Analytical hierarchy process based framework for supply chain risk management

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Abstract— Facing to a very risky economic environment, companies should implement effective supply chain risk systems which allows on one side to drive the performance (manage poor performance: "normal risks") and on the other side to manage the abnormal risks (disruption, incidents, worker accidents, …). This paper proposes a supply chain risk management framework, that allows effective supply chain risk management and it permit also aligning risk management with performance monitoring. In this study we introduce also a new risk assessment method based on a multicriteria decision analysis in order to reduce the subjectivity of qualitative risk analysis.

Index Terms— Supply Chain, Risk Management, Analytic hierarchy process, Multicriteria decision analysis, Framework.

1 Introduction

The actual economic environment faces many factors that result in higher risk more so than at any time in modern history. Increased globalization through outsourcing, increased levels of economic uncertainty and market volatility, shorter product life cycles, complex networks of suppliers, Natural disasters and external environmental events and additional regulatory compliance imposed by government entities are some factors that explain the necessity of implementing the supply chain risk management.

In this paper and after presenting some risk management frameworks, we introduce a supply chain risk management framework which involves three main components, a planning component, an execution component (real time risk scanning) and a supply chain risk database containing the four categories of risks: supply, process, demand and corporate level risks.

Finally, in order to reduce some of the subjectivity of qualitative risk analysis we are going to propose and test by a case study a new risk assessment method based on a multicriteria decision analysis: the analytic hierarchy process.

2 Supply chain Risk management

2.1 supply chain and risk management

The supply chain risk management is the implementation of strategies to manage risks along the supply chain through an effective risk identification, assessment, and management of all significant risks with the objective of reducing vulnerability and ensuring continuity [1].

As Enterprise Risk Management, supply chain risk management consists of four steps, first we identify risks, then we analyses and assess these risks, after we treat them and finally we Respond to incidents through communication, coordination and other means [3]. Depending on the context of the supply chain and the severity of the impact of risk, several treatment approaches are possible:

1. Risk mitigation means taking actions to reduce both the probability of occurrence and the impact of a risk.
2. Risk prevention means taking actions to reduce the probability of occurrence of a risk.
3. Risk avoidance involves avoiding activities that increase the probability of occurrence of a risk.
4. Risk acceptance means to take on and assume a risk, no action is taken because the impact of risk is negligible or because cost/benefit analysis reveals that the cost of treating the risk exceeds the expected impact of the latter.
5. Risk sharing involves transferring a proportion of a risk, buying insurance is a risk sharing method.

2.2 Supply chain risk identification and categorization

The first step of any risk management approach is risk identification, there are many ways to identify and categorize risks, we categorize risks in sight of helping us to understand the distinctions between these risks and to prioritize different risk mitigation investment decisions [3].

A set of supply chain risks categorization methods are identified. One method involves two different types of supply chain risks, delays in material flows which are usually predictable and disruptions to material flows anywhere in the supply chain which are unpredictable and often plenty damaging [3]. A second method involves two other types of supply chain risk, internal risks (involving issues such as capacity variations, regulations, manufacturing yield and costs, information delays, and organizational factors) and external risks (market prices, actions of competitors, supplier quality, and political issues) [5]. Third method is a way in which we consider the four categories that defines enterprise risk management, strategic risks which impact the ability to perform business strategy and preserve asset and brand value, hazard risks (random disruptions, some of which involve natural disasters), financial risks and operational risks [1]. A final method is motivated by the supply chain organization; Figure 1 illustrate the principals process of any supply chain, for each process we distinguish a risk category, supply risks for Source process, process risks for Make process, demand risks for Deliver

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process and corporate level risks for the holistic view of the entire supply chain.

Fig.1. SCOR Model with its processes, from CSC [9].

In this study we opt for the latter method, Table 1 summarizes the risks in the supply chain according to its main processes.

2.3 Risk analysis methods

To assess supply chain risks, most companies employ different methods whether formal quantitative models or informal qualitative methods, risk analysis usually requires two parameters, likelihood or frequency of risk event and the impact of associated consequences, the combination of the two parameter form the risk intensity [3].

In the literature several risk analysis methods are defined, below a selection of methods that can be used when carrying out a risk analysis [4]:

1. Coarse risk analysis is a common method for establishing a crude risk picture, performed by dividing system into sub-elements and then determine initiating events and perform cause and consequence analysis for each of these sub-elements.
2. Failure modes and effects analysis(FMEA) involves possible failures and predict the failure effects on the system as a whole. A specific form is used to perform the analysis, for each component of the system we specify: identification, function, failure modes, effect on other units in the system, effect on system, corrective measures, failure frequency and failure effect ranking.
3. Structured What-If Technique (SWIFT), in this method we use the fundamental question What if systematically in order to identify deviations from normal conditions. Possible problems and combinations that could be problematic are analyzed and possible treatments are identified.
4. Event Tree Analysis, this method it provides a set of possible scenarios, it tries to respond to question: what type of event sequences can the initiating event produce? It can be both a qualitative method and a quantitative method.

2.4 Supply chain risk mitigation

Companies generally find it difficult to justify the implementation of costly strategies for risk mitigation, especially in the case of eventual risks that have occurred rarely in the past and which may not manifest in the future, therefore mitigation actions should allow on one side to efficiently manage the supply chain and on the other side they must make the supply chain more resistant to disruptions. There are three general risk mitigation strategies, the first is alignment of supply chain partners incentives to reduce the behavioral risks within the supply chain. Second is flexibility to reduce all together supply risks, process risks and demand risks. The third is building reserves for redundancy which is useful for reducing the impact of disruptions or delays [3]. Table 2 summarizes a set of mitigation strategies which satisfy both efficiency and resilience of supply chain.

TABLE 1
SUPPLY CHAIN RISKS BY CATEGORY, INSPIRED FROM [1], [5] AND [3]

Supply Risks	Process Risks	Demand Risks	Corporate level Risks
Supplier lead times	Manufacturing yield	Forecast error	Currency exchange rates
Supplier quality	Capacity	Time delays	Political environment
Transportation lead time	Information delays	Outbound transit times	Customs regulations
Subcontractor availability	Time delays	change customer requirements	Weather/acts of God
Supplier pricing	Disruption	Customer pricing	Environmental regulations
Time delay	Systems breakdown	Customer promotions	Industry regulations
Disruption	Receivables	Customer bankruptcy	Country regulations
Import delays	Payables	Product failure	Counterfeiting
Supplier insolvency	Inventory	Warranty issues	Fraud/corruption
Fraud/corruption	Intellectual property	Customer loss	supply chain visibility
Counterfeit material	Human/process error	New product introduction	
Supplier delivery	Planning		
	Product failure		
	Equipment failure		
	Organizational management		
	safety(worker accidents)		

3 RISK MANAGEMENT FRAMEWORKS

A risk management framework is a skeletal, openwork, or structural frame for implementing strategies to manage risks within the enterprise through continuous risk identification, assessment, mitigation with the objective of reducing vulnerability and ensuring sustainability [1].

Over the last few decades several enterprise risks management are emerged, below the main frameworks:

1. Enterprise Risk Management (ERM) Framework can be described as risk based approach to manage an enterprise, initially comes from finance and classical risk insurance disciplines. By this framework an organization in any industry assess, controls, exploits, finances and monitors risks from all sources for the purpose of increasing the short and long-term value to its shareholders [1].
2. Committee of Sponsoring Organizations Enterprise Risk Management Framework (COSO ERM) consists of eight components of ERM that are needed to help a firm achieve its objectives at each level of the organization: strategic, operations, reporting and compliance. The nine components of COSO Framework are, Internal environment, Objective setting, Event identification, Risk assessment, Risk response, Control activities, Information and communications and finally monitoring [2].
3. Governance, Risk and Compliance (GRC), this framework is composed by three basic tenets, the first is Governance which include tools, policies, procedures, controls and decision making hierarchy used to manage the business. The second is Risk Management who is a set of processes through which we identify, analyses, and treats risks that could impact the achievement of objectives. The third tenet is Compliance which means conforming to requirements (internal, law, contracts, regulation and policies) [1].
4. ISO 31000, in order to provide a foundation of enterprise risk management implementation, the International Organization for standardization (ISO), published ISO 31000 [7]. According to this standard the risk management process consists of establishing the context, identifying risks, analyzing risks, evaluating risks, treating risks and monitoring and reviewing risks.

All frameworks described above are action based frameworks for risk management, they are all based on identifying, assessing, treating and monitoring risks.

TABLE 2
SUPPLY CHAIN RISK MITIGATION STRATEGIES

Mitigation strategy	Main objective	Benefits under supply chain disruption
Postponement	Increases product flexibility	Change the configurations of different products quickly
Strategic stock	Increases product availability	Respond to market demand quickly during a major disruption
Flexible supply base	Increases supply flexibility	Shift production among suppliers promptly
Make-and-Buy	Increases supply flexibility	Shift production between in-house production facility and suppliers rapidly
Economic supply incentives	Increases product availability	Adjust order quantities quickly
Flexible transportation	Increases flexibility in transportation	Change the mode of transportation rapidly
Revenue management	Increases control of product demand	Influence the customer product selection dynamically
Dynamic assortment planning	Increases control of product demand	Influence the demands of different products quickly
Silent product rollover	Increases control of product exposure to customers	Increases control of product exposure to customers
Flexible supply contracts	Increase replenishment flexibility	Shift order quantities across time
Flexible manufacturing process	Increase flexibility in producing different products	Shift production quantities across internal resources (plants or machines)
Aggregate or pool demand	Increases control of product demand	Respond to unpredictable grows
Centralize/decentralize inventory	Increases product availability and reduces costs	Decentralize inventory for low value product with stable demand centralize inventory for high value product with uncertain demand

4 SUPPLY CHAIN RISK MANAGEMENT FRAMEWORK

4.1 Proposed Supply chain risk management framework

The proposed supply chain risk management framework consists of three main components (Figure 2). The first main component is the supply chain risks database which contains a set of predefined risks related to the different processes of the supply chain (see in Table 1 the different kinds of risks: supply risk, process risk, demand risk and level corporate risk). This database is mainly used by risks assessment and updated continuously by risks scanning & identification. The second main component is planning component, this component involves the risk assessment and the definition of mitigation plans. In the proposed framework a new assessment method is defined, it is based on AHP, a multi-criteria decision analysis, this will be detailed in the following paragraphs. The third component of the framework is the execution component, this part of the framework is most critical component, operating continuously it helps to identify potential risks that affect the performance of the supply chain or that may cause a chain disruption. This component is also responsible of execution and monitoring of mitigation plans defined in the planning component.

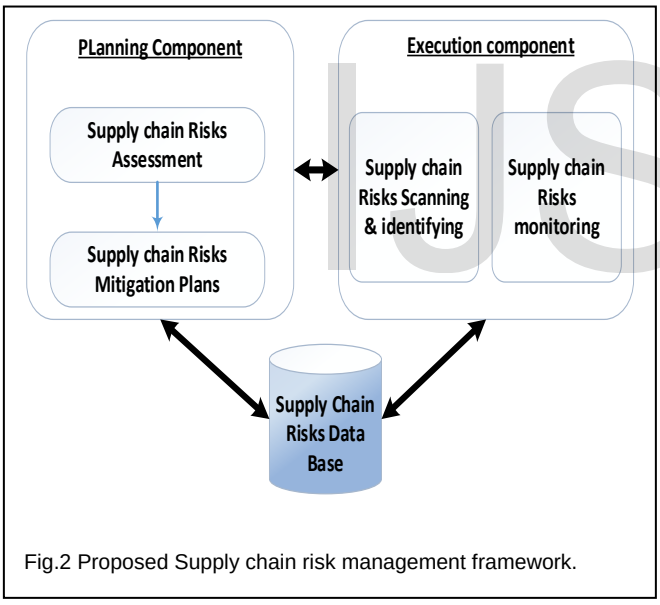

Fig.2 Proposed Supply chain risk management framework.

4.2 Risk assessment based on Analytic hierarchy process

As seen in a previous paragraph, risk assessment consists of the evaluation of two parameters, frequency and impact of risk event. in practice, evaluation of the parameters involves assigning a value using a scale from 1 to 4, the intensity of a risk can be calculated with the following formula.

Risk intensity (RI) = Impact x Frequency, where impact and frequency are natural values between 1 and 4

Risk is considered:

- low risk, if $0 < RI \leq 4$
- medium risk, if $4 < RI \leq 8$
- high risk, if $8 < RI \leq 12$
- blocking risk, if $12 < RI \leq 16$

In some cases, it is difficult to assign a value for the impact or frequency of a risk event, this is why we propose to establish the relationship between all risks by using AHP analysis, and then simply assign the value of the impact or frequency of one risk and deduct the value of other risks by using the relationship.

AHP is a multi-criteria decision analysis tool developed by Saaty [8], this is the most appropriate method in the context of the hierarchical analysis and problems whose elements are structured sequentially.

An effective way to get the relationship between a set of alternatives is to use pairwise comparisons matrix, $\mathbf{A} = (a_{ij})\ n \times n$, structured as follows:

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix}$$

with $a_{ij} > 0$ expressing the degree of difference between the impact or frequency of two risks, Ri and Rj.

If $w = (w1, \dots, wn)^T$ is the priority vector then $a_{ij} = w_i / w_j$, and A can be written as:

$$\mathbf{Aw} = \begin{pmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{pmatrix} \begin{pmatrix} w_1 \\ \vdots \\ w_n \end{pmatrix} = \begin{pmatrix} nw_1 \\ \vdots \\ nw_n \end{pmatrix} = n\mathbf{w}$$

From linear algebra, we know that a formulation of the kind Aw = nw implies that n and w are an eigenvalue and an eigenvector of A [6].

In summary the vector priority is obtained by calculating the eigenvector of pairwise comparison matrix. If $w = (w_1, \dots, w_n)^T$ is the priority vector and V_k is the value for impact of risk K, then the values of impact of other risks are obtained by following formula:

$$Vi = E\left(\frac{Wi}{Wk}\right) * Vk \quad , \forall i \text{ and where } E(X) \textit{ is integer part of } X \quad (formula\ 1)$$

4.3 Practical case of the proposed risk assessment method

To apply the proposed approach, we performed the risk assessment of a small factory manufacturing shoes soles. We used super decision tool to facilitate the calculation of priorities, Figure 3 presents risks that can impact the supply chain of the studied company. This company is primarily concerned with a set of risks organized by the three main risks categories: supply, process and demand risks (see the diagram below).

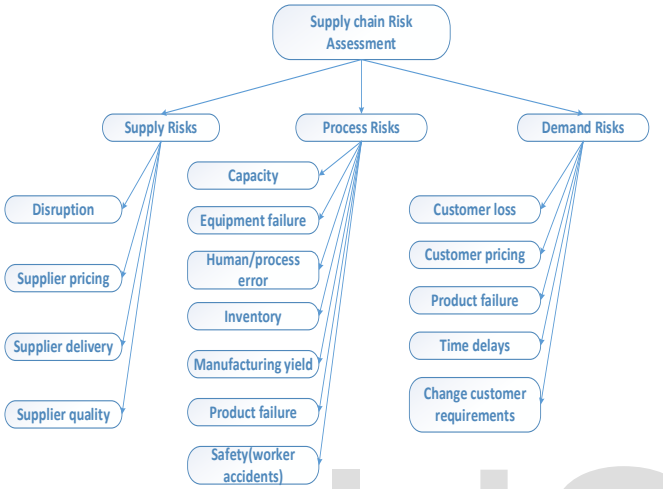

Fig.3.studied enterprise risks under super decisions

After performing the pairwise comparisons and getting the priority vectors two times, one for comparing frequencies and the other for comparing impacts of risks. We determine the impact value of a single risk, preferably a risk that we can determine its impact with precision and we do the same for a frequency value.

We assign the value 4 for the impact of losing customer (highest impact) and the value 1 for the frequency of product failure (lowest frequency). Then we get the results listed in Table 3 by using formula (1).

For the studied company, Change customer requirements, Product failure, Time delays, Supplier quality, Disruption and Capacity are medium risks and all the rest are low risks.

TABLE 3
RESULTS OF RISK ASSESSMENT

Risks	Impact priority	Impact	Frequency priority	Frequency	Risk Intensity
Change customer requirements	8%	2	15%	4	8
Customer loss	19%	4	2%	1	4
Customer pricing	2%	1	3%	2	2
Product failure : demand	9%	2	7%	4	8
Time delays	10%	2	9%	4	8
Capacity	1%	3	3%	2	6
Equipment failure	2%	1	7%	4	4
Human/process error	2%	1	9%	4	4
Inventory	2%	1	5%	3	3
Manufacturing yield	1%	1	6%	3	3
Product failure: process	3%	1	8%	4	4
Safety(worker accidents)	3%	1	1%	1	1
Systems breakdown	3%	1	8%	4	4
Disruption	14%	3	3%	2	6
Supplier delivery	5%	1	5%	3	3
Supplier pricing	7%	2	3%	2	4
Supplier quality	9%	2	7%	4	8

5. CONCLUSION

This study has allowed us to suggest a framework for managing supply chain risks, due to its three main components, this framework allows to manage effectively the supply chain risks by scanning risks and monitoring mitigation plans in real time and by aligning risks and main supply chain processes. Taking into account the different risk categories from the supply chain risk database allows us on one side to manage major risks and on the other side to monitor the supply chain performance.
In regards to the proposed risk analysis method, we tried to reduce some of the subjectivity of qualitative risk analysis by using a multicriteria decision analysis which provide priorities between risks.

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