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Risk Modelling of Retail Supply Chain based on Fuzzy Petri Nets

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Abstract: To study the complexity and uncertainty of risks in retail supply chain, FPN(fuzzy Petri net) is used to establish a model based on the risk factors. This method could well describe and analysis the correlation characteristics of complex network chain. The weight of different premise conditions and the initial reliability in FPN are quantified by the structure entropy weight method and the direct fuzzy statistics. Finally, the model is tested with the formal reasoning algorithm. Results show the reasonable analysis ability of the model and the consistent effects with the actual operating of the retail supply chain. This study could provide situational and theoretical support for the retail supply chain enterprise to avoid the risks effectively.

Key words: Supply chain system modeling, fuzzy Petri nets, structure entropy right method, fuzzy statistics, formalized reasoning algorithm

INTRODUCTION

The risk analysis and warning capability is significant to the chain retail enterprises. Risk early warning could make effective measures in advance for the potential risks and assist determining the strategies in time to evade the risks.

Early studies are paid more attention to the risk source analysis (Ding *et al*., 2003; Alberts *et al*., 2010), the building of forewarning index system (Shi *et al*., 2008; Liang *et al*., 2006). Later the researches are based on the supply chain risk modeling and early warning is structured. The dynamic property of retail supply chain usually is modeling with data acquisition from the supply chain and predicted by BP neural network (Fei and Wang, 2008; Li and Wang, 2009), the grey system theory (Shi *et al*., 2008) and so on. For indistinct and uncertain preference characteristics, fuzzy theory and the risk assessment method are provided to build risk prediction and assessment model by Zhang *et al*. (2008). Although these ways are effective analysis methods, the structural properties and preferences of the retail supply chain are not considered and so how to integrate the fitting method with the system performance should be considered.

For the essential network structure of the retail supply chain, the fuzziness of risk factors and the preference characteristics, a risk model is provided in this study by using the FPN (fuzzy Petri net). The quantitative method of the initial reliability on fuzzy place and the network connection weight of the FPN are expressed with formal reasoning algorithm. An example of retail enterprises in supply chain is analysis and simulating. The results show that this method fits for modeling and analysis the risk warning of the complex supply chain with the well feasibility and validity.

THE MAIN RELATION FACTORS

Supply chain risks are defined as uncertain factors and accidents which would cut down the operating efficiency and even lead to supply chain disruption. The analysis of supply chain risk sources and categories is carried based on domestic and foreign literature research (Guo, 2011; Zhang and Li, 2010) and the risk source classification (Fig. 1), which is divided into 6 categories: market and economic environment factors, goods supply factors, inventory factors, the distribution process factors, information transfer factors, strategic culture between enterprises factors.

PRINCIPLE OF MODELING AND REASONING

For the multiple influence factors between enterprises of the retail supply chain are with fuzzy uncertainty during the operation. FPN are used for the risk early warning and assessment in retail supply chain which could well describe intuitively the correlation characteristics of complex network chain.

Petri net is a high-performance modeling and analysis tool, fuzzy Petri net is an expansion and important branch of it (He, 1994), which has been applied to computer

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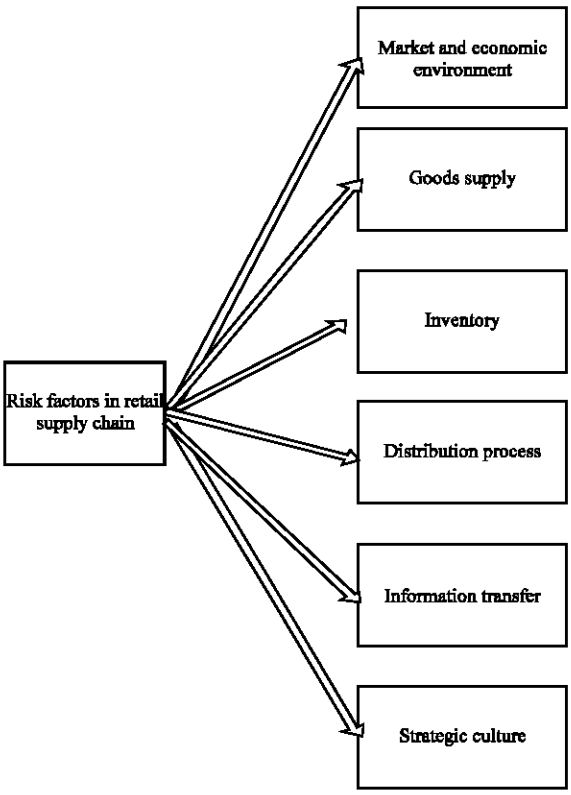

Fig. 1: Risk resources and classifications of the retail supply chain system

networks, engineering management heavily. In essence, considering the structural property of supply chain, the fuzzy Petri net would assist the analysis and reveal the operation characteristics of supply chain system tomorrow.

FPN could be defined as six element array form to describe the interaction of concurrent behavior with fuzzy reasoning.

FPN = {P,T,I,O,τ(t),S0(p)}, while P = {p1, p2, … , pn} is the finite set of the all fuzzy places node, which is also the representation of fuzzy proposition. T = {T1,T2,…,Tm} is the finite set of the all fuzzy transitions node which is also the representation of the fuzzy production rules. I indicates the connection weight coefficient from places to transitions and is subject to 0<I(pi,Tj) = ≤1. O indicates the connection weight coefficient from transitions to places and is subject to 0<O(pi,Tj)≤1. τ(t) indicates the threshold value of transitions and is subject to 0<τ(t) ≤1. Status S and S0(P) indicates the initial status of places, which is also the credibility of known proposition, where the credibility of unknown proposition is defined as zero.

Suppose there are n propositions, m inference rules during the inference procedure with correspond to the n places, m transitions of fuzzy Petri net. Let input I of FPN and output O, threshold τ, status S are defined as matrix or vector (Jia *et al*., 2003), the formal steps reasoning algorithm of the fuzzy Petri net is as follows:

Step 1: Initialization of variables P, T, Δ, Γ , τ, S0(P)
Step 2: Set the counter k = 1
Step 3: Iterating as in Eq. 1, where S_k indicates the status or the proposition of credibility after the k step reasoning

$$S_k = S_{k-1} \oplus \Gamma \cdot ((\Delta^T \cdot S_{k-1}) \otimes ((\Delta^T \cdot S_{k-1}) \Theta \tau)) \quad (1)$$

where, ⊕ indicates the symbol of maximum operation on fuzzy matrix; ⊕ the direct product; Θ the comparison operation, shown as:

$$D = A \Theta B \rightarrow \text{if } a_{ij} \geq b_{ij}, \text{then } d_{ij} = 1; \text{ if } a_{ij} \leq b_{ij}, \text{then } d_{ij} = 0$$

Step 4: If making no change on credibility of any proposition by reasoning, that is $S_k = S_{k-1}$ which means the reasoning is over. Otherwise jump to the reasoning step 3

Clearly, if the initial credibility in input places of FPN and the premise condition of weights in fuzzy rules could be determined objectively, the validity and practicality of the reasoning is easier to accept.

METHOD OF FUZZY STATISTICAL

Evaluation and analysis of the node enterprises (that is the places in Petri net) in supply chain could change with the time and uncertain information change. In this study a fuzzy statistical method is provided to determine the initial credibility of the fuzzy places in the FPN. By direct fuzzy statistical method, the more objective membership functions are obtained which make the quantitative analysis on fuzzy variables in chain retail enterprises feasibly and relatively accurately.

If a node enterprise of the supply chain system want evaluates its ten suppliers on flexibility, a number of experts would score the flexibility performance on each supplier from 0 to 100 at each quarter. The upper 20% suppliers are set as 1, the later 20% are 0 and the linear interpolation is used by their giving scores to get a relative coarse fuzzy membership degree of the flexibility performance by fuzzy statistical shown in Fig. 2a. Where horizontal axis indicates the expert evaluate the performance in a quarter of 2000 year between 55 and 100. The upper score is 85.5 which mean if the average scores

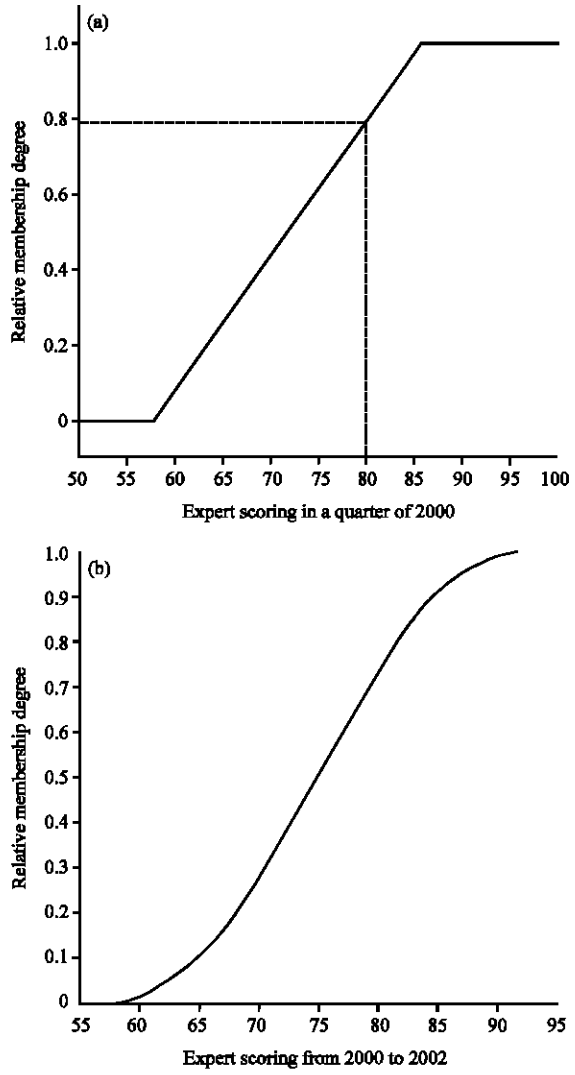

Fig. 2(a-b): Relative fuzzy membership of a retail enterprise in FPN, (a) Determination of relative membership degree in single quarter and (b) Determination of relative membership degree with more quarters

given by experts is over this value then the relative membership degree is 1. While the later score is 58.5, if the scores is under this value then the relative membership degree is 0. The relative membership degree of other scores could be calculated by linear interpolation based on their expert scoring.

Calculate the equation:

$$M(\phi) = \sum_{i=1}^{n} \frac{\phi_{ij}}{nr}$$

to make a count on the flexibility of each supplier at a quarter from 2000 to 2002 year. Where the nr is the total time of the quarter during the evaluation period ϕ_{ii} is a relative fuzzy membership at a quarter and then let M (ϕ) is an average relative fuzzy membership during the statistical period. Figure 2b provides the average relative fuzzy membership of the illustrated enterprise from 2000 to 2002. This is based on 12 quarters data of evaluation and the average expert scores is between 55 and 95.

From the above described, conclusion can be obtained:

- The relative fuzzy membership at each quarter is a curve as half a trapezoid. While the average relative fuzzy membership based on the cumulative scores more than a quarter by direct fuzzy statistics is a unipolar sigmoidal function. Membership function curve would be more smooth and stable with the accretion on the statistical number nr
- For the final relative fuzzy membership is the statistical average on statistical number n from each expert in the panel of judges, eliminate the possible dominant control from anyone. Every expert scoring would influence the shape of the curve on final membership
- It could be seen easily when the status of the system change, the relative fuzzy membership is changing with the scores. Each round of score evaluation could result in amending the relative fuzzy membership function
- For the fuzzy membership function is not select the typical membership function, it could reflect the objectivity and consistency of quality evaluation. So the initial credibility of the fuzzy places in the FPN on supply chain system are set by this way would be more practical and it could be regulated according the change of status with policy or the development trend of the industry

And later the initial credibility of FPN could be quantified. If the raw score on the flexibility of a supplier is 80 in spring quarter of 2003 year, in the light of the average relative fuzzy membership in Fig. 2b, the flexibility is in good state which initial confidence is 0.7338.

STRUCTURE ENTROPY METHOD

Input matrix $\Delta n \times m$ indicates the relationship from inputs or premises to conditions or rules, in this study means the weight from place Pi to transition Tj. When Pi is the input of Tj, $\Delta i \times j$ is the weighting coefficients on the arc, else it is set zero. Where the letter i indicate a number from places n, j is a number from transitions m.

For $\Delta n \times m$ of FPN is on behalf of the premise condition of each contribution to the conclusion, if it is given by experts the human and subjective arbitrariness is unavoidable. This would influence the later inference procedure and even lead to subsequent reliability calculation error.

Structure entropy method (Cheng, 2010) is a way to set prerequisite weight conditions of FPN which combining the subjective preference and objective measure. The specific steps to compute the weights are as follows:

- In accordance with Delphi method, the opinions of k experts are collected so as to form a typical scheduling by the importance under the n preconditions $a_i = \{ a_{i1}, a_{i2}, \ldots , a_{in}\}$ in the same rules where i = 1, 2, ..., k. Using natural numbers {1, 2, …,n} successively indicate the contribution size of each precondition, that is 1 stands for "the greatest contribution" and 2 stands for "the second great contribution" and the meaning of other number take the analogy above
- With the results of the typical scheduling, typical scheduling matrix $A = (a_{ij})_{k\times n}$ could be obtained
- The membership value deduced as (2) by the theory of entropy and the derivation process described detail in Cheng (2010). From the qualitative typical scheduling to make a fuzzy membership matrix $B = (b_{ij})_{k\times n}$, where $b_{ij} = \mu(a_{ij})$ is the fuzzy membership value according to the typical scheduling, r is a transformation parameters r = n+2

$$\mu(a_{ij}) = -\frac{\ln(r - a_{ij})}{\ln(r-1)} \quad (2)$$

- Calculating the average cognition degree of the k experts with the same premise conditions by the equation:

$$b_j = \sum_{i=1}^{k} b_{ij} / k$$

- Cognitive blind degree is marked as Q_j and $Q_j = |\max(b_{1j}+b_{2j}+b_{nj})|-b_j$ which is defined according to the cognitive uncertainty of different experts on the prerequisite d_j. The general cognitive degree of expert on each prerequisite is marked x_j and $x_j = b_j (1-Q_j)$
- Normalization is made on x_j, let:

$$c_j = x_j / \sum_{i=1}^{n} x_i$$

and the weight set $W = \{c_1, c_2, \ldots , c_n\}$ which indicates the influence degree that the prerequisite condition a_i contribution to the conclusion.

It is clear that the weight set could be obtained with full consideration on subjective experience preference of the expert and scientific computing by structure entropy method. Which eliminate the noise appearing to the typical scheduling from the acquisition data and reduce the uncertainty and fuzziness in data source and make the weight set more objective.

RESULTS AND DISCUSSION

A risk model of retail supply chain by FPN could be in Fig. 3 where the meaning of places is list in Table 1. Establish the rules are as follows by the transitive relation between node enterprises risks in retail supply chain, where Rule 1 to Rule 6 is the base rule of the fuzzy and their reasoning results are the prerequisites of Rule 7.

Rule 1: If the seasonal adjustments of the market environment are very little, the fluctuation on price of

Table 1: Meanings of places in FPN of retail supply chain on risks

Places	Risk factors in retail supply chain	Fuzzy description of risk factors
p_1	Seasonal adjustments and changes of the market environment	Very little
p_2	The fluctuation on price of capital goods	Small
p_3	Demand uncertainty	Stable
p_4	Supplier flexibility	In good state on flexibility
p_5	Supplier delivery delay	Very small
p_6	Financial situation of supplier	In fine condition
p_7	Product quality	Qualified
p_8	The level of safety on stock	High
p_9	The stock funds occupancy rate	Low
p_{10}	The nnmber of the transport vehicle of distribution company	Sufficient
p_{11}	The turnover rate of the key employees in distribution company	Low
p_{12}	Traffic conditions during the distribution process	In good condition
p_{13}	Information sharing level	High
p_{14}	Data transmission security	Very safe
p_{15}	Consistency of strategic objectives between node enterprises in retail supply chain	Consistent
p_{16}	Rationality of supply chain structure	Reasonable
p_{17}	Consistency of enterprise culture	Unified
p_{18}	The probability risk on the economic and environmental	Very small
p_{19}	Probability risk on the supplier	Very small
p_{20}	Probability risk on the inventory factors	Very small
p_{21}	Probability risk on the distribution process factors	Very small
p_{22}	Probability risk on the information factors	Very small
p_{23}	Probability risk on cultural factors between the enterprise strategy	Very small
p_{24}	Probability of chain retail enterprise supply chain risk	Very small

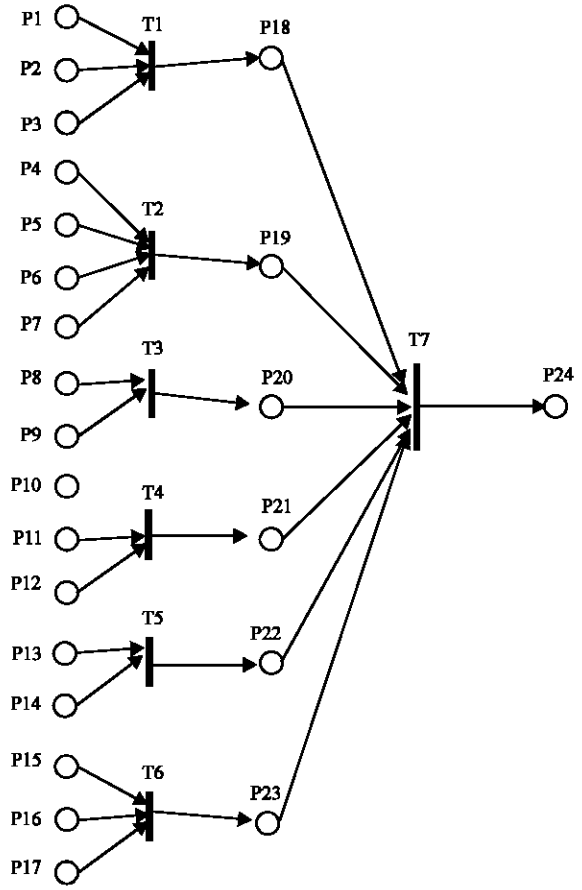

Fig. 3: Risk early warning network model of retail supply chain

capital goods is small and the market demand is stable, then the probability risk on the economic and environmental is small. This means if the market operates smoothly, the possibility of risk is small in the near future. For example if the weight of fuzzy place p_1 was calculated 0.4153 by structure entropy method. The weight p_2 is 0.3132 and the weight p_3 is 0.2715 with the threshold $\tau 1=0.5$ which could be given by experts or optimization calculation results. Then it could be concluded $p_{18}= 0.96$ which means the confidence of rule 1 is 0.96 under these premises.

Rule 2: If the supplier is in good state on flexibility, the supplier delivery delay is very small, the supplier financial condition is in fine condition and the product quality is qualified, then the probability risk on the supplier is small. For example if the weight of fuzzy place p_4 was calculated 0.3357 <0.5 by structure entropy method. The weight of p_5 is 0.3132, the weight of p_6 is 0.2023 and the weight of p_7 is 0.1580 with the threshold $\tau_2 = 0.4$. Then it could be concluded $p_{19} = 0.98$ which means the confidence of rule 2 is 0.98 under these premises.

Rule 3: If the level of safe stock is high (p_8,0.5248) and the stock funds occupancy rate is low (p_9,0.4752), then probability risk on the inventory factors is small (under the condition that threshold τ_3=0.5 and then $p_{20} = 0.83$).

Rule 4: If transport vehicle of distribution company is sufficient (p10 = 0.3150). The turnover rate of the key employees in distribution company is low ($p_{11} = 0.2864$). The road traffic is in good condition during the distribution process ($p_{12} = 0.3986$) and the threshold $\tau_4 = 0.3$. The result is that the probability risk on the distribution process factors is small ($p_{21} = 0.98$), under these premises.

Rule 5: If the information sharing level is high (p_{13},0.4628) and data transmission process is very safe (p_{14},0.5372), then probability risk on the information factors is small (if the threshold $\tau_5 = 0.3$ then $p_{22} = 0.92$).

Rule 6: If the strategic objectives between node enterprises in retail supply chain are consistent (p15,0.3986), the supply chain structure is reasonable (p_{16},0.2864) and enterprise culture is unified, then probability risk on cultural factors between the enterprise strategy is small (under the condition that the threshold $\tau_6 = 0.4$ and then $p_{23} = 0.85$).

Rule 7 (higher rule): If the possibility of environment risk factors on the market and economic is very small ($p_{18} = 0.2377$). The possibility of the supplier risk factors is very small ($p_{19} = 0.1846$). The possibility of inventory risk factors is very small ($p_{20} = 0.1532$). The possibility of distribution process risk factors is very small ($p_{21} = 0.1876$). The possibility of information risk factors is very small ($p_{22} = 0.1220$) and the possible strategies for cultural factors between enterprises risk is very small ($p_{23} = 0.1148$). The result is that the probability of chain retail enterprise supply chain risk is very small ($p_{24} = 0.90$) with the threshold $\tau_7 = 0.5$ under these premises.

Example: The survey risk factors data were obtained from the node enterprises in retail supply chain system, the relative membership degree function of direct fuzzy statistics for fuzzy processing of survey data and then the initial reliability can be obtained as below:

$$S_0 = [0.5,0.5,0.8,0.8,0.6,0.9,0.8,0.7,1,0.6,0.9,$$
$$0.9,0.6,0.7,0.4,0.4,0.7,0,0,0,0,0,0,0]$$

Implementation of fuzzy Petri net reasoning and computing matrix by using Matlab software programming, after 3 rounds of iterative calculation the status vector of fuzzy Petri nets would no longer change which indicates the end of that reasoning. The end result is:

$$S_3 = S_2 = [0.5,0.5,0.8,0.8,0.6,0.9,0.8,0.7,1,0.6,0.9,0.9,0.6,0.7,$$
$$0.4,0.4,0.7,0.5582,0.7442,0.6993,$$
$$0.7894,0.6014,0.4203,0.5822]$$

This suggests the possibility of the supply chain risk is little and the credibility is 0.5882.

The reasoning results also show that in spite of the credibility on the possibility of the occurrence of risks in the supply chain is little, the operation of supply chain is not in very high (0.5882-0.5 = 0.0882) safety zone, which means that the supply chain is easier to be in the potential risk. Observe the initial state vector, show that the credibility of the places such as p_1, p_2, p_{15}, p_{16} are not high. This indicate the most likely lead to the risk of supply chain are four causes which are the seasonal adjustments in the market, the production material price fluctuations, the consistent on node enterprises of supply chain strategic objectives and the reasonable supply chain structure. Later these causes should be studied further to take some right measures or decisions to avoid, shift and control the inherent risk in the system.

It is clear that this study is easy to understand and do not need very much data to model than BP neural network (Fei and Wang, 2008; Li and Wang, 2009). It is provide a more objective evaluation method comparing with the direct assignment (Zhang *et al*., 2008). It promotes and expands the application scopes of the structure entropy weight method (Cheng, 2010).

CONCLUSION

- Analysis of supply chain risk source and risk factors mutual relationship and the risk warning model of fuzzy reasoning ability by fuzzy Petri net in retail enterprises supply chain is established
- Combining the expert opinions, the structure entropy weights determine the conditions of each fuzzy rule the right law value, which make an effective combination of subjective preferences and objective measures
- By using the direct fuzzy statistics, the membership quantization on fuzzy variables corresponding to fuzzy database is obtained. The later initial reliability of fuzzy proposition could be calculated with it
- Finally, numerical simulation results show that the model has good ability of parallel fuzzy inference and could provide effective early risk warning for the retail supply chain, which help the enterprise to find theoretical reference for effective risk aversion

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