Identification and Evaluation of Supply Chain Fault Risk

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Abstract: Supply chain risk is the key factor which affects supply chain practice application, and accordingly supply chain risk management becomes the important content. Fault tree analysis and fuzzy theory are applied to analyze supply chain risk. Fault tree of supply chain failure risk is built. The fault tree is made up of supplier, manufacturer and distribution dealer. The failure reasons of every part are analyzed. The fuzzy operators of normal fuzzy function are designed. The computation methods of supply chain risk are expounded. A supply chain risk instance is presented. Every events failure risk is quantified and computed. Finally, the risk rank of supply chain failure is ascertained.

Keywords: supply chain, risk, fault tree analysis, fuzzy

1. Introduction

Supply chain will be main unit in future market. However, supply chain risk has become the main obstacle of supply chain management. The risk destruction degree for supply chain is severer than for single enterprise. In order to reinforce the competition ability and reduce the loss, enterprise must analyze the supply chain risk deep, and adopt ways to control the risk which may destroy the supply chain. The objectives can be achieved only if the fit risk management and control measures are adopted. Hence, the enterprise should pay attention to the supply chain management and actualize the effective risk identification methods.

Supply chain risk is the probability of some uncertain loss arising from supply chain. The uncertain includes all factors which affect supply chain safe operation. These factors can prevent supply chain from achieving the prospective objective, and accordingly lead to the whole cost increase and the efficiency decline.

Though supply chain is the hot research spot recently and lots of relevant papers are published, supply chain risk evaluation is researched seldom and the relevant papers are few [1]. David [2], Prater [3], Teresa [4] and other scholars has researched the problem, and achieved some fruits. Fault tree theory is derived from the reliability engineering and is one of most effective methods for reliability analysis of system[5]. In the paper, supply chain risk will be studied with fault tree theory and fuzzy theory.

2. Fault Tree Analysis

When H. A. Watson analyzed the safe of the missile launch control system in 1961, fault tree model was firstly set up and the exact judgment result was obtained. The fault tree model improved the safe of the missile launch control system very much. Hereafter, more and more theoretical researchers started to go into the research and application of the fault tree theory, and accordingly the fault tree theory is developed continually. With the development of the fault tree theory, the technology component became less and less, and the scientific component became more and more. Nowadays the fault tree theory has been applied widely in many fields such as the aviation, the mechanics, the electron industry and the economy management.

2.1 Conception of fault tree

(1) event

Top event is defined as the fault state the system hope to produce least of all. Middle event is defined as the direct reasons which lead to the fault state. Basic event is defined as the direct reasons which lead to the middle event.

(2) minimal cut set

Minimal cut set is defined as the minimal basic event set lead to top event. The amount of the basic event is named as order. In the minimal cut set, each basic event appearance maybe lead to top event appearance.

(3) fault tree

Basic event, middle event and top event are connected with the symbol and the logic gate to form the logic tree chart. The logic tree chart is named as fault tree. Fault tree is special logic causality chart like headstand tree. It expresses the causality relation among all events with the event symbol, the logic gate and the transition symbol.

(4) or gate

Or gate is the logic relation where if only one or more input event appearance can make output event appearance.

(5) and gate

And gate is the logic relation where only if all input events appearance can make output event appearance.

2.2 Fault tree construction

Fault tree construction is the precondition of applying fault tree analysis. The perfect integrality of fault tree directly decides whether judgment is exact. Hence it's very important to build clear and complete fault tree. The detailed construction steps of fault tree is as follows: ① write down the most unwilling fault event of system (top event), and list the direct reasons leading to the fault event under the top event (middle event); ② express the top event and the middle events with symbol, and connect them with logic

gates; ③ farther educe the direct reasons for the middle events under them, and connect them with the middle events with the logic gates. Repeat step ①, ② and ③ until all reasons lead to system fault are discovered (basic event).

3. Fuzzy Fault Tree

In traditional fault tree analysis, basic factor (basic event) appearance probability is considered as the exact value. However, the risk event appears with probability, and it's very difficult to ascertain the probability exactly because the factors affecting the events appearance are complex or the statistical data are few, it's difficult to solve the risk analysis problem with the probability model and the statistics methods. Consequently based on the traditional fault tree analysis, the fuzzy fault tree based risk analysis is studied in the paper.

3.1 Fuzzy probability of basic factor

Fuzzy statistics is a kind of method to ascertain the basic factor probability, but this method requires lots of indispensable investigation and statistics. In actual supply chain risk analysis, it's management to ascertain the probability of the basic factor. Because the experience and knowledge level of management differ, the probability values obtained vary very much and accordingly the probability value of basic event appearance is fuzzy. The normal distribution can describe the fuzzy probability of the event with reason, so the normal fuzzy function is adopted in the paper to describe the fuzzy probability $p^{\sim}$ of the event, and the membership function is defined as follows.

$$u_{p^{\sim}}(x) = e^{-[(x-p)/\sigma]^2} \qquad (1)$$

In Equation (1), *P* is the average value of the fuzzy probability, and σ is the deviation of the fuzzy probability. The value of *p* and σ can be obtained by minimal probability value *a*, most possible probability value *b* and maximal probability value *c* from the experience, and the formula are as follows.

$$p = \frac{a+4b+c}{6} \qquad (2)$$

$$\sigma = \frac{c-a}{6} \qquad (3)$$

It's obvious that the most possible probability is not the experiential probability value *b* but the average value *p* of the fuzzy probability. This may be thought as the emendation for the experience.

3.2 Fuzzy function operation

Assuming there are two normal fuzzy numbers. According to the expansion operation principle of the fuzzy function, the probability distribution and the membership function of plus, minus and product for the normal fuzzy function can be deduced [6].

The plus of normal fuzzy numbers is still normal fuzzy number and the membership function is as follows.

$$u_{p_i^{\sim}+p_j^{\sim}}(x) = e^{-[(x-p_i-p_j)/(\sigma_i+\sigma_j)]^2} \qquad (4)$$

The minus of normal fuzzy numbers is still normal fuzzy number and the membership function is as follows.

$$u_{p_i^{\sim}-p_j^{\sim}}(x) = e^{-[(x-p_i+p_j)/(\sigma_i+\sigma_j)]^2} \qquad (5)$$

Especially, $p_j^{\sim} = 1 - p_i^{\sim}$, and it is still normal fuzzy number and the membership function is $u_{1-p_i^{\sim}}(x) = e^{-[(x-1+p_i)/\sigma_i]^2}$.

According to the decomposition theorem of fuzzy number, α-cut set of fuzzy probability $p_i^{\sim}$ can be expressed with $[L_\alpha, R_\alpha]$, here L_α and R_α are respectively the left boundary and the right boundary of α-cut set. According to the expansion operation principle of the fuzzy function, some deductions can be done as follows.

$$\begin{aligned}(p_i^{\sim} \times p_j^{\sim})_\alpha &= [L_{i\alpha} \times L_{j\alpha}, R_{i\alpha} \times R_{j\alpha}] \\ &= [p_i \times p_j - (p_i \times \sigma_j + p_j \times \sigma_i)\sqrt{-\ln\alpha} + \sigma_j \times \sigma_i \times \ln(-\alpha), \\ &\quad p_i \times p_j + (p_i \times \sigma_j + p_j \times \sigma_i)\sqrt{-\ln\alpha} + \sigma_j \times \sigma_i \times \ln(-\alpha)]\end{aligned} \qquad (6)$$

If the last part of boundary above is omitted, simpler result can be obtained as follows.

$$\begin{aligned}(p_i^{\sim} \times p_j^{\sim})_\alpha \approx [&p_i \times p_j - (p_i \times \sigma_j + p_j \times \sigma_i)\sqrt{-\ln\alpha}, \\ &p_i \times p_j + (p_i \times \sigma_j + p_j \times \sigma_i)\sqrt{-\ln\alpha}]\end{aligned} \qquad (7)$$

Hence, the minus of normal fuzzy numbers can be approximately considered as normal fuzzy number and the membership function is as follows.

$$u_{p_i^{\sim} \times p_j^{\sim}}(x) \approx e^{-[(x-p_i \times p_j)/(\sigma_i \times p_j + \sigma_j \times p_i)]^2} \qquad (8)$$

3.3 Fault risk model of supply chain

According to the configuration of the supply chain, it can be known that supply chain fault result from supplier fault or manufacturer fault or distribution dealer fault. According to the intrinsic relation of the supply chain, the fault risk model of the supply chain can be set up. The supply chain fault is defined as top event. Every supplier fault, manufacturer fault and distribution dealer fault is defined as middle event. Basic event is made up of the reasons of supplier fault, the reasons of manufacturer fault and the reasons of distribution dealer fault. All events are connected with logic gates. The fault risk model of the supply chain based on above analysis is built as Fig.1. If any of the supplier, the manufacturer and the distribution dealer fails, supply chain will fail necessarily. So the relation between supply chain fault and supplier fault, manufacturer fault and distribution dealer fault is logic or. Since there *m* suppliers, the supplier comes into existence fault only if they all fail. Accordingly the relation between

supplier fault and Supplier 1 fault, Supplier 2 fault, $\cdots$, Supplier *m* fault is logic and. Similarly, if any of the basic event under supplier fault necessarily results in supplier fault, so the relation between supplier fault and its basic event is logic or. The fault analysis of the manufacturer and the distribution dealer and their logic relation among the basic events are similar.

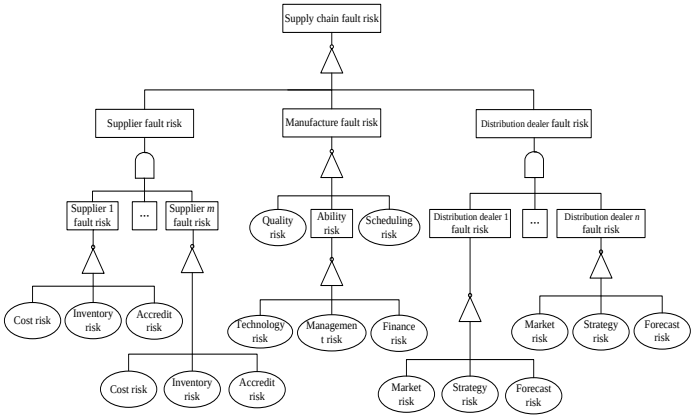

Fig.1 Fault risk tree of supply chain

4. Instance Analysis

A supply chain instance whose core enterprise is a manufacturing enterprise is introduced here and the application of the methods above are shown by the instance. The supply chain is made up of three suppliers (expressed with G_1, G_2, G_3), one manufacture and two distribution dealers (expressed with F_1, F_2, F_3). All basic events are independence each other. Fault tree is built as Fig.2.

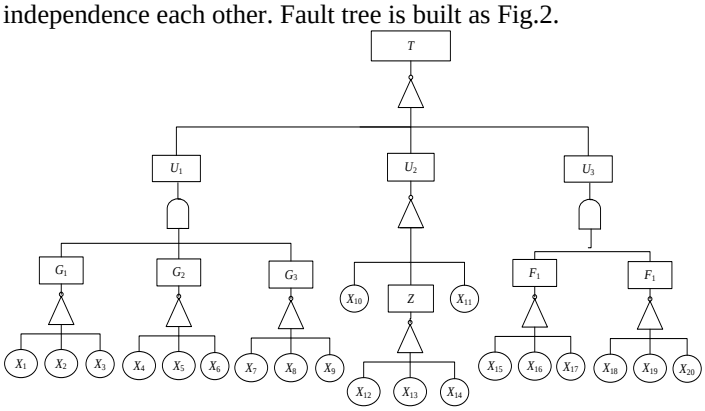

Fig.2 Fault risk tree of supply chain instance

According to statistics analysis of fault event and based on expert judgment, the probability of every basic event appearance in the fault tree can be obtained. The average value and the deviation can be farther achieved by computation with Equation (2) and (3), and the results are shown as Tab.1.

Tab.1 Fuzzy probability of basic factor appearance

factor	Symbol	*a*	*b*	*c*	*p*	σ
Cost risk	X_1	0	0.11	0.22	0.11	0.037
Inventory risk	X_2	0	0.12	0.24	0.12	0.040
Accredit risk	X_3	0	0.12	0.26	0.12	0.043
Cost risk	X_4	0	0.09	0.19	0.09	0.032
Inventory risk	X_5	0	0.10	0.20	0.10	0.033
Accredit risk	X_6	0	0.08	0.17	0.08	0.028
Cost risk	X_7	0	0.14	0.29	0.14	0.048
Inventory risk	X_8	0	0.12	0.25	0.12	0.042
Accredit risk	X_9	0	0.11	0.23	0.11	0.038
Quality risk	X_{10}	0	0.07	0.17	0.07	0.028
Scheduling risk	X_{11}	0	0.06	0.14	0.06	0.023
Technology risk	X_{12}	0	0.06	0.17	0.06	0.028
Management risk	X_{13}	0	0.06	0.14	0.06	0.023
Finance risk	X_{14}	0	0.07	0.16	0.07	0.027
Market risk	X_{15}	0	0.09	0.19	0.09	0.032
Strategy risk	X_{16}	0	0.11	0.21	0.11	0.035
Forecast risk	X_{17}	0	0.13	0.28	0.13	0.047
Market risk	X_{18}	0	0.16	0.32	0.16	0.053
Strategy risk	X_{19}	0	0.11	0.22	0.11	0.037
Forecast risk	X_{20}	0	0.15	0.30	0.15	0.050

According to Fig.2, the real functions of these middle events can be obtained which include G_1(Supplier 1 fault), G_1(Supplier 2 fault), G_3(Supplier 3 fault), Z(Manufacturer ability fault), F_1(Distribution dealer 1 fault), F_2(Distribution dealer 2 fault), U_1(Supplier fault), U_2 (Manufacturer fault), U_3(Distribution dealer fault). These real functions are as follows.

$$G_1 = X_1 + X_2 + X_3$$
$$G_2 = X_4 + X_5 + X_6$$
$$G_3 = X_7 + X_8 + X_9$$
$$Z = X_{12} + X_{13} + X_{14}$$
$$F_1 = X_{15} + X_{16} + X_{17}$$
$$F_2 = X_{18} + X_{19} + X_{20}$$
$$U_1 = G_1 G_2 G_3$$
$$U_2 = X_{10} + Z + X_{11}$$
$$U_3 = F_1 F_2$$

Consequently the real function of top event can be obtained, namely $T = U_1 + U_2 + U_3$, and its fuzzy form is as follows.

$$\tilde{p}_{G_1} = \tilde{p}_{X_1} \oplus \tilde{p}_{X_2} \oplus \tilde{p}_{X_3}$$
$$\tilde{p}_{G_2} = \tilde{p}_{X_4} \oplus \tilde{p}_{X_5} \oplus \tilde{p}_{X_6}$$
$$\tilde{p}_{G_3} = \tilde{p}_{X_7} \oplus \tilde{p}_{X_8} \oplus \tilde{p}_{X_9}$$
$$\tilde{p}_{Z} = \tilde{p}_{X_{12}} \oplus \tilde{p}_{X_{13}} \oplus \tilde{p}_{X_{14}}$$
$$\tilde{p}_{F_1} = \tilde{p}_{X_{15}} \oplus \tilde{p}_{X_{16}} \oplus \tilde{p}_{X_{17}}$$
$$\tilde{p}_{F_1} = \tilde{p}_{X_{18}} \oplus \tilde{p}_{X_{19}} \oplus \tilde{p}_{X_{20}}$$

$$p_{U_1}^{\sim} = p_{G_1}^{\sim} \odot p_{G_2}^{\sim} \odot p_{G_3}^{\sim}$$
$$p_{U_2}^{\sim} = p_{X_{10}}^{\sim} \oplus p_{Z}^{\sim} \oplus p_{X_{11}}^{\sim}$$
$$p_{U_3}^{\sim} = p_{F_1}^{\sim} \odot p_{F_2}^{\sim}$$
$$p_{T}^{\sim} = p_{U_1}^{\sim} \oplus p_{U_2}^{\sim} \oplus p_{U_3}^{\sim}$$

After normal fuzzy operators defined by Equation (4), (5) and (8) are applied to compute the probability, the probability of middle event and top event appearance can be obtained, and the results are shown as Tab.2.

Tab.2 Fuzzy probability of middle event and top event appearance

Risk event	Symbol	Average Value *p*	Deviation σ
Supplier fault risk	U_1	0.035	0.0361
Manufacturer fault risk	U_2	0.320	0.1290
Distribution dealer fault risk	U_3	0.139	0.0479
Distribution dealer 1 fault risk	F_1	0.330	0.1140
Distribution dealer 2 fault risk	F_2	0.420	0.1400
Manufacturer ability fault risk	Z	0.190	0.0780
Supplier 1 fault risk	G_1	0.350	0.1200
Supplier 2 fault risk	G_2	0.270	0.0930
Supplier 3 fault risk	G_3	0.370	0.1280

According to risk rank method, risk can be divided into five ranks, namely, low risk, comparatively low risk, middle risk, comparatively high risk and high risk. Their value range are respectively: [0，0.2], [0.2，0.4], [0.4，0.6], [0.6，0.8], [0.8，1]. It' appear that the fault risk of the supply chain instance belong to middle risk. Related managements should pay attention to the risk event control.

5. Conclusion

Supply chain has been paid attention to by both the academe and the enterprise, but its successful application in practice is still few. A key reason is that people can't manage the risk of supply chain. Hence, supply chain risk management is becoming a hot spot. In the paper, fault tree analysis and fuzzy theory are adopted to study the fault risk of supply chain. The Fault risk tree is built for supply chain. The risk probability is computed and analyzed by a supply chain instance. The supply chain fault risk is quantified and evaluated. These methods provide supply chain risk research with new idea.

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Background of Authors

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