	35	61	90	35	39	60	36	49	67	30	48	74
		Technical effect uncertain	0.1155	32	33	47	20	29	46	28	43	60	29	44	65	25	46	59