TOWARD AN INTEGRATION OF RISK ANALYSIS IN SUPPLY CHAIN ASSESSMENT

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ABSTRACT
This study analyzes the risks incurred by supply chains, both externally and internally. Several alternatives are presented to evaluate the risks of disruption of a supply chain and bankruptcy of one or several of its member enterprises. The issue is then to integrate risk management within classical supply chain management approaches. The difficulty of this integration is described through contradictions between Supply Chain Management and Risk Management in objectives and practice.

Keywords: vulnerability, hazard, risk analysis, risk management

1. INTRODUCTION

According to Christopher (1998), a supply chain is a "network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer". Some of these linkages are physical, to carry flows of products. Others are informational, to exchange messages and negotiate terms of trade.

A supply chain can also be viewed as a virtual system subject to possible dynamic reconfigurations, through arrival or departure of partner enterprises. As for any physical system, a supply chain is prone to accidents, undesirable events leading to consequences or damages on vulnerable targets. The origin of undesirable events can be related to political, social, economical, natural, technological, or organizational aspects. However, the reconfigurable nature of supply chain probably explains why risk analysis is not currently considered a leading approach in supply chain design and supply chain management (SCM). In the SCM literature, risks are often under evaluated and treated as one among many factors in economic evaluation. Typically, risk is defined as the cost of supply-demand mismatches (Ülkü, Toktay, and Yücesan 2007).

This study proposes to identify some risks incurred by supply chains, apply a risk management approach and attempt to conciliate this approach with the more traditional Supply Chain Management techniques.

2. RISKS IN SUPPLY CHAINS

The concept of risk is crucial in many sectors of todays

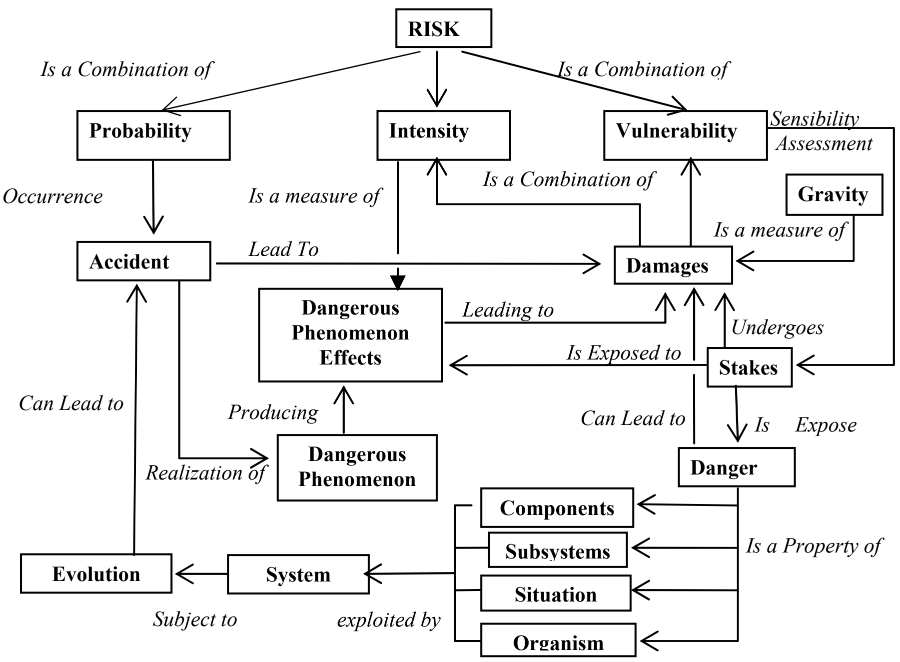

Figure 1: Some concepts and relations to define risks

Society: health, environment, economy, finance. Several international incentives have concurred to clearly define this concept.

2.1. Some definitions

According to the ISO-IEC (2002), risk can be defined as the combination of the probability of an undesired event (accident) and its consequences (damages). The notions of hazard and accident are linked with the presence of stakes that are vulnerable to the consequences of an accident. Without a stake carrying a vulnerability property, the risk related to an event is null. As a consequence, an accident is defined as the accomplishment of a dangerous phenomenon, combined with the presence of vulnerable targets exposed to the effects of this phenomenon. Some concepts and the links between them are represented in figure 1.

2.2. Vulnerability of supply chains

2.2.1. The virtual nature of supply chains

As a virtual entity non reducible to its constitutive enterprises, a supply chain seems at first sight to keep away from the structural and operational vulnerability of traditional corporate firms. Risks seem to be located in the enterprises rather than in the network that they constitute.

In its design stage the structure and components of a supply chain can be easily modified. Hence, a simple risk reduction measure consists in replacing a risky firm by a less risky one. However, risk then becomes a key factor in choosing the partners of a supply chain. And conversely, firms may become reluctant to participate to a supply chain if they correctly assess the risk of being pushed away from partnership precisely when they encounter difficulties and would rather need support.

2.2.2. SMEs in supply chains

A major problem in the design and organization of supply chains is heterogeneity of the enterprises involved. In terms of risks, Finch (2004), has clearly shown that SMEs (Small and Medium Enterprises) greatly increase their exposure to risk when becoming part of a supply chain. It is clearly more risky for an SME to invest all its assets and use investment loans than for a large company to devote a marginal part of its resources for a joint venture.

As noted in (Hennet 2008), SMEs are often considered as the weakest links in supply chains and many of them have started to realize the risk of their involvement in a global supply chain. From the very definition of a supply chain, its main stake and reason for being is to provide goods and/or services in a cheap, efficient and profitable manner.

Failure to fulfill any of these requirements on a permanent basis inevitably leads to disruption of the supply chain. And if this is not a relevant risk for a virtual entity, this is a real risk for companies that have invested a significant part of their resources in setting up the supply chain.

2.2.3. Complexity as a source of vulnerability

Increasing complexity of supply networks that connect suppliers, manufacturers, distributors, retailers, and customers, leads to more interdependence between firms. At each stage of a supply chain, different types of social, environmental and economical risks will affect system performance. Ultimately, user satisfaction will determine the viability of the supply chain.

Indeed the probability that something happens at a particular node or connection is higher than for a small and simple network.

2.2.4. Disturbance amplification

The literature on supply chains, and specially studies devoted to existing supply chains, provides a valuable source in risk identification. As an example, the literature on the bullwhip effect has clearly identified as a dangerous phenomenon the amplified fluctuation of inventory levels upward a supply chain (Lee, Padmanabhan, and Whang 1997; Towill 2005).

The second main risk that can be generated by uncertainties within the supply chain has been called the “chaos” risk (Childerhouse et al. 2003; Li and Hong 2007). This risk is mainly characterized by a high probability of strong distortions on key information and critical decisions

Another example of a phenomenon that has proven itself dangerous for a supply chain is the fact that market has put a lot of pressure on firms to differentiate their products. This has led companies to rely on several third parties and has consequently increased the risks by increasing interactions and complexity in the supply chain.

2.3. Risk analysis

Risk analysis firstly requires a methodology for identifying all the risks applying to the considered system, a supply chain, along its life-cycle. Then, each risk is associated with a system vulnerability that can be revealed through scenarios to be simulated to measure risk intensity.

Risks that can lead to supply-chain disruptions are as different as natural catastrophes, strikes, political instability, fires or terrorism. Vulnerability of supply chains to these risks has increased because of modern practices such as lean management and just-in-time inventory.

Taxonomy of supply chains risks can be derived from a careful scanning of internal and external hazards. A classification can be obtained from the different views, roles and activities of the system in its environment. As a starting example, supply chain disruptions can arise:

- from external sources - such as natural phenomena, financial disturbances (changes in exchange rates, taxes), social movements (labor strikes, new regulations), economical problems (unavailability of some product).
- from internal sources - such as products and processes in use at the different stages, design

and dimensioning of the supply chain, failure to integrate all functions in a supply chain, synchronization of product flows, qualitative or quantitative policies at the different stages.

The Risk Breakdown Structure (RBS) technique can be used for supply chains as it has shown its efficiency in many sectors of activity, such as software development projects (Kwak and Stoddard 2004), construction design (Chapman 2001).

MIT research group on "Supply Chain Response to Global Terrorism" has shown that firms usually focus on the type of disruption and not its source in order to know how to prepare against risks. What is important is the type of "failure modes, i.e. the limited ways in which the disruption affects the supply-chain".

A disruption in supply for example can be caused by a strike, an earthquake or a terrorism action and in each case will have the same impact. The team distinguishes 6 different types of failure modes (see Table 1) that are: "Disruption in supply, Disruption in transportation, Disruption at facilities, Freight breaches, Disruption in communications, and Disruption in demand."

Table 1: Supply-Chain Failure Modes

Failure Mode	Description
Disruption in supply	Delay or unavailability of materials from suppliers, leading to a shortage of inputs that could paralyze the activity of the company.
Disruption in transportation	Delay or unavailability of the transportation infrastructure, leading to the impossibility to move goods, either inbound and outbound.
Disruption at facilities	Delay or unavailability of plants, warehouses and office buildings, hampering the ability to continue operations.
Freight breaches	Violation of the integrity of cargoes and products, leading to the loss or adulteration of goods (can be due either to theft or tampering with criminal purpose, e.g. smuggling weapons inside containers).
Disruption in communications	Delay or unavailability of the information and communication infrastructure, either within or outside the company, leading to the inability to coordinate operations and execute transactions.
Disruption in demand	Delay or disruption downstream can lead to the loss of demand, temporarily or permanently, thus affecting all the companies upstream.

3. RISK MANAGEMENT

3.1. The RM process

Classically, the Risk Management (RM) process consists of a series of measures and steps to gradually decrease the risks through a decrease of their probability of occurrence and a decrease of the system vulnerability by developing resilience.

The first step after the risk analysis is to identify and correctly assess the largest set of actions that can be taken to reduce the risks. Then, the second step is to select the most appropriate risk reduction actions.

Risk Management (RM) methodology can be applied through a classical decomposition into the following stages:

- assessment of risk reduction measures,
- selection of risk reduction measures,
- risk supervision in supply chains.

The strategic issue is to determine which actions to undertake in order to manage disruption risks.

3.2. Multi-sourcing

A classical risk mitigation technique consists in introducing redundancy. As a typical application of Risk Management to supply chains, the approach developed in (Pochard 2003) relies on dual sourcing and shows that the real options concept is an adapted tool to evaluate such a strategy. It develops an analytic model to analyze and value the benefits of relying on dual sourcing. This model takes into account various parameters such as the frequency of disruption and the loss of market share.

Retailers often face random variations both on the demand and the supply side. In such cases, Arda and Hennet (2006) show that it is generally more profitable for the retailer to procure from several suppliers rather than to use a single one. Similar results apply when the retailer is concerned with supplier default risk (Babich, Ritchken, and Burnetas 2007). An increase of wholesale prices for smaller delivered quantities could balance this trend. Except that wholesale price increase is often very limited, in particular if the retailer is in a dominant position or if there is a strong competition between suppliers. A possible response in this situation is to develop a symmetric strategy, as described in (Sucky 2007) where a supplier dynamically selects his (her) retailer. However, this would be an attempt to become a dominant partner, which is particularly difficult for a small enterprise facing larger ones.

3.3. Supervision and monitoring

In terms of implementation, a frequent updating of business plans and aggregate planning are essential to organize production with reactivity and flexibility. Risk supervision should play an essential part in the monitoring policy of each enterprise that belongs to a supply chain.

In particular, if dual sourcing is part of the current strategy, managers need to monitor the usefulness of such a solution over time. Their environment may change and firms need to adapt their sourcing strategies over time.

4. CONVERGENCE BETWEEN RM AND SCM

RM and SCM methodologies are so different that a strong effort is needed to conciliate the two viewpoints. The objective of the section is to propose some guidelines toward the design and operation of efficient and sustainable supply chains.

4.1. Integration of risks in Business Process Management Techniques

4.1.1. The SCOR model

One of the leading methods for Supply Chain Management is based on the SCOR (Supply Chain Operations Reference) Model. This model provides a framework for assessing and evaluating a Supply Chain in terms of process models. Three levels of process models are distinguished (Supply Chain Council 2008). The top level contains 5 core management processes called: Plan, Source, Make, Deliver, Return. The second level is the configuration level with 3 processes: Planning, Execution, Enable. The third level details level 2 processes, often in the form of workflows.

This approach can be very useful to identify the weak links in supply chains, both (but not simultaneously) from the viewpoints of risks and effectiveness.

Integration of Risk Management in business process management techniques has recently become a major concern in Supply Chain Management. Clearly, disruptions may damage strongly the supply process and firms may loose business. Protecting the supply-chain against such events may also become a strategic advantage toward the competitors. For instance, in case several firms suffer from the same disruption, companies that are well prepared will limit their loss, recover faster and may even take market shares from their competitors.

As stated in the SCOR booklet (Supply Chain Council 2008), “the new release of the SCOR model enables a company to more effectively balance risk impact and costs of risk mitigation with overall supply-chain management costs”. Supply chain operations are described as a series of activities. Then, a Cross-Functional Process Map (CFMP) is constructed to identify and redesign non value-added activities (SCM view), and to identify and eliminate highly risky steps (RM view) (Li and Hong 2007).

4.1.2. Quality Management

An effort to conciliate supply chain effectiveness with security has been described in (Lee and Wolfe 2003). For them, quality management is the key to conciliate RM and SCM through reducing defects without increasing costs. Thus, firms must “promote measures that also increase supply-chain flexibility”. Applying the principles of this theory to supply-chain security, the authors argue that firms need to focus on prevention rather than inspection and have an advanced process control.

4.2. Toward a model-based approach to RM and SCM

4.2.1. Semi-formal models of supply chains

SCM methods may rely on models of two different types: semi-formal models such as the process models of the SCOR (Supply Chain Operations Reference) approach and analytical models, based on mathematical expressions.

Business process models have been widely used for design, evaluation and management of supply chains from the viewpoints of architecture, organization and communication. Multi-agent models also belong to the class of semi-formal models, mainly used to organize information flows in Supply Chains and improve their performance (Labarthe et al. 2006).

In risk analysis and management for supply chains, models are mainly used to simulate hazardous scenarios and evaluate the vulnerability of the whole system and its components, the partner enterprises.

Quantitative models of supply chains are better suited to describe dynamical and balance equations for product flows and cash flows.

According to Pundoor and Herrmann (2006), three types of simulation approaches have been developed: Discrete event models, specialized softwares and distributed simulation. Integration of risks in Supply Chain models requires a representation of uncertainties and unexpected phenomena. This requirement seems to indicate that stochastic discrete event models may be suitable to represent and evaluate risks in supply chains. However, such models are rather complex, especially to study transient dynamical effects of disturbances.

4.2.2. Discrete event models

In this paper, queuing networks and time-series models are proposed as candidate simulation models to represent the occurrence of hazardous phenomena and their impact on a supply chains.

As for many Discrete Event models, queuing networks models of supply chain hardly differentiate the system and its control. This is particularly true in inventory management, where dynamics of state evolution are intimately dependent upon the inventory policy. A comparative evaluation of several inventory systems would then require several different simulation models. It is thus important to combine analytical studies with simulation to select the most efficient controls in terms of profit and/or risks. In distributed inventory control, base-stock policies with respect to inventory position levels have been shown optimal and robust for typical supply chains.

According to the (S_i - 1, S_i) base-stock policy, the inventory initially contains S_i units and a unitary replenishment order is placed whenever the inventory position declines to the reorder point S_i - 1, i.e. whenever a demand occurs.

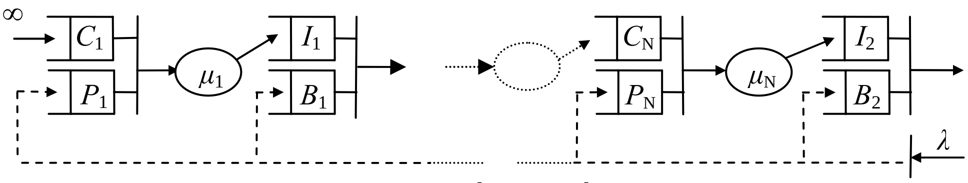

Figure 2. N-stage make-to-stock queuing system

The (S_i - 1, S_i) base-stock policy maintains the inventory position (*stock on hand – backorders + outstanding orders*) constant at the base-stock level S_i and the production facility operates if the inventory (*stock on hand - backorders*) is short of the base-stock level S_i. Whenever a customer order arrives, the manufacturer places not only one end-product processing order, but also one unitary component order to the supplier. Likewise, a demand arrival at the supplier immediately triggers a component processing order and a unitary demand of raw material.

Figure 2 illustrates the queuing network of a serial system with N manufacturing stages. Solid arrows represent material flow and dashed arrows represent information flows. For $i \in [1, N]$, P_i denotes the number of uncompleted orders waiting in the processing queue; K_i, the number of uncompleted orders in the system (P_i plus the order eventually in service); C_i, the number of units delivered from stage i-1 waiting in the processing queue of stage i; N_i, the number of units in the system (C_i plus the unit eventually in service); I_i, the number of units in the finished-goods inventory; B_i, the number of outstanding backorders.

In (Arda and Hennet 2008), the model of figure 2 has been analyzed analytically for N = 2, to compute the limiting performance of the system in steady state.

Disturbances can be introduced in this model through sudden changes in demand, processing and/or transportation rates λ, μ_i, or in inventory levels I_i. The influence of such disturbances is clearly difficult to analyze mathematically, but the model can be used in simulation to identify the cascade of risks generated by such changes, represented as scenarios with attached probability.

Another promising approach to model a supply chain subject to uncertainties, randomness and risks is the time series ARIMA (Auto-Regressive Integrated Moving Average) model. It is an input-output model in which the current output depends linearly on past inputs, past outputs and on current random inputs. The basic model of Box and Jenkins (1976), is monovariable. However many multivariable extensions have been constructed to forecast and control coupled systems.

The ARIMA model of Gilbert (2005) combines

- an ARMA(p, q) model of demand: Z_t with stationary mean value, μ and a random input sequence $\{a_t\}$:

$$Z_t = \mu + \sum_{i=1}^{p} \phi_i (Z_{t-i} - \mu) + \sum_{j=0}^{q} \theta_j a_{t-j}$$

- an inventory balance equation to model the supply chain:

$$I_t = I_{t-1} + O_{t-L} - Z_t$$

- with I_t the inventory at the end of period t and O_{t-L} the order placed at the end of period $t-L$ and expected in period t.

Using this model, the author shows that the sequence of inventories $\{I_t\}$ and the sequence of orders, $\{O_t\}$ can be represented by ARIMA models. Furthermore, the parameters of these models allow quantifying the bullwhip effect along the chain.

However, until recently, such models have been used without integrating the risks aspects. A convenient manner to represent risky situations could be through identification of hazardous states. A supervisory control objective for risk avoidance would then be to consider such states as forbidden. Another technique for avoiding risks could be, as in (Hennet 2003), to maintain the system state in an invariant region contained in the domain of safe conditions.

Hazardous phenomena often occur suddenly and their intensity, which may be very high, is a key property that determines the intensity of their effect. Using the ARMA model of demand described above, the random input sequence $\{a_t\}$ can be used to represent the occurrence of one or several hazardous events.

Simulation can then be used to determine if the system can be maintained in its viable region. Scenarios are translated into pseudo-random input sequences and the system evolves under supervisory actions. A key issue is then the controllability problem in the presence of constraints on the system state.

In general, it is very unlikely that a single enterprise could resist high intensity damages without the help of its partner companies in the supply chain. In this respect, contracts can be seen as an essential tool to conciliate risk sharing with economic efficiency.

4.2.3. Contracts between supply chain partners

Contracts may reduce the risks of financial losses and even bankruptcy of Supply Chain partners. A part of the risk is then supported by the other partners and by the supply chain itself. Multi-sourcing and multi-selling can reduce the risk that an accident occurring in the supply chain would propagate to all the other partners through non satisfaction of final customers. However, for such diversifications not to generate instability in demand, it is necessary to establish trade contracts such as the ones proposed in Cachon and Larivière (2001) between a manufacturer and his suppliers. Under such contracts, orders are divided in 2 parts: firm commitments and options. Firm commitments clearly guarantee a minimum level of revenue to the suppliers, while satisfaction of the manufacturer's maximum order level forces the supplier to install a sufficient capacity.

5. CONCLUSIONS

A major improvement in the understanding of Supply Chains has recently emerged from setting into evidence the importance of risk analysis and management for the survival of a supply chain and its member enterprises. Beyond the recent integration of risk analysis in the leading approach for Supply Chain Management, namely the SCOR model, new models and new tools are needed to help firm managers. Key issues are internal and external hazard identification, vulnerability assessment, construction of risk mitigation policies, and a persistent effort to supervise the system to maintain it as far as possible from its most risky boundaries.

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