VULNERABILITY IN SUPPLY CHAIN RISK MANAGEMENT

Jyri Vilko*, Lauri Lättilä**

**School of Business, Lappeenranta University of Technology, Lappeenranta, Finland*

***Kouvola Research Unit, School of Engineering and Management, Lappeenranta University of Technology, Lappeenranta, Finland*

** Corresponding author: jyri.vilko@lut.fi*

Introduction

Transportation and supply chains have become the focal point of many firms trying to improve competitiveness in an increasingly global marketplace. Global supply chains are comprised of a multitude of companies acting as part of a long and complex, logistics system that is increasingly vulnerable to various disturbances (Wagner and Neshat, 2010; Vilko, 2012). The length and complexity of supply chains derive from the many parallel physical and information flows in place to ensure that products are delivered in the right quantities, to the right place, in a cost-effective manner (Jüttner, 2005). The increased length and complexity of transportation chains is attributable to globalization, the development of communications and other technologies, e-business, complex international networks of industrial partners, unpredictable demand, cost pressures, outsourcing, reliance on suppliers, international governmental intervention and more lean and agile logistics; such complexity, in turn, drives supply chain vulnerability (Waters 2007; Craighead et al., 2007; Harland et al., 2003; Hult, 2004; Mason-Jones et al., 2000; Narasimhan and Talluri, 2009; Thun and Hoenig, 2009, 2011; Brindley, 2004).

Transport logistics have become increasingly significant in an era of international trade (Beresford et al. 2011). Although logistics were previously considered to be purely operational by nature, nowadays it can be considered a strategic issue for many organizations (Gattorna, 1998; Frankel et al., 2008). There are currently more than two billion containers delivering cargo globally, and this choice of transport mode, or combination of modes, may have a direct impact on the efficiency of a supply chain (Hu, 2011; Beresford et al., 2011). In order to be competitive companies are leaning towards complex logistic networks that act more as an extension of the core competitive advantage. In doing this, supply chains are becoming more agile with a view of getting products to customer more quickly and at a minimum total cost (Gunasekaran et al., 2008). Thus, it becomes clear that the level of logistics service provision can determine how competitive an organization is and whether it will retain its customers or attract new ones (Oflac et al., 2012).

The transportation system has increased inter-organizational dependency and inter-organizational relationships have become increasingly important (Scosay et al., 2008). Integrated and seamless logistics can play a crucial role in facilitating global transportation processes (Banomyong, 2005). Yet, in practice, greater integration increases dependency between companies, which can have the undesirable effect of increasing vulnerability. Organisations, therefore, need to understand and analyze the causalities of network processes in order to ensure that the goals of the supply chain fit with their own organizational strategy. It is essential that actors collaborate and share information in their network in order to avoid interruptions in logistic flows (Edwards et al., 2001; Svensson, 2001).

It is clear from the above example that logistics is undergoing continuous, considerable and rapid changes with a primary focus on supply chain vulnerability (Frankel et al., 2008). For the past decade, scientific discussion has focused on supply chain risk management, and while some scholars (e.g. Peck, 2005; Sheffi, 2005) have contributed on the issue of vulnerability, in the context of supply chains, it has received only limited attention. Therefore this paper aims to give light to the supply chain vulnerability by illustrating the factor when using discrete-event-based simulation as an analysis method. The paper continues by presenting the relevant theoretical concepts. Thereafter, different focuses for using simulation in supply chain vulnerability are introduced and then followed by the simulation analysis. Finally, concluding discussion is presented.

Theory

This section of the paper presents the main concepts, namely: supply chain, vulnerability and risk and supply chain risk management and analysis in terms of transport logistics.

Supply chain, vulnerability and risk

A supply chain is defined as a system of suppliers, manufacturers, distributors, retailers and customers in which material, financial and information flows connect participants in both directions (Fiala, 2005). According to Lambert et al. (1998), supply chains consist of networks of structures, processes and management components that provide the linkages between supply and demand. Meanwhile, Waters (2007) describes a supply chain as consisting of a series of activities and organizations through which material moves on its journey from initial suppliers to final customers. Material can include everything that an organization moves—both tangible and intangible.

To define supply chain vulnerability it is essential to first examine the characteristics of risk. Risks can be defined in a multitude of ways, as found in literature. Waters (2007) defines risks as a threat that something might happen to disrupt normal activities, which stop things happening as planned. Finance-related literature views risks in terms of probabilities of expected outcomes (Beaver, 1966). This point of a view is probably the oldest one known, as it was used for insuring merchant ships hundreds of years ago. In strategy literature, risk is used to adjust rates of capital return of investment (Christensen and Montgomery, 1981), variability of expected and actual returns (Bettis, 1981), risk of strategic actions and relational risks (opportunism, cheating, stealing from customers, etc.) (Baird and Thomas, 1985; Bettis and Mahajan 1985; Manuj and Mentzer, 2008). Marketing literature views risks as concerned with the nature and importance of buying goals and failure of meeting psychological or performance goals (Cox, 1967; Manuj and Mentzer, 2008).

Other literature defines risk as purely negative and sees it leading to undesired results or consequences (Harland et al., 2003; Manuj and Mentzer, 2008). A standard formula for the quantitative definition of supply chain risk is:

$$Risk = P \times I \qquad (1)$$

where P is probability of risk event and I is impact of the risk event (Mitchell, 1995).

Hetland (2003) and Diekmann et al. (1989) view risk as an implication of the phenomena of being uncertain. The difference, however, is explained by Waters (2007), who states that "the key difference is that risk has some quantifiable measure for future events, uncertainty does not". Trkman and McCormack (2009) classify uncertainty into two categories: endogenous and exogenous, whether they are deriving from within or outside the supply chain. The supply chain risk can be considered as originating from any unwanted event that concerns the material, information or cash flow from the initial supplier to the end customer. Risks can arise from organizations, from supply chain partners, or from the external environment (Waters, 2007). How sensitive a supply chain is to these disturbances is measured by its vulnerability.

According to Wagner and Bode (2006, p. 304), "supply chain vulnerability is a function of certain supply chain characteristics, and the loss a firm incurs is a result of its supply chain vulnerability to a given supply chain disruption". Asbjørnslett (2008) defines vulnerability as "the properties of a supply chain system; its premises, facilities and equipment, including human resources, human organization and all its software, hardware, net-ware that may weaken or limit its ability to endure threats and survive accidental events that originate both within and outside system boundaries." Previous definitions have differed somewhat from this. For example, Peck (2005) describes vulnerability as an "exposure to serious disturbance, arising from risks within the supply chain as well as risks external to the supply chain." Furthermore, according to Waters (2007), "supply chain vulnerability reflects the susceptibility of a supply chain to disruption and is a consequence of the risks to the chain". Jüttner et al. (2003) describes supply chain vulnerability as the propensity of risk sources and risk drivers to outweigh risk-mitigating strategies, thus causing adverse supply chain consequences and jeopardizing the supply chain's ability to effectively serve the end customer market. Synthesising from the previous definitions found in the literature, we define supply chain vulnerability as the supply chain system's exposure to unwanted and unexpected risk events that originate both within and outside the supply chain system.

According to Asbjørnslett (2008) the difference between vulnerability analysis and risk analysis comes from the focus of the analysis. While vulnerability analysis focuses on the more holistic supply chain perspective in terms of system mission and security of supply, risk analysis focuses more on the impacts of individual events. When examined from a quantitative perspective, the difference between risk and vulnerability comes from the exposure-element; here we define the supply chain vulnerability formula as follows:

$$Vulnerability = P \times I \times E \quad (2)$$

where P is probability of a risk event, I is the impact of the risk event and E is the exposure to the risk.

In reality, when considering supply chain vulnerability, the actors can better affect the propability of a risk event when they have control over the operations (risk coming inside the supply chain) or affecting the exposure to the risk events (risk that comes from outside the supply chain). Thus, when analyzing the proper responses to supply chain vulnerability, the origin of the risk event needs to be taken into account.

Using simulation as a method for vulnerability analysis

Complete understanding of the consequences of a risk is impossible to analyze. Basically we are always acting with limited and uncertain data that offers only a limited view of the vulnerabilities facing a complex supply chain system. In many cases, supply chain information sharing is limited, which can hinder visibility of the vulnerabilities and processes in the supply chain. In these cases, the focus of the analysis method (in here simulation) has to be carefully selected in order to obtain relevant results. By selecting proper focus for analysis, the accuracy of the assessment can be improved, yet on the other hand, when trying to optimize the system where not enough information is available of a complex supply chain system, the results cannot be considered reliable. Thus, an organization can waste resources by trying to get too rigorous results.

There are several factors contributing to the success of vulnerability analysis, such as the personal skills of the logistics managers and the availability of software. However, essentially the accuracy of the analysis is based on the data, namely the amount (and availability) of it and the quality of. In terms analysing and managing supply chain vulnerability, supply complexity defines the focus of the simulation. Thus, these categories are used to illustrate the simulation focus in Table 1.

The available information is divided into two categories: High amount of data with low uncertainty and to the low amount of data with high uncertainty. The left column of the Table illustrates the level of complexity inherent to the supply chain system. It is divided into two categories, namely high and low.

	High amount of data with low uncertainty	Low amount of data with high uncertainty
Low complexity of the supply chain	Optimization	Estimation
High complexity of the supply chain	Structures	Causalities

Table 1: Simulation focus in supply chain risk management

Illustrative example

In this section we present a simulation study where simulation is used to give some estimations about the performance of a potential supply chain. The case consists of off-shore supply with a long lead-time (30 days) to a central warehouse, which in turn feeds five local warehouses. The supply chains has been illustrated in **Figure 1**. However, it is not well known what kind of delays might exist from the off-shore supplier. As such, the supply chain is simulated with predefined operation policies but the potential disruption are given different likelihoods, as well as, lengths.

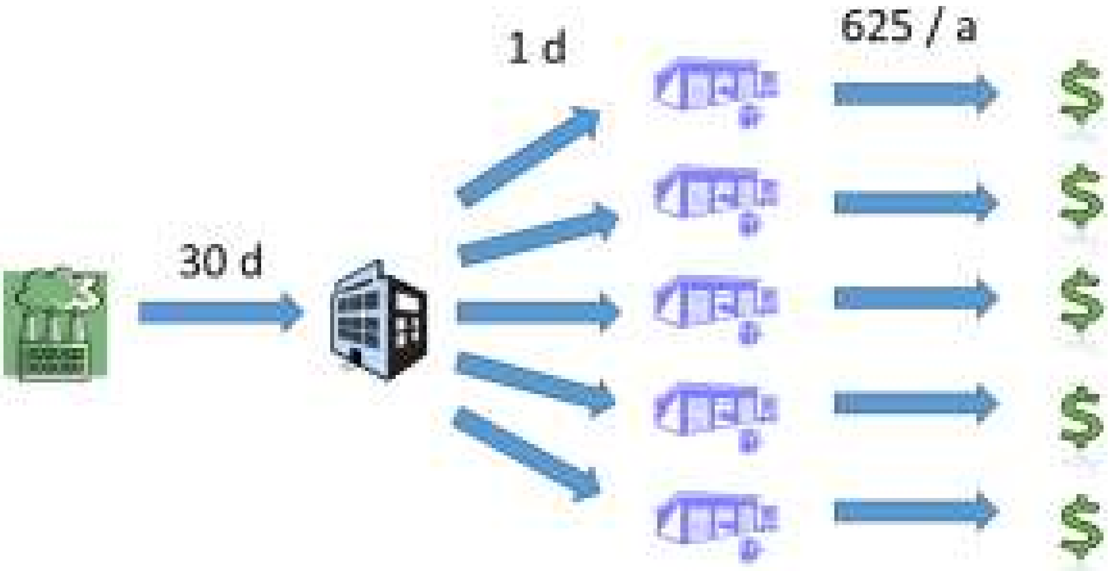

Figure 7: The analyzed supply chain.

The central warehouse has a maximum stock of 1000 units and will order in lots of 250 units from the supplier. The local distributors, on the other hand, have a maximum stock of 65 units and orders with a lot size of 50 units. The delay from the off-shore supplier is 30 days to the central warehouse while the delivery delay to the local distributors is only one day. The demand for the local distributors is stochastic following a basic poisson process with an annual demand of 625 units.

The disruptions occur between the off-shore supplier and the central warehouse. Each time a delivery is made from the supplier to the warehouse, the system randomizes whether a disruption occurs. If the disruption occurs, the delivery is delayed by a fixed amount. With the simulation model we use different chances for the delay and different lengths for the disruptions.

The simulation model was constructed using Anylogic. The basic connections are presented in **Figure 8**. The stock of the central warehouse contains all of the goods in the warehouse. Whenever a sale is made at a distributor, it will send this information to the central warehouse. The warehouse then releases a unit for the specific distributor and moves them into batching operation, where the unit waits until a full lot is ready. After this the goods are delivered to the distributor. A similar connection exists between the central warehouse and the off-shore supplier.

Figure 8: Basic connections in the simulation model.

The simulation model will calculate the total costs of the system. These include the total warehousing costs, total delivery costs, as well as the cost of lost sales. These values will depend on different parameters and they are presented in Table 2.

Variable	Value

Warehousing cost	$ 200 / year per unit (25% warehousing cost)
Cost of lost sales	$ 1000
Fixed ordering cost for distributor	$ 500
Fixed ordering cost for central warehouse	$ 4000

Table 2: Simulation parameters

Results of the model

The supply chain was analysed with 10 different likelihoods of disruptions and 8 different lengths for the disruptions. The model had a warm up period of 1000 weeks and the simulation period was 520 weeks. A long simulation period was used to smooth out the disruptions in the results of the simulation model. We finally divided the total costs with 10 to come up with a yearly cost for the whole supply chain. Overall all different options were run for 100 times and the average values are used. Final results of the model are presented in Figure 3.

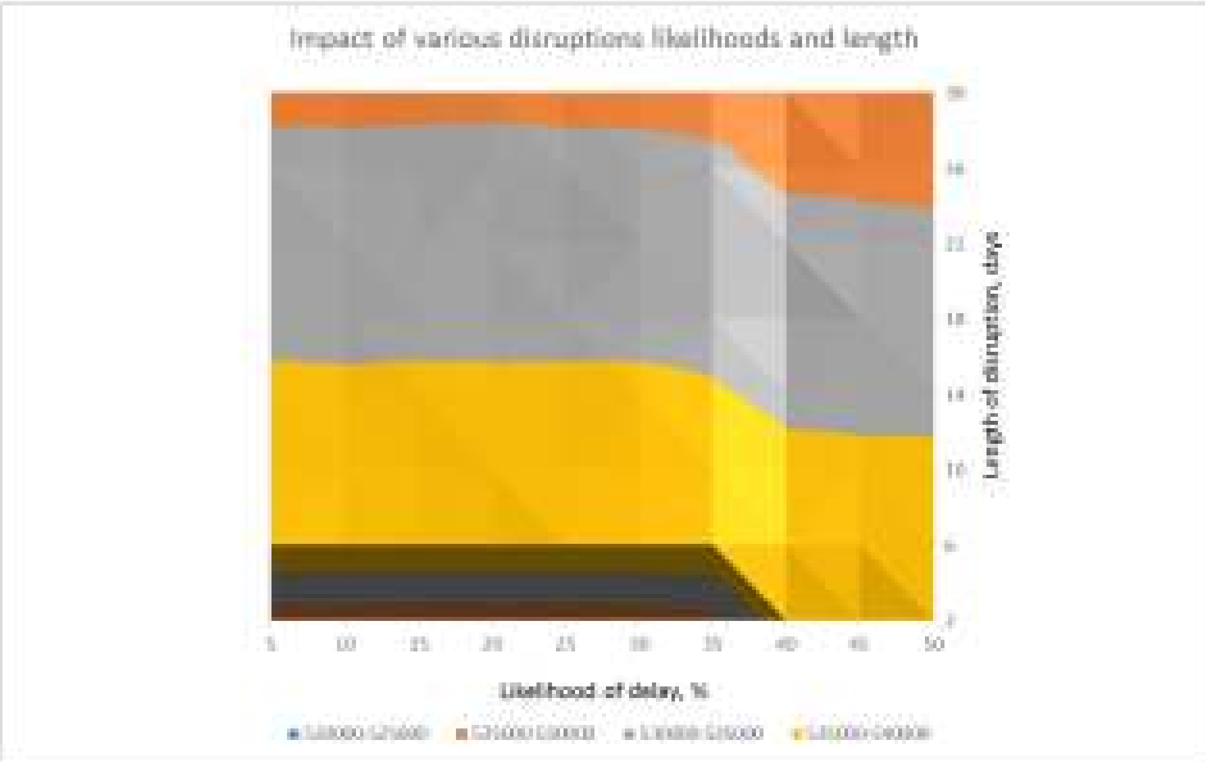

Figure 9: Basic connections in the simulation model.

The performance of the supply chain clearly depends on these disruptions. With the current ordering policy, the likelihood of the disruption has an impact if the disruption likelihood goes over 35 percent. Anything between 5 and 35 % has similar results. On the other hand, if the length of the disruptions are long (30 days), the costs of the supply chain are lower than with a disruption with a length of 6 days. This indicates that the chosen ordering policy leads to too high warehouses and the organization should lower them. The exposure to the risks is possibly too low and it leads to excessively high costs in most cases.

The same simulation model could be used later to optimize the performance of the supply chain when more information becomes available. If the likelihood of the disruptions would be known, as well as the length of the delay, the organization could use the simulation model to optimize the performance of supply chain. However, in the current state this would not be possible as the disruptions most likely have a bigger impact on the results when the lot sizes would be decreased.

Concluding discussion

Supply chains have become increasingly important to the global economy. Numerous trends have affected the development of complex logistic systems during the last decade, and many of those trends have also exposed the supply chains to various risks, making them more vulnerable than ever before (Wagner and Nethat, 2011). In many ways, coping with this vulnerability is still in its infancy. Assessing the vulnerability of an international supply chain has proven difficult. In order for decision makers to properly make these assessments, managers need to have a proper meta-level understanding of the problem domain.

This paper aims to increase the understanding of the current level of knowledge over vulnerability analysis by a twofold contribution: firstly, we improve the clarity of the current academic discussion of the topic of vulnerabilities in supply chain risk management by taking into account both the risk and exposure elements and by illustrating the impact of those in a simulation. Secondly, we put forward a managerial framework for choosing proper vulnerability analysis methods using available data.

The understanding of the causalities at the theoretical and practical levels is essential in order to properly analyze vulnerabilities. As a part of supply chain risk management, the conceptual maturity of supply chain vulnerability is still very much developing. Our scientific contribution is drawn from synthesizing previous literature (e.g. Asbjørnslett, 2008; Peck, 2005; Waters, 2007; Wagner and Bode, 2006) and building our own definition of supply chain vulnerability. In doing this, we aim to improve the conceptual clarity by using a differentiating element - exposure - in supply chain vulnerability.

In order to analyse the supply chain vulnerabilities properly the supply chain's operations and risks need to be identified by the actors involved. The importance of a comprehensive view is vital especially in the case of long and complex supply chains where there are several different modes of transportation in different environments that reflect the variation in vulnerability with different exposure to some risks and different probability of other events occurring. In order to attain a comprehensive view of the supply chain, extensive knowledge about the different phases of operations is required. In this study we utilized a simulation model as they can grasp dynamic and stochastic behavior, as well as provide confidence intervals about the performance of the whole supply chain, not only individual parts of the complex supply chain system.

Simulation is a multipurpose tool and is suitable in order to analyze complex supply chains. The more complex the supply chain, the more difficult it is to optimize all parts of the supply chain. However, simulation can be used to look for optimal structures, e.g. a supply chain design which should fit well with environment and products involved. Even in cases with a small amount of unreliable information, simulation can provided insights into the causalities which exist between different parts of the supply chain. In this study we presented how simulation can be used to gain some estimates about the performance of a hypothetical supply chain even with a limited amount of information. Choosing the correct method to utilize simulation should help managers make more informed decisions regarding supply chain risk management.

In reality it is virtually impossible to list every conceivable risk, and identification gives a list of the most significant risks that have an effect on the supply chain. Inter-organizational employees typically have the most intimate knowledge of the organization and its conditions, but not necessarily the capability to identify risks (Waters, 2007). This illustrates the benefits of having a holistic perspective, which is also essential for supply chain vulnerability analysis. By understanding the importance of using the appropriate focus with the information organizations are able to more efficiently benefit from the risk management practice. Thus, organizations can achieve a competitive advantage from engaging in effective risk management, especially when acting in high-risk environments, by appropriately focusing their risk management efforts according to relevant vulnerabilities.

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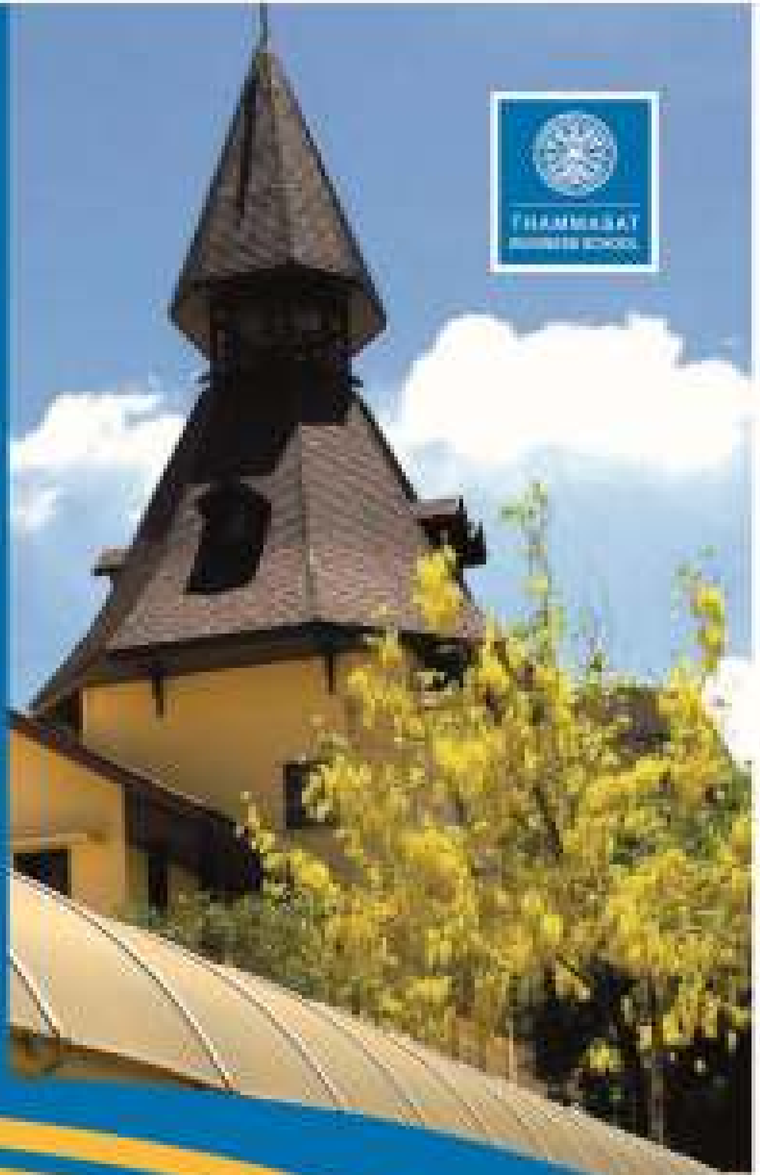
Tuition and general fees are approximately 230,000 Baht per annum.



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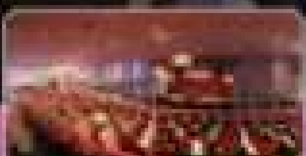

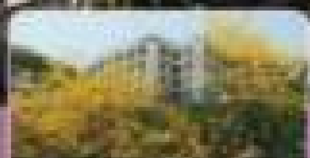

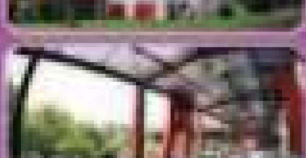

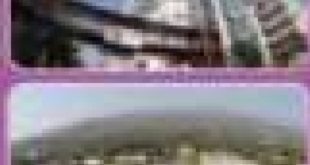

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