

A Dempster Shafer Theory and Fuzzy-Based Integrated Framework for Supply Chain Risk Assessment

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Abstract. This paper presents an integrated framework for supply chain risk assessment. The framework consists of some main components: risk identification, D-S calculation, fuzzy inference, risk analysis and risk evaluation. The risk identification comprises three parts, literature review, expert opinion interview, and questionnaire there are all used to identify the risk categories and their reasons and hazards. D-S calculation utilizes Dempster-Shafer Evidence Theory to fuse the potential risk's information which are identified by the experts' knowledge, historical data, literature review and questionnaire. The fuzzy inference part aims to solve how to identify the risk's impact when there are no explicit data. The risk analysis part use the data from D-S calculation and fuzzy inference to define the main bodies of risk, it's total probability, impact, and the final score of this risk-event. The risk evaluation component integrates all resources from the risk analysis part and gets a final supply chain score based on the assignment weight which are decided by the experts. A case study from a computer manufacturing environment is considered. Through the analysis of the supply chain, integrating the probability, hazard, and weight of the risk events and calculating a final score, managers can have a comprehensive understanding of the risks in the supply chain, and make some reasonable adjustment to avoid risks and reduce error rate for the purpose of maximizing their profits.

Keywords: Risk identification · D-S calculation · Risk analysis · Risk aggregation · Fuzzy logic

1 Introduction

Supply chain was sought after by business and academia from its birth date for the information sharing, cohesion of the core competitiveness of enterprises, rapid response to the market demand, effective allocation and optimization of resources, reducing of the unnecessary circulation, reducing of the costs, improvement of customer satisfaction and improvement of competitiveness of global economic integration. Supply-Chain risk which uses the vulnerability of supply-chain systems is a potential threat, and it can bring enterprise losses, damage to the supply chain system. How to measure and manage supply-chain risk has become an important field of it's research.

The key drivers for supply chain profitability are: responsiveness, efficiency, and reliability. To maintain their profitability, supply-chains must be able to respond quickly to external and internal risk events, and keep their businesses efficient and dynamic. This paper define risk as two big categories, external risk and internal risk. As for external risk, there are some specific branches like natural risk, market risk, political risk and so on. Another big class is internal risk, which includes all procedures, information, resources and players such as suppliers, manufacturers, intermediaries, third-party service providers, logistics activities, merchandising and sales activities, finance and information technology. These risks are common in each system, every risk has their own elements with the probability defined by the experts, literature review or questionnaire in process of risk identification. Considering the supply-chain risk elements have great uncertainty, it is hard to make accurate estimates of risk based on historical data or information and only rely on experts or decision makers based on their own experience and knowledge to make subjective estimates of risk. But this kind of subjective estimate is not accurate, it's the uncertain information, if the expert opinion has big deviation, the assessment of the whole system may totally wrong. The level of uncertainty depends on the amount and type of information available for estimating risk likelihood and impact.

All studies were screened through 4 steps: Risk identification is a critical step for the success of whole system's risk management. Risk identification is the process of classifying the risk affair, defining the risk's element, documenting, and gathering the risk information form experts and questionnaire. Risk identification in this paper through expert opinion with an open questionnaire, It is trying to select experts from different kind of companies and organizations with different owner ships and field of work to cover all points of view in the industry. In this step, risks which have certain special structure are classified and defined explicitly, it's subsidiary information also be collected. This structure consists of three components: risk event, the elements of the risk (we believe each elements of the risk are independent), each element has a probability, and it's hazard index based on the fuzzy set. From the survey part, the weights of each risk also be collected. Step 2: D-S calculation. Because of the uncertainty of the information from the experts, this step aims to fuse the data suitably. Dempster Shafer theory is used to fuse the probability of each element of the risk, and also acquire a confidence interval of each risk's element. When a whole system is established, before the risk analysis step, basic information must be input due to the characteristic of each risk. D-S calculation process provides the final data from the multiple input system to the risk analysis part. Step 3: Risk analysis. In this step, according to the confidence interval of each element, some risk elements which interval value below the threshold value defined by the authority personnel should be sifted out. Through the specific algorithm, those probabilities of each risk's element are calculating into a integration probability which are used to help the managers make the right decisions. The focus of this step is to figure out the risk score of the event, using the data from step 2, and step 3. Based on the different computational scheme decided by the management, a overall score of the supply chain can be calculated to be the input data of the risk evaluation process. Step 4: Risk evaluation. In this step, corresponding risk rank can be revealed to the management due to the final score of the whole system

from the previous step. Different risk levels may provides the information and some suggestion for supply chain risk management.

The rest of this paper is organized as follows: Sect. 2 presents the proposed framework for supply chain risk management. Section 3 discusses the application of the proposed framework for risk assessment in a computer manufacturing case. Finally, conclusions and future work are presented in Sect. 4.

2 Proposed Framework

The proposed framework (see Fig. 1) combines human involvement and mathematical analysis methods for whole system risk assessment. For each supply-chain, risk events are clearly defined and the basic elements of the supply-chain belong to specific risk affair. The main risk affair’s elements and their probability are identified based on experts’ knowledge, historical data, document literature. A survey in the risk identification part is developed to identify the basic risk affair and their elements in the whole system, the investigation of this part has generality. What kind of basic risk and the event’s elements are well-defined in this survey. Another survey is used to obtain estimates for the other parameters of the risk in the start of the information fusion part. The parameters consist of the probability, hazard index and the weight of each risk affair’s element. The quantity of this part depends on the number of experts. The estimates for risk parameters are used as inputs to the D-S calculation part, because of the uncertainty of each parameter investigated by different experts, some fusion rules are used in here for the purpose obtaining a integrated probability of each risk affair’s element.

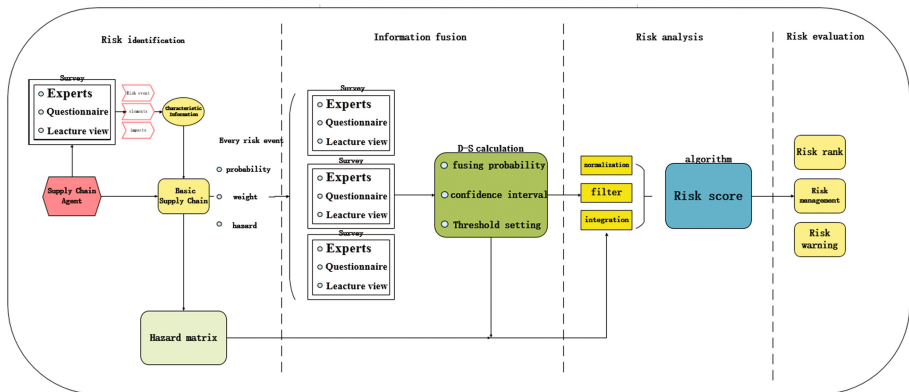


Fig. 1. A proposed framework for supply chain risk management.

When the probability fusion from different experts is completed, there also has a confidence interval of each risk’s element. Not all elements which are defined in the first step are necessary in every specific supply chain. Therefore, next step aim to delete the corresponding element by setting the threshold. Through screening and normalization, the complete information of the supply-chain risk has been collected and

processed. Previously we assumed elements are independent of each other, so the rules for element’s synthesis are formulated in the risk analysis part. To this end, the probability of each event in the whole system has been derived, and by interacting with the previously defined hazard index matrix, there have output score of each risk affair. Different risk events have different weights, finally get a total score of supply-chain risk. The weights are obtained from the supply-chain’s experts in the company.

2.1 Risk Identification

In this paper, a risk may be involved in the whole system are defined for two categories: Internal risks and external risks. Internal risks include the basic elements of the supply-chain. External risks include some social, environmental, and market factors. Each risk has a specific structure: event of risk, risk elements. The difference between risk element and it’s event is that risk element is the driver for the event of risk. For example, a customer risk’s event can be caused by order cancellation, returns, customer liquidation, demand variability. Such structure is showed in Fig. 2. The example above shows the elements of the event. The risk element has two parameters: probability and hazard index. For example, the elements of order cancellation has probability and hazard index which are defined by the experts. A typical supply-chain consists of supplier(s), manufacturer(s), customer(s), and transportation. Any part of a supply-chain always be corresponding to the above basic types (see Fig. 3).

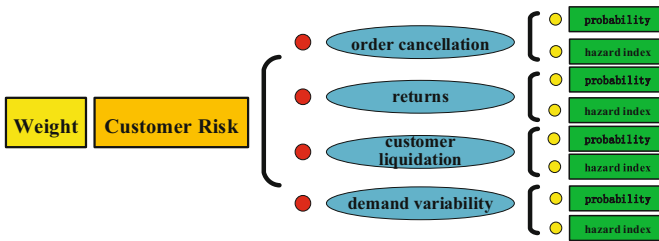


Fig. 2. Structure of supply chain risk

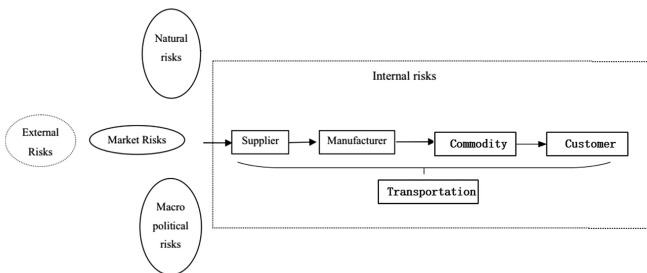


Fig. 3. Supply Chain Risk

As for the internal risks, there are several categories: For each supplier, the corresponding risk is called “Supplier Risk”; for customers or customer regions, risk is called “Customer Risk”; for transportation, it is called “Transportation Risk”; for each manufacturer the risk is called “Manufacturer Risk”. Except the Customers risk and it’s element, other risk’s structure (risk affair’s element) should be well-defined in the risk identification step. Possible elements of other risk affairs are as follows: Supplier risks consist of the elements like: Capacity constraints, supplier bankruptcy, quality issues; Commodity risk consists of price change, technology risk, quality risks; Manufacturer risks consist of Poor planning and scheduling, lack of standardization, process variability, forecasting errors, contract management, payment errors, Technical limitations, technology change, innovation risk, Design changes, quality issues. Natural risk consists of natural disaster, force majeure risk, disease and so on. Political risks consists of Social, political turmoil, laws and regulations change, exchange rate change, inflation. Market risks consist of industry volatility, competing risks. The above process is completed in the first part. It is assumed that each element is independent of each other. Second survey part is used to input the probability and hazard index of each element from it’s event of risk. This quantity of survey is determined by the number of experts. Each expert makes judgments based on his own experience, including the probability and hazard index of each element. These data will be used as input for the next step. About the hazard index, this paper makes a evaluation set $V = \{\text{low, less secondary, medium, significant, high}\} = \{0.1, 0.3, 0.5, 0.7, 0.9\}$, experts can decide the hazard index score based on this set. For example, a expert thinks the element of the risk has a great harm, he may decide the hazard index score of the risk affair’s element as 0.8. On the contrary, when the expert believes the element is unimportant, the hazard index score may set as 0.2. Thus we can get an hazard matrix from all experts, it collects all hazard index score of one risk affair’s elements. The rows of the matrix are equal to the number of the elements from a event. The columns of the matrix is equal to the number of experts. Different number in a columns represents a expert’s evaluation for different element’s hazard index score form one risk affair.

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} \\ M & M & M & M & M \\ r_{n1} & r_{n2} & r_{n3} & r_{n4} & r_{n5} \end{bmatrix}$$

The survey of the first part is general and universal, this step can be omitted when the system is not used for the first time. The survey of the next part is special and different, experts need to input the information based on the characteristics of the whole system differently when the supply chain is different.

2.2 D-S Calculation

The uncertainty of information from the different experts is the greatest problem in the previous step. Probability and hazard index from each risk affair’s element are decided by experts own experience. The main idea in this step is fusing the probability from the experts which towards to one risk’s event. Dempster Shafer theory is used to accomplish this goal. The beginning of this section first has a brief review on dempster Shafer

theory. The theory of belief functions initiated from Dempster’s work in understanding and perfecting Gisher’s approach to probability inference, and was then mathematically formalized by Shafer toward a general theory of reasoning based on evidence. Belief functions theory is a popular method to deal with uncertainty and imprecision with a theoretically attractive evidential reasoning framework. Dempster-Shafer theory introduces the notion of assigning beliefs and plausibility to possible measurement hypotheses along with the required combination rule to fuse them. It can be considered as a generalization to the Bayesian theory that deals with probability mass functions.

Mathematically speaking, consider X to represent all possible states of a system, in this paper, X represents all the elements from one event including a universal set which express the meaning of uncertain. Shafer theory assigns belief mass m to each element of X, which represent the probability receive from one expert regarding the opinion on each element. Function m has two properties as follows:

1. $m(\phi) = 0$

2. $\sum_{E \in X} m(E) = 1$

This step believes each element is independent of each other, we discuss the connection between elements in next section. Value m is decided by the expert represents the probability of each element. When an expert evaluation is completed, all the elements including a universal set from one risk affair have the m value. Evaluation from different experts is fused using the Dempster’s rule of combination. Consider two sources of information with belief mass functions m_1 and m_2 , respectively. The joint belief mass function $m_{1,2}$ is computed as follows:

$$m_{1,2}(E) = (m_1 \oplus m_2)(E) = \frac{1}{1 - K} \sum_{B \cap C = E \neq \phi} m_1(B) m_2(C)$$

$$m_{1,2}(\phi) = 0$$

where K represents the amount of conflict between the sources and is given by:

$$K = \sum_{B \cap C = \phi} m_1(B) m_2(C)$$

Thus we can get a fused evaluation from two experts. According to this rule, we can achieve any number of expert’s evaluation fusion. $bel(E)$ is called belief of E and $pl(E)$ is called plausibility of E they are defined as below:

$$bel(E) = \sum_{B \subseteq E} m(B)$$

$$pl(E) = \sum_{B \cap E \neq \phi} m(B)$$

An interval constituted by the value $[bel(E), pl(E)]$ is so called confidence interval. It is used to remove corresponding elements through the setting threshold in next section. If the median of confidence interval less than the threshold setting by the experts, it is believed that the element of the risk affair is a small probability factor, contributing almost nothing to the event, then remove it from collection of risk affair. Based on this, the final probability of each element from a event could be deduced. The integrated data as the input for the next part.

2.3 Risk Analysis

After the step 1 and step 2, three valid information has been formed: the specific risk events involved in the whole system, the integrated probability of each element from a risk event, the hazard index matrix had the weight of each risk affair. This step aims to solve three problems: 1. It is assumed that the elements of risk event are independent of each other in step 2. Considering the combination of different elements, this part figure out the final probability of each event and the data is used to be the input for the risk evaluation step; 2. Calculate the risk affair score using the data from integrated probability and hazard index matrix; 3. Calculate the whole supply chain risk score via every risk's event score in the overall structure and their weight.

In the use of probability fusion from different experts, it is assumed that the elements of risk affair are independent of each other. However, in reality the elements of one risk affair may have some interrelated relations. In this paper, the relations divided into two part: AND and OR (Fig. 4). The AND rule indicates the elements are parallel in a risk affair, every element is necessary to compose the whole risk affair. The OR rule indicates some elements only occur just one of it. For example, in customer risk, the two elements customer liquidation and demand variability, just one of them can be occurred. This AND and OR structure can be multi-level in a supply chain's risk affair.

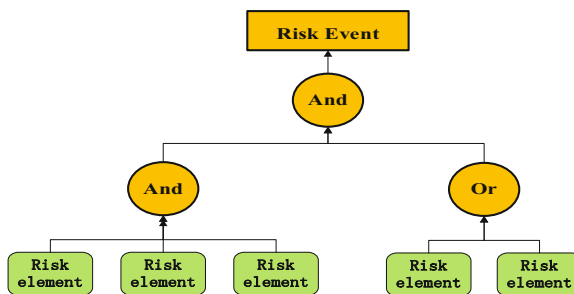


Fig. 4. A AND and OR structure

Based on the combination rule (AND or OR) among the risk elements, the aggregated risk's event probability is calculated as: 1. For AND rule (there are only And structure) in the left formula; For OR rule (there are only OR structure) in the right formula:

$$P_k = \prod_{i=1}^I p_i \qquad P_k = 1 - \prod_{i=1}^I (1 - p_i)$$

where P_k is the probability of occurrence of risk’s event k and P_i is the probability of occurrence of risk element i . If the estimates involve both OR and AND rules together as shown in Fig. 4, the aggregated risk probabilities will be calculated based on the two formulas above. The probability of risk affair k is calculated as:

$$P_k = \prod_{j=1}^M p_j \left[1 - \prod_{i=1}^I (1 - p_i) \right]$$

This formula can be seen as a combination of the first two formulas, the part of AND rule and the part of OR rule as a whole respectively, and then to be the input for the superior And rule. The superior similarly can also be the Or rule, the related formulas will also change based on the first two formulas. Specific problems should be analyzed differently. The final probability of occurrence of risk affair can show the risks probability distribution in a overall structure to the experts and management.

The next goal is to obtain the score of the risk affair. Through the step 2, the fused probability of each element from a risk affair and the hazard index matrix decide by different expert which towards a risk’s event have already obtained. For example, a event has n elements. The $m_1 m_2 \dots m_n$ is the fused probability (threshold filtering and normalization) from D-S calculation. The table as below. The final probabilities of different events of the risk need to be normalized.

Risk event	Element 1	Element 1	Element 1	Element ...	Element n
Probability	m_1	m_2	m_3	...	m_n

A one row, n column probabilistic matrix P is defined as below $P = [m_1, m_2, m_3, m_4, \dots, m_n]$ n is the number of elements of a risk affair which has been screened by the threshold setting by expert. In the risk identification part, a hazard index matrix gathered by all experts has been initially generated. Some elements are generic in the risk affair, determined by general experience. But in a specific overall structure, the element’s probability collected by the experts is tiny, which means the element of the event that almost certainly didn’t happen. Through the threshold selection in the beginning of this section, the hazard index matrix will change accordingly. Here define the new hazard index matrix as below: where n is the number of the expert in the survey part, m is the number of the elements from a risk affair after screening. Next we define a initial score function B , calculating a preliminary score towards a risk’s event. The define as below:

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{21} & \dots & r_{11} \\ r_{\dots} & r_{\dots} & \dots & r_{\dots} \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}$$

$$B = P \times R = [m1, m2, m3, m4, \dots mn] \times \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{21} & \dots & r_{11} \\ r_{\dots} & r_{\dots} & \dots & r_{\dots} \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}$$

The value of B is a normalized score. In the first section, a fuzzy evaluation set is defined. The evaluation set V according to the degree of harm = {low, less secondary, medium, significant, high} = {0.1, 0.3, 0.5, 0.7, 0.9}, experts can decide the hazard index score based on this set. The final score of a risk affair is defined as below (E is the importance weights towards the experts):

$$S = B \times E^T$$

The value of B is also a normalized score between 0 and 1. If the final score of a risk affair is close to the value 1, it represents the event has significant risk based on the two parameters, probability and hazard. On the contrary, if the final score of a risk affair is close to the value 0, it represents the event is unimportant. In the same way, other risk events in the overall structure can be calculated. The table as below:

Risk event	Event 1	Event 2	Event ...	Event n
Score	S1	S2	...	Sn
Weight	W1	W2	...	Wn

The weights are normalized and are collected by the expert in the first section. The total risk score of the overall structure is calculated as:

$$D = \sum_{i=1}^n S_i W_i = S_1 \times W_1 + S_2 \times W_2 + \dots S_n \times W_n$$

The total risk score D reflects the whole overall structure risk index, according to different scores, supply-chain risk will be divided into several levels. Different risk levels will give some reasonable advice to the management in the next step.

2.4 Risk Evaluation

According to different scores, overall structure risk will be divided into several levels: low, medium, high. Based on the different level, there are several suggestions. It is generally accepted, When the risk value is greater than 0.7, the risk level is high; When the risk value is between 0.3 and 0.7, the risk is medium; When the risk value is less than 0.3, the risk is low. Interval values are as follows:

D value	Risk level	Action required
$D \leq 0.3$	Low	No further risk mitigation is required
$0.3 < D \leq 0.7$	Medium	Risk mitigation required to reduce the risk level to low is optional, monitoring is required
$D > 0.7$	High	Risk mitigation required to reduce the risk level to medium or low. If the risk is not mitigated, monitoring and making a contingency plan is required

A supply-chain get a risk level through the above classification. The accuracy of the level can be defined into more detailed classification (No impact-no impact on the company, Small impact-small loss, Medium impact-cause short-term difficulties, serious impact-cause long-term difficulties, Disastrous impact-business interruption) as needed. The action required of each risk level should close to the specific business requirements based on the expert’s experience in different fields. Decision makers should take effective measures to prevent the occurrence of risk according to the level of warning signals. The data obtained from the previous step which consists of the information about the probability, score, weight from each event in a supply chain. The table as below:

Risk event	Event 1	Event 2	Event ...	Event n
Probability	m1	m2	m...	mn
Score	S1	S2	S....	Sn
Weight	W1	W2	W...	Wn

These data reflects the details of the supply-chain’s risk more intuitively and concretely. Supply-chain’s risk assessment is an important part of risk management. Because of the complexity and uncertainty of supply-chain risk, enterprises need to deal with risks and adjust business strategy immediately so as to reduce the losses and for guaranteeing the supply and the business with the continuous and the balanced.

3 Risk Assessment in Household Appliance Industry Supply Chain

The proposed framework was applied in a household appliance manufacturing environment that is mostly based on the different parts of components from different suppliers in different geographical locations (Fig. 5).

Many risk’s events can occur and affect the overall structure. Examples of risks include internal risk: supplier risks, customer risks, manufacture risk, transportation risks, commodity risks, management risk and others. And external risk: natural risk, political risk, market risk and others. Each risk event has many elements individually and elements are independent of each other. The order cancellation in customer risk, for example, has a large business impact on the marketing plan because the change of customer’s order can strongly influence the in a business. The table above is

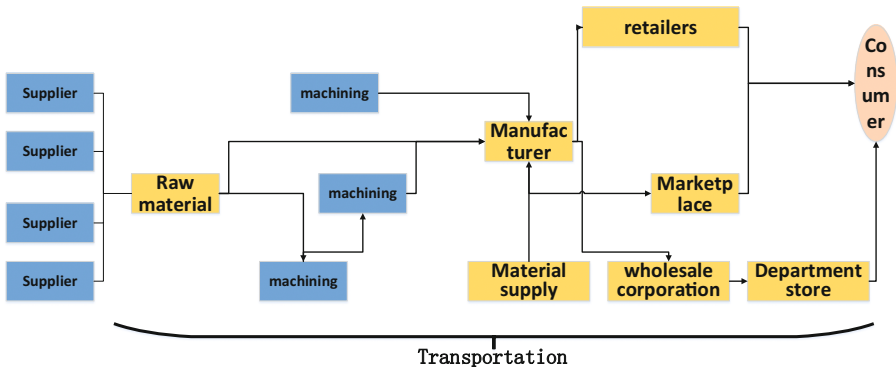


Fig. 5. A Supply chain structure in household appliance industry and a table of risk classification

established in the risk identification part’s first survey based on the expert’s experience, questionnaire and literature review. The information in table is possessed of stronger applicability and generality in current industry chain. For example, when another electronic product supply-chain needs to be evaluated, those information above can still be used with a little modification.

According to the specific overall structure (see Fig. 6.), the second survey needs to establish the probability of each element from every risk event, and the hazard index towards each element. The establishment of this information is based on each expert. The customer risks, for example, has four elements: order cancellation, returns, customer liquidation, demand variability. Each element has a probability and a hazard index from different expert (Probabilistic data need to be normalized-the probability sum is 1). In addition, these data are dynamic, changing, most difficult to describe, and showed great ambiguity. Those data need to be judged according to the specific supply-chain by the expert. The table of information from one expert list below:

Manufacture risk	Design changes	Quality issues	Technical limitations	Process variability	Forecast errors
Probability	0.3	0.2	0.25	0.05	0.2
Hazard index	0.71	0.52	0.31	0.44	0.12

(Probability set also includes a complete set consists of all risk events for the purpose of expressing the opinion of unclear from experts. In order to show more intuitive, the complete set are not written in the previous table.) The hazard index above reference to the evaluation set $V = \{low, less\ secondary, medium, significant, high\} = \{0.1, 0.3, 0.5, 0.7, 0.9\}$. There are 4 experts in this case. Another four experts’ assessment of probability is: $\{0.25, 0.25, 0.1, 0.1, 0.3\}$, $\{0.2, 0.25, 0.4, 0.05, 0.1\}$, $\{0.35, 0.1, 0.2, 0.15, 0.2\}$, $\{0.1, 0.3, 0.3, 0.1, 0.2\}$. The number of experts is determined according to the actual needs Another four experts’ assessment of hazard index score is: $\{0.62, 0.52, 0.61, 0.45, 0.31\}$, $\{0.47, 0.42, 0.28, 0.68, 0.21\}$, $\{0.42, 0.25, 0.75, 0.62, 0.51\}$, $\{0.52, 0.64, 0.18, 0.25, 0.37\}$. The data of different experts are not the

Risk classification	Risk event	Risk element				
Internal risk	Supplier risks	capacity constraints	supplier bankruptcy	quality issues		
	Customer risks	order cancellation	returns	customer liquidation	demand variability	
	Manufacture risk	design changes	quality issues	technical limitations	process variability	forecasting errors
	Transportation risks	Proximity to airports	quality of roads	logistics provider problems		
	Commodity risks	Price change	technology risk	quality risks		
	Management risk	job security control	financial control	regulatory obligations		
External risk	Natural risk	natural disaster	force majeure risk	Disease		
	Political risk	laws and regulations change	social, political turmoil	Exchange rate changes	Inflation	
	Market risk	industry Volatility	competing risks			

Fig. 6. A Supply chain structure in household appliance industry and a table of risk classification

same, after D-S data fusion, the integration probabilities of each element from manufacture risk and the hazard index matrix R which contain all impact index from every expert towards the risk event are established.

Manufacture risk	Design changes	Quality issues	Technical limitations	Process variability	Forecast errors
Probability	0.34	0.24	0.18	0.09	0.15

Hazard index matrix R is used to record the hazard assessment of each expert for different risk events. The risk event score formula from the previous chapter defines the final score according to the above two sets of data.

$$R = \begin{bmatrix} 0.71 & 0.62 & 0.47 & 0.42 & 0.52 \\ 0.52 & 0.52 & 0.42 & 0.25 & 0.64 \\ 0.31 & 0.61 & 0.28 & 0.75 & 0.18 \\ 0.44 & 0.45 & 0.68 & 0.62 & 0.25 \\ 0.12 & 0.31 & 0.21 & 0.51 & 0.37 \end{bmatrix}$$

$$B = P \times R = [0.48, 0.53, 0.40, 0.47, 0.44]$$

$$S = B \times E^T = 0.469$$

The value B is the initial score of manufacture risk, and the value S is the final score of manufacture risk which is used to be a input of the whole supply-chain’s risk assessment. The set E is the wrights of each expert in the evaluation procedures. In this household appliance industry overall structure, the set E is {0.4, 3, 0.2, 0.1, 0.1} based on the importance of each expert in this industry. For example, the first value of set E may represent an authoritative expert in household appliance industry and the second value may reflect the corporate adviser’s weight. At the same way, the final score of Supplier risk, Customer risks, Transportation risk, Commodity risk, Management risk, Natural risk, Political risk, Market risk are calculated respectively as below: {0.781,

0.523, 0.627, 0.261, 0.392, 0.097, 0.124, 0.217}. Every risk event including the internal risk and the external risk has a risk score through the process above. Then use the weights that defined in the risk identification section to calculate the final score of the whole supply chain including the risk events involved. At the same time every risk event in the overall structure has a total probability based on the AND and OR rules in the previous chapter, and it intuitively reflects the probability of the occurrence of the event. (The probabilities of these events are normalized.)

	Weights	Risk events	Weights
Internal risk	0.8	Supplier risk	0.3
		Customer risks	0.2
		Transportation risk	0.05
		Manufacture risk	0.2
		Commodity risk	0.1
		Management risk	0.15
External risk	0.2	Natural risk	0.1
		Political risk	0.4
		Market risk	0.5

Using the weighted summation formula of the previous chapter, the final risk score D is calculated by the weights in the table above as: $0.8[0.469 * 0.2 + 0.781 * 0.3 + 0.523 * 0.2 + 0.627 * 0.05 + 0.261 * 0.1 + 0.392 * 0.15] + .02[0.097 * 0.1 + 0.124 * 0.4 + 0.217 * 0.5] = 0.486$. Based on the partition rule mentioned in risk evaluation part, this supply chain risk level is medium and the action required is risk mitigation required to reduce the risk level to low is optional, monitoring is required. Or according to the actual needs, the level should to be divided into more grades and more suggestions will be displayed.

Total risk score	Risk level	Action required		
0.486	medium	<i>risk mitigation required to reduce the risk level to low is optional, monitoring is required</i>		
Risk event	Supplier	Customer	Transportation	Manufacture
Probability	0.11	0.16	0.10	0.21
Risk event	Natural	Political	Commodity	Market
Probability	0.03	0.09	0.13	0.17

The related information of the household appliance industry supply is fully displayed table above. It shows the final risk level and the suggestions to the enterprise management, and the probabilities of each risk event from the supply chain also provide the crucial information about which risk event most likely to occur and which is small probability event.

4 Conclusions and Future Work

This study proposed a framework for supply chain risk identification, data fusion, risk analysis and risk evaluation. The framework combines mathematics and decision making methods for an effective assessment of supply chain risks. The risk identification part was developed to identify the scores of the risks considering risk elements, risk probability and the hazard index towards each element from different experts. Given the individual and aggregated risk scores, decision makers can either see the final risk score of the supply chain and the risk level or the probability of each risk event and focus on the significant risks that can affect their business operations. The greatest problem in supply chain risk assessment is how to define a risk and how to relative accurately define the prior probability of each risk event. In this paper, the type of risk and structure is clearly defined. The prior probability of each risk event are collected by the different experts and fused by the Dempster Shafer theory.

Because of the limitation of the Dempster Shafer theory, this paper believe that the risk elements are independent of each other from a risk event. And then use a AND and OR rules to merge each risk element from a risk event. This approach is feasible logically, but the accuracy of the algorithm needs further study to prove.

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