Developing a framework on supply chain risk mapping, prioritization and engagement

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ABSTRACT

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Kiana Dehkhoda

Supply chain risk and uncertainty have been drawing much attention in the past few decades. In this thesis, a holistic risk management framework is developed to cope with such risks and uncertainty. The framework assists decision-makers first by detecting internal and/or external risks at early stages. In order to visualize the probability of risks and their impacts, risk-mapping techniques are then proposed. Risk assessment is used to determine risk occurrence and the effects in either quantitative or qualitative terms. Once risks are analyzed, risks relations should be investigated to further adopt risk management strategies for high importance items. Finally, ongoing control of existing and emerging risks requires an appropriate management strategy in order to increase supply chain efficiency. The framework is validated through an application in a small manufacturing company that struggles with outsourcing risk arising from both lead time and demand uncertainties. We first detect uncertainties, then design a simulation model to illustrate the impact of these uncertainties on the company's performance, where we use the number of lost customers as the company's performance indicator. Moreover, we conduct an experimental design to investigate risk relation and their impact on the number of lost customers. The experimental design also allows for comparing various supplier's performance and indicates which supplier would be most beneficial to work with.

Keywords: supply chain risk management, framework, case study

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1 Introduction

In today's marketplace, demand variations require manufacturers to provide products with short lifecycles at high speeds, which results in adding risk and complexity to supply chains. Supply chains must react quickly and use risk management strategies to diminish impacts significantly. Many examples exist of supply chains that could not adequately respond to risks. Ericsson, for example, lost millions of dollars due to a fire accident that occurred at a sub-supplier (Norrman & Jansson, 2004), while Apple failed to satisfy customers' demands as a result of an earthquake that took place at its supplier in Taiwan (C. S. Tang, 2006). Many researchers have highlighted the need for proactive and reactive risk management strategies to deal with current and emerging risks (Ponomarov & Holcomb, 2009; Ghadge, Dani, Chester, & Kalawsky, 2013; Ghadge et al., 2012). This study contributes to the existing literature about supply chain risk management in several ways. We expand on previous studies by defining a generic comprehensive framework to investigate and map the risk, evaluate risk magnitude and risk interactions, prioritize risks, employ proper risk management strategies and control risk continuously. Additionally, we elaborate more about the framework functionality in an industry specific case study. The implication of the framework on the experiment sheds light on outsourcing risk investigation, evaluating risk by a simulation model, analyzing risk factor interactions by conducting an experimental design and proposing risk management strategies to diminish risk magnitude significantly as well as allowing an ongoing control on existing and new risks.

1.1 Thesis organization

In chapter 2, we review the literature on risk definition and broaden our understanding by investigating risk management in-depth. We detect gaps in the literature; some studies underestimated risks interactions impact. Therefore, we propose risk interaction approaches to examine any relations among risks before implementing any management strategies, which are highly reliant upon risk relations. We also propose required tools and techniques to completely scrutinize risks. Moreover, the defined risk management framework is not limited to a specific industry as some studies' findings are constrained to industry specific examples.

In chapter 3, we propose a supply chain management framework based on previous studies and extend it in different ways. Former studies reveal a lack in illustrating risk magnitude, risk relations and risk prioritization and associated tools and techniques. We thoroughly explain all stages to study risk from the beginning and it is an iterative and ongoing loop investigating existing and new risks.

In chapter 4, we employ the defined framework on an industry specific example and use various tools and techniques to identify risks and verify the framework implementation. In line with the risk management framework, process mapping, inventory management model, simulation model, experimental design, risk avoidance and risk mitigation strategies are used.

In the final chapter, we summarize our findings and compare them with previous studies. We further address the limitations of our study and conclude with the potential for future studies.

2 Literature review

Supply chain risk has been an emerging issue in which several studies concentrating on risk reduction by implementing various risk management strategies (Jüttner, Peck, & Christopher, 2003;Jüttner, 2005; Manuj & Mentzer, 2008; C. S. Tang, 2006;O. Khan & Burnes, 2007). To this end, we study risks associated with supply chain and develop a framework to cope with any disruptions by implementing proper risk management strategies. In this chapter, we present an exhaustive discussion of risk definition, risk classification, risk mapping, risk assessment, risk interactions, risk prioritization and risk management.

2.1 Risk definition

Risk has been a controversial topic for a long time, where researchers in different disciplines take different approaches in defining the term. In finance, risk is regarded as hazard and chance and account for "upside" and "downside" potential (Zsidisin & Ritchie, 2008). Many researchers focus solely on the negative aspect of risk (March & Shapira, 1987; Royal Society, 1992). In particular, some researchers consider risk as the probability of occurrence of undesirable outcomes stemming from activities (Chiles & McMackin, 1996; Rowe, 1980; Yates & Stone, 1992). Similarly, risk is defined as an uncertainty which might have a negative, unfavorable, harmful influence on objectives (Hillson & Murray-Webster, 2007). Moreover, (Lowrance, 1980) defines risk as the likelihood and impact of unwanted effect.

Over time, the concept of risk has evolved and researchers changed their perspective on its definition. The new definition of risk, including downside as well as upside effect on objectives is presented by (Hillson, 2006; Hillson & Murray-Webster, 2007; Peck, 2006; Wagner & Bode, 2008). Some provided an explanation for the risk which is aligned with uncertainty in the sense that both arise from information insufficiency and lack of knowledge (J. Li & Hong, 2007; Paulsson, 2004; Ritchie & Marshall, 1993). Moreover, (Hyneman, 1971) addresses the difference between risk and uncertainty in that risk is a quantitative measure and its outcomes can be assessed, whereas uncertainty is qualitative and no further estimation can be made on it. Risk is different from uncertainty in that risk incorporates not only uncertainty but also loss or damage (Kaplan & Garrick, 1981). It is also conceived that "risk is possibility of loss" whereas hazard is "source of danger" (Kaplan & Garrick, 1981). On the other hand, a different perception of risk is introduced defining the risk as a measure with both positive and negative outcomes (Moore, 1983). For instance, long term commitments with suppliers are beneficial for both supplier and business unless one party is determined to exploit the other side (Burnes & Dale, 1998; Cousin, Lamming, & Bowen, 2004; Womack, Jones, & Roos, 1990). Additionally, supply chain risk is recognized as occurrences of any disruption or interruption in the flow of material or information from the upstream (suppliers) to the downstream level (customers) (Jüttner, 2005). (Zsidisin, 2003) defines risk as a probable disruption to inbound supply chain contributing to the inability to satisfy customer's needs.

2.2 Risk classification

Risk taxonomy is crucial for assessing and managing risks. Risks are generally classified at the macro level into two areas: external and internal. External risks originate from the environment external to the local company. Conversely, any problems deriving from the local company are called internal risks. Disruption risks are comprised of natural or environmental risks (for example, earthquakes and volcanoes) and human-related risks (such as war and hijacking) (C. S. Tang, 2006). In addition to disruption risks, any uncertainties in demand or supply are assumed to constitute process or operation risks (C. S. Tang, 2006). Risk categorization also includes socio-political risks (e.g. sanctions) and process risks (e.g. machine and process failure) (Jüttner et al., 2003; Jüttner, 2005; Kleindorfer & Saad, 2005).

Furthermore, (Kleindorfer & Saad, 2005; Sheffi & Rice Jr, 2005) provide a classification of risk domains which incorporate market features (such as, market size, new products and new players) and political risks (e.g. government instability). On the other hand, (Kara, Kayis, & Gomez, 2008) emphasize sourcing risks (such as outsourcing, sole sourcing, disruption in supply) and governmental risk (e.g. tax problem, duty issues). Different risk factors are presented including political factors (e.g. Airbus, which is a four-nation association, is exposed to lose a remarkable amount of money due to a trade-off among four nations interests) (C. Tang & Tomlin, 2009), social factors (e.g. child labor at Nike company), market factors (e.g. overstocking or understocking as a result of demand uncertainty), sourcing factors (e.g. issues in regards to Intellectual Property (IP), especially some overseas suppliers disregarding regulations) and process related factors (e.g. any ambiguity in capacity) (C. Tang & Tomlin, 2008).

(Jüttner, 2005) argues that disruptions arising from political source (e.g. fuel crisis), social source (e.g. terrorist attacks), sourcing (e.g. long lead times) are the main risk origins. (Singhal, Agarwal, & Mittal, 2011; Zsidisin & Ritchie, 2008) emphasize the likelihood of supply chains being encountered by economic hazards (for instance deviation in tax and exchange rates), by market factors for example, presenting improper products regardless of markets features, customers and competitors' behavior, customer anticipation and any variation in regards to price). (Manuj & Mentzer, 2008) define other risk drivers originating from sourcing (e.g. discontinuity in supply due to fire and insolvency) and internal processes (e.g. insufficient capacity in procurement). These are all external hazard resulting in adverse consequences. (Ritchie & Brindley, 2007) consider other risks triggered by economic hazard (e.g. tax rate shifts and inflation), process (e.g. process or procedure issues) and sourcing (e.g. issues consisting upholding stock, lead-times, support, and service).

The inability to be adaptive to market features, variation in lead-times, low quality, supplier insolvency, delivery issues and machine failures are all circumstances which endanger supply chains to an eventual complete failure (Gaonkar & Viswanadham, 2007). Different risk terms are also presented, encompassing market risks (for instance commodity price, interest, and exchange rate) and process risks (e.g. system downtime related) by (Scandizzo, 2005). Although some researchers emphasize other aspects of risk (e.g. tariff shifts, import, export regulations and being highly reliant on single supplier) (Zsidisin, Panelli, & Upton, 2000; Zsidisin, Ellram, Carter, & Cavinato, 2004), others stress that the inability of suppliers in providing customers' demands expose the supply chain to hazards and subsequently adverse effects (Zsidisin et al., 2004).

Some researchers argue that even though implementing a risk management strategy might reduce risk exposure in some ways, the probability of being subjected to another risk might increase as well. For example, while using lean techniques necessitates lower demand forecast errors, such techniques also expose the company to supply disruptions (Chopra & Sodhi, 2012). Some scholars accentuate that the bullwhip effect is induced by a number of drivers such as disruptions in capacity, information distortion, shifts in demand and lack of knowledge (sourcing risk) (Ketikidis, Lenny Koh, Gunasekaran, Cucchiella, & Gastaldi, 2006; T. Wu, Blackhurst, & O'grady, 2007). Other experts point out that the effect of transportation hazards should not be underestimated (e.g. long lead time, delay in deliveries, port strike, paper scheduling, and high transportation expenses) (O. Tang & Musa, 2011; Yu, Zeng, & Zhao, 2009). In addition to the external risks mentioned above, a series of other factors determine internal risk including excessive holding cost, human errors, system and process failures, as well as modification in material or processes (Cachon, 2004; Davies, Finlay, McLenaghen, & Wilson, 2006; Han & Chen, 2007;Lockamy III & McCormack, 2010). *Table 2-1* demonstrates a summary of risk categorization and associated definitions.

Table 2-1 Risk categorization and definition

Risk domain			**Articles**	**Definition**
Level 0	**Level 1**	**Level 2**		
External risks	Natural or environmental risk		(C. S. Tang, 2006)	Natural disasters (for instance hurricanes, earthquakes, volcano eruption)
	Man-made disasters		(C. S. Tang, 2006)	Terrorism, war, hijacking
	Political risk		(Jüttner et al., 2003; Jüttner, 2005; Kara et al., 2008; O. Khan & Burnes, 2007; Kleindorfer & Saad, 2005; Sheffi & Rice Jr, 2005; C. Tang & Tomlin, 2008; C. Tang & Tomlin, 2009; C. S. Tang, 2006)	Any radical changes in government can influence taxation constitution. Government instability, sanctions.
	Social/reputational /cultural risk		(Jüttner, 2005; Spekman & Davis, 2004; C. Tang & Tomlin, 2008; C. Tang & Tomlin, 2009; C. S. Tang, 2006)	Labour strike and rebel, customs, social, and language barriers (For instance, well-known company such as Nike was accused of using child labour in shoe production.
	Economic risk		(Manuj & Mentzer, 2008; Ritchie & Brindley, 2007; Wagner & Bode, 2006)	Fuel price fluctuations changes, tax rate changes, inflation , exchange rates

	Market risk	Competitive risk, financial risk, demand risk, forecasting risk	(Gaonkar & Viswanadham, 2007; Kara et al., 2008; Ketikidis et al., 2006; Lockamy III & McCormack, 2010; Manuj & Mentzer, 2008; Scandizzo, 2005; Singhal et al., 2011; C. Tang & Tomlin, 2008; C. S. Tang, 2006; Zsidisin et al., 2000; Zsidisin et al., 2004; Zsidisin & Ritchie, 2008)	Businesses are threatened by new products, new players, low profit margin, commodity price, market size and product.
	Governmental risk		(Kara et al., 2008; Kiser & Cantrell, 2006; Zsidisin et al., 2000)	Regulatory risks, tax rules, duty issues
	Sourcing risk	Single/ multiple sourcing risks, lack of information Sharing risk/ supply risk	(Childerhouse, Hermiz, Mason-Jones, Popp, & Towill, 2003; Chopra & Sodhi, 2012; Davies et al., 2006; Gaonkar & Viswanadham, 2007; Ghadge, Dani, & Kalawsky, 2012; Jüttner, 2005; Kara et al., 2008; Kaya & Özer, 2009; Ketikidis et al., 2006; Manuj & Mentzer, 2008; Norrman & Jansson, 2004; Ritchie & Brindley, 2007; Singhal et al., 2011; C. Tang & Tomlin, 2008; T. Wu et al., 2007; Zsidisin et al., 2004)	• Improper forecasting which leads to inaccurate understanding of customer's needs. • Bullwhip effect due to lack of information or information distortion • Long lead times • Poor quality • Lack of raw materials or inability to meet customer's demand

	Transportation risk		(Gaonkar & Viswanadham, 2007; O. Tang & Musa, 2011; Yu, Zeng, & Zhao, 2009)	Transportation modes, delivery costs, late deliveries
Internal risks	Process risk	Machine breakdown or obsolescence , interruption of service or system due to power failures, labour strikes	(Cachon, 2004; Childerhouse et al., 2003; Chopra & Sodhi, 2012; Davies et al., 2006; Gaonkar & Viswanadham, 2007; Ghadge et al., 2012; Han & Chen, 2007; Jüttner et al., 2003; Kleindorfer & Saad, 2005; Lockamy III & McCormack, 2010; Manuj & Mentzer, 2008; Ritchie & Brindley, 2007; Scandizzo, 2005; Singhal et al., 2011; C. Tang & Tomlin, 2008; C. S. Tang, 2006; Zsidisin & Ritchie, 2008)	Which addresses any failures in regards to procedure, process, system or machine

2.3 Risk mapping

In order to inform companies about the likelihood of risk occurrence and severity of its impact, risk mapping is an imperative step before adopting any risk management strategies. Some scientists stress the necessity of risk mapping for risk identification, evaluation, auditing and control (Basel Committee, 2003). The plain and general form of mapping is composed of two elements; likelihood and levels of impact. Risks with high probability and severity have priority to be assessed (Scandizzo, 2005). Figure 2-1 shows one way of mapping risks on a two-dimensional axis (Scandizzo, 2005).

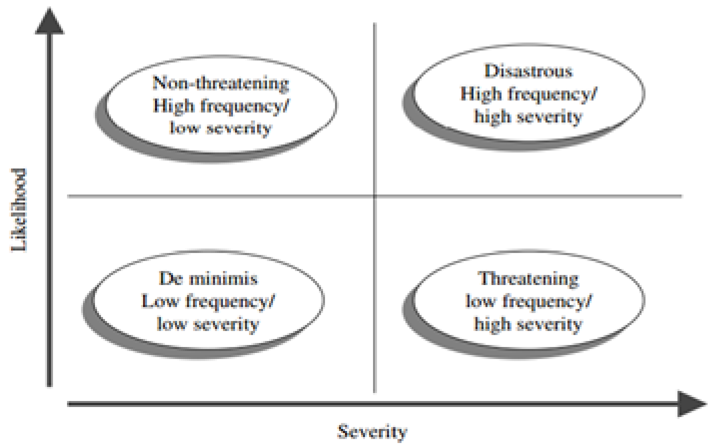


Figure 2-1 Risk mapping structure based on likelihood vs severity (Scandizzo, 2005)

2.3.1 Risk heat map and risk matrix

One type of risk mapping is the risk heat map where the possibility of risk taking place and its impact is displayed. Risk levels are categorized into low, medium, high level and are achieved by the likelihood × consequence of risk incidence (Cox Jr, Louis Anthony Tony, 2012; Dominguez-Chicas & Scrimshaw, 2010). Figure 2-2 is a demonstration of the risk heat map (Dominguez-Chicas & Scrimshaw, 2010). Another type of graphical depiction approach, which is similar to risk heat map, is risk matrix. As illustrated in Figure 2-3, a risk matrix is a combination of risk probability and its impact and is beneficial in finding and assessing critical risks (Markowski & Mannan, 2008).

As shown in Figure 2-2, the risks levels categorization are low, medium and high. A risk heat map is a 5 by 5 matrix in which both the likelihood and consequence elements can get a score of 1 to 5. The likelihood element is increasing on the x-axis, while the consequence element is likewise rising. Between factors ranked in the risk heat map, 20 hazard (9%) factors are ranked as “Low Risk”, 109 hazard (49%) factors are rated as “Medium Risk” and the rest of the hazard factors (42%) are scored as “High Risk”.

As depicted in Figure 2-3, if the probability of risk is within the range of 0-0.6 and risk has minimal to moderate impact, risk is considered as Low (L). However, if risk probability is within 0.6-0.9

and risk has serious to critical impact, risk is determined as Medium (M). If risk likelihood is within 0.9 to 1 and risk has critical impact, risk is considered as High (H).

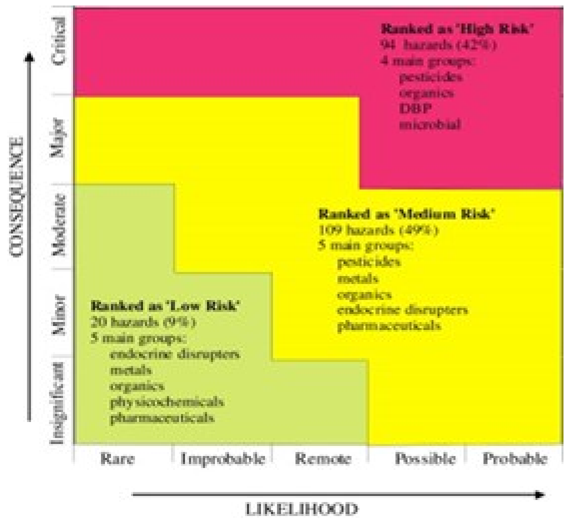


Figure 2-2 Risk heat map (Dominguez-Chicas & Scrimshaw, 2010)

Critical	M	H	H	H	H
Serious	M	M	M	H	H
Moderate	L	M	M	M	H
Minor	L	L	M	M	H
Negligible	L	L	L	M	M
Origin	0.00~0.10	0.10~0.40	0.40~0.60	0.60~0.90	0.90~1.00

Figure 2-3 Original risk matrix (Markowski & Mannan, 2008)

2.3.2 Risk value map

Although a risk heat map is constrained in demonstrating the negative risk aspects, a risk value map displays both the negative and positive aspects. Risk circumstances and trends can be simply tracked over time by a risk value map. For example, in Figure 2-4, risk #1 is at low probability in the previous state whereas in the present state, risk #1 is in critical condition and requires immediate action.

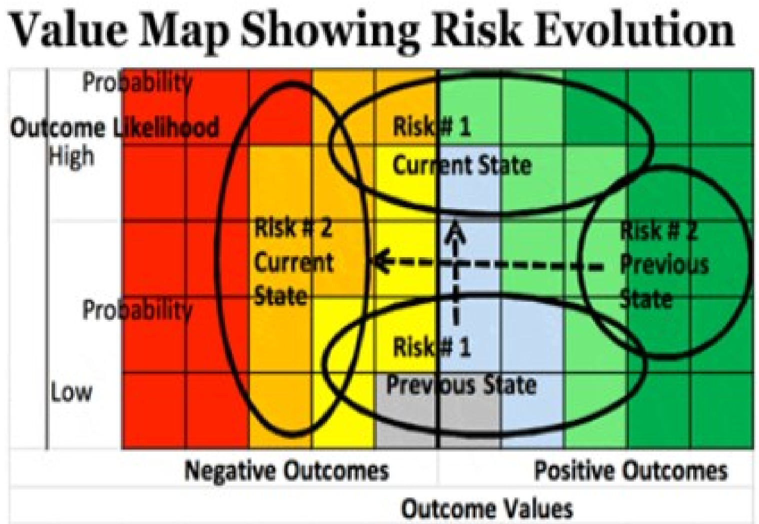


Figure 2-4 Risk value map (http://ww2.cfo.com/risk-management/2013/02/how-to-map-your-risks/)

2.3.3 Risk Breakdown Structure (RBS)

(Cagliano, De Marco, Grimaldi, & Rafele, 2012; Hillson, 2003) present a framework which the risk sources are determined with the use of RBS (risk breakdown structure) and activities are classified based on ABS (Activity Breakdown Structure). The effect of risk sources on activities are demonstrated by RBM (Risk Break down Matrix) (Hillson, Grimaldi, & Rafele, 2006). As apparent from Figure 2-5, grey cells demonstrate the impacts of risk resources on activities (Cagliano et al., 2012). ABS provides an insight into activities occurring in the supply chains. However, RBS identifies risk sources and sorts them into different categories (Hillson, 2003). The inspection of risk occurrence is achieved through RBM and the impact of risk occurrence on activity is measured by KPIs (Key Performance Indicators).

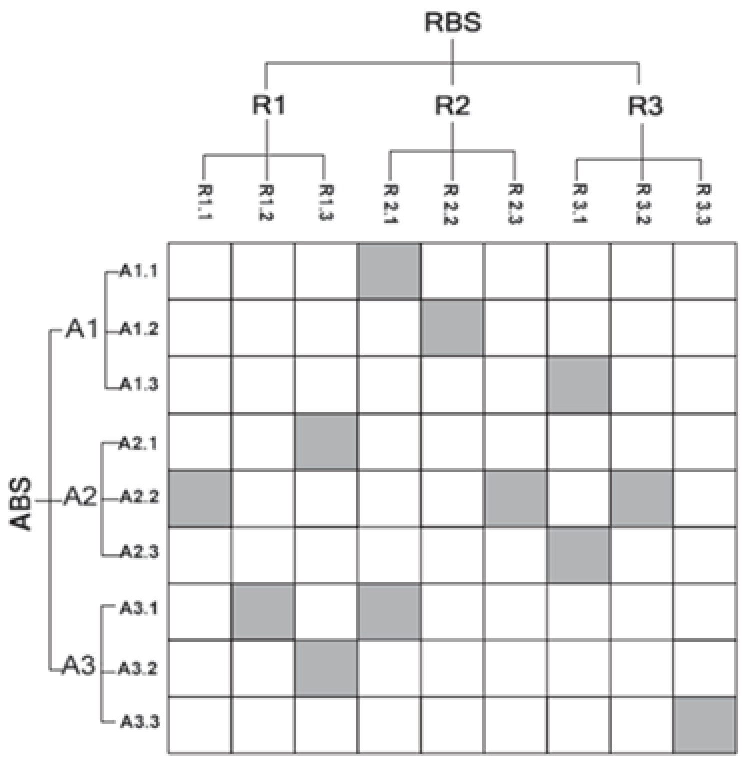


Figure 2-5 Demonstration of ABS, RBS, and RBM (Cagliano et al., 2012)

2.4 Risk assessment

Once risk domains are detected and mapped, risk magnitude should be taken into consideration. Several studies have been done to evaluate risks likelihood and their impact on supply chain (Cox & Townsend, 1998; Cohen & Kunreuther, 2007; Knemeyer, Zinn, & Eroglu, 2009; Sheffi & Rice Jr, 2005; Thun & Hoenig, 2011).

Quantitative and hybrid approaches allow calculating risk magnitude and potential loss quantitatively while in cases where risk magnitude is unlikely to be assessed, qualitative approaches derived from subjective information (such as what if analysis, brainstorming, expert interview, etc.) are used. In Equation 2-1, each error mode (EM) is calculated by the probability of error mode $P(EM_{ik})$ and severity$D(EM_{ik})$. The following mathematical equation is suggested by (Trucco & Cavallin, 2006).

$$R(EM_{ik}) = P(EM_{ik}) * D(EM_{ik}) \quad \text{Equation 2-1}$$

Hybrid techniques are the combination of qualitative techniques (relying upon process analysis and experts ability), quantitative techniques (mathematical assessments and analysis on real data collection) and semi-quantitative (probability and impact indications such as unlikely, improbable, probable, insignificant, minor, serious and catastrophic impact; numerical rate from 1 to 4) (Hallikas, Virolainen, & Tuominen, 2002). A qualitative index assessment categorizes the possibility of hazard (e.g. 'rare', 'unlikely', 'likely' and 'almost certain') and the severity of its effect (e.g. 'severe' and 'light', or three or more levels, such as 'high', 'medium' and 'low' or 'negligible', 'minor', 'major' and 'severe') (Raj Sinha, Whitman, & Malzahn, 2004a; Sheffi & Rice Jr, 2005). However, in some cases, the risk level can be assessed by combining categories (e.g. such as 'low', 'medium', 'high' and 'very high' (Norrman & Jansson, 2004).

2.5 Risk interactions

In order to have an efficient risk control, it is vital to assess risk interactions. (Faisal, 2009) enumerates the reasons of why risks should not be evaluated in isolation. Some firms employ risk management strategies without taking into account any probable interactions among risk factors. For example, hedging some risks which can be neutralized by other risks is unnecessary and it leads to excessive costs in risk management. Moreover, failure to ignore risk interactions results in underestimation of risk exposure. In order to capture risk interactions, risk interaction maps, correlation matrices, bow-tie diagrams and statistical analysis are suggested. Risk interaction map is the demonstration of same list of risks on x and y axes and risks relations are specified by X. Figure 2-6 is an illustration of risk factors.

Risk	Supply Chain Disruption	Customer Preference Shift	Copper Price Increase >25%	Work Stoppage >1 Week	Economic Downturn	Supplier Consolidation	Local Competitor Enters Market	New Substitutes Available	Cost of Capital Increase >5%	Tighter Emission Standards	FCPA Violation	Exchange Rate Fluctuations
Supply Chain Disruption			×	×	×	×	×					
Customer Preference Shift					×		×	×		×		×
Copper Price Increase >25%	×				×	×						×
Work Stoppage >1 Week	×				×	×					×	
Economic Downturn	×	×	×	×		×	×	×	×		×	×
Supplier Consolidation	×		×	×	×				×			
Local Competitor Enters Market	×	×			×							×
New Substitutes Available		×			×					×		
Cost of Capital Increase >5%					×	×						×
Tighter Emission Standards		×						×				
FCPA Violation				×	×							
Exchange Rate Fluctuations		×	×		×		×		×			

Figure 2-6 Risks interaction map (by Deloitte & Touche LLP)

A correlation matrix is used to indicate any interactions among risks quantitatively based on historical data. Moreover, a bow-tie diagram is an integration of fault tree and an event tree indicating a complicated risk occurrence from risk factors to consequences. Figure 2-7 is a demonstration of a bow-tie diagram.

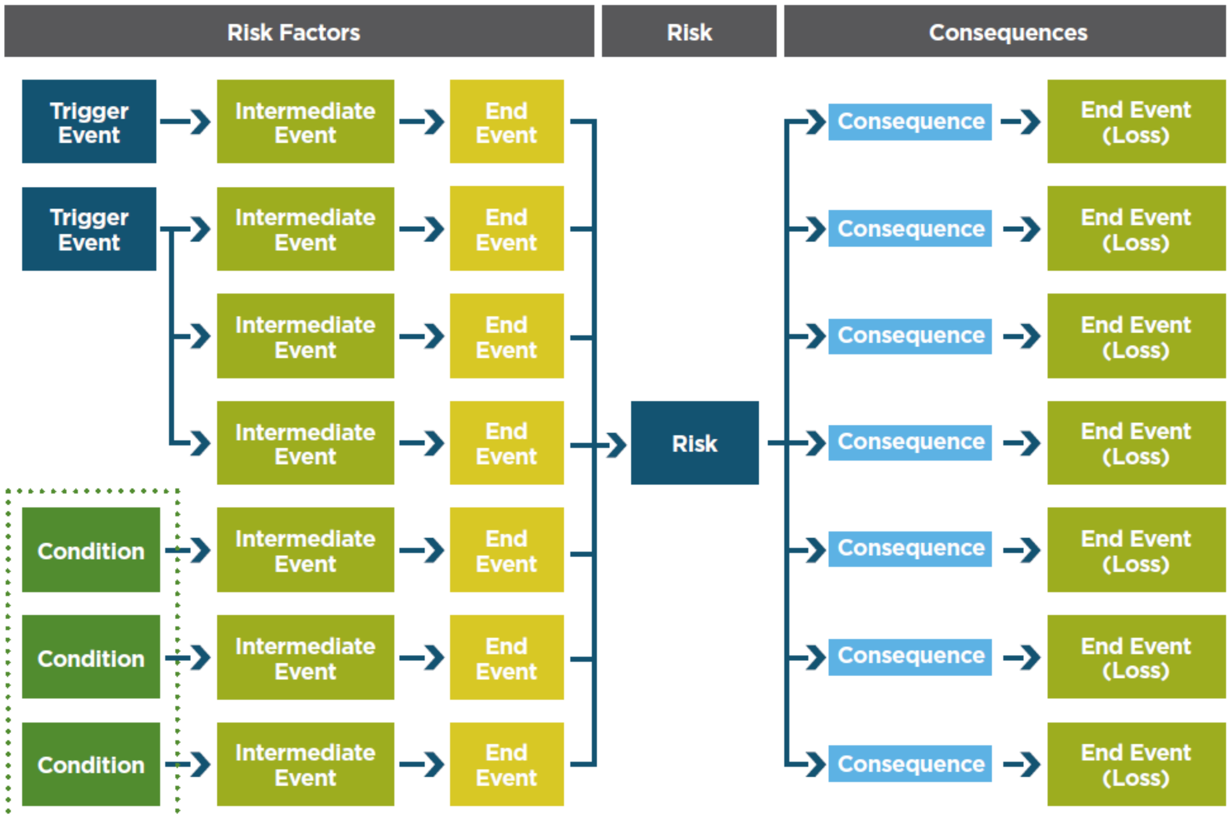


Figure 2-7 Bow-Tie Diagram by Deloitte & Touche LLP

2.6 Risk prioritization

2.6.1 Severity analysis techniques

Prior to risk occurrence, when designing processes for new product or operation phase, potential failure modes of product or operation and the impact of each failure mode are mapped by the use of FMEA (Lipol & Haq, 2011). Moreover, in FMECA analysis, failures are ranked according to how crucial they are and the probability of occurrence. (Lipol & Haq, 2011) enumerates the deficiency of this technique in identifying complicated failure modes and ordinal scale numbers in displaying the severity, occurrence and detection. For instance, assigning an ordinal number to a failure mode does not necessarily indicate a risk corresponding to the number. Similarly, scores are given to risk factors to find the ones with high importance (Kutlu & Ekmekçioğlu, 2012). Short Cut Risk Assessment (SCRA) is a risk estimation method where a quantitative result, in terms of occurrence and severity, is derived from qualitative evaluation and the results would be achieved in terms of occurrence and severity (Rogers, 2000). Rapid Ranking (RR) assists operating managers in a way that risks are prioritized based on severity and probability of occurrence after they have been detected. Rapid Ranking applications keep users informed about risks occurrences, provide a base for comparing various risks and assist in inspecting risks with high and low significance (Tweeddale, Cameron, & Sylvester, 1992).

2.7 Supply chain risk management

As global supply chain network becomes more sophisticated, managers have difficulties in detecting risks within their supply chains (Ryding & Sahlin, 2013). Supply chain risk management encompasses several processes; risk identification, risk evaluation, risk management, strategic actions and inspection (Bandaly, Satir, Kahyaoglu, & Shanker, 2012; Blackhurst, Scheibe, & Johnson, 2008; Sachdeva, Sharma, Arvind Bhardwaj, Kayis, & Dana Karningsih, 2012; Xie, Anumba, Lee, Tummala, & Schoenherr, 2011). (Ghadge et al., 2013) propose risk mitigation strategy incorporating two elements, namely; strategic planning and risk mitigation. In strategic planning stage, better understanding of risk trends and abnormal behavior mode are obtained for the best, average and worse conditions with the use of statistical and simulation models. In particular, risk modelling methods assist decision makers with illustrating risk impacts in terms of cost, time variables and potential failure (Ghadge et al., 2013). Risk modelling systems are perceived as "an early warning system" where the effective risk features and risks interactions are modeled. In second stage, risk mitigation, decision makers are enable to employ strategy leading to reduce risk impact with the use of information deriving from risk modelling. (Ponomarov & Holcomb, 2009) present common strategies (e.g. incorporating flexibility, responsiveness, agility and preparedness) as to decrease both reactive and proactive risks. Prospective decisions regarding to choosing proper strategies highly rely on past and current events and decisions (e.g. risk transfer, risk sharing, and risk avoidance) are made according to risk trends and project managers (Ghadge et al., 2013).

There is a long lasting discussion over supply chain practices among authors accentuating on positive aspects of supply chain practices and those emphasizing on negative aspects (Bandaly et al., 2012). Some authors assume that sole sourcing contributes to reducing cost, order lead time and easy to manage (Burke, Carrillo, & Vakharia, 2007). On the other hand, others believe that any issues regarding to sole supplier can highly influence buyers (Kelle & Miller, 2001). (Bandaly et al., 2012) enumerate supply chain features such as collaboration among supply chain members, risk evaluation all at once and applying risk management to deal with risk effectively. In many cases, decisions making disregarding other supply chain member contribute to loss (Froot, Scharfstein, & Stein, 1994). Reduction in one risk factor can increase the probability of supply chain exposure to other risks. In addition, risk mitigation decisions have impacts on firm's performance. For these reasons, it is agreed that risk should be managed simultaneously (Chopra & Sodhi, 2012; Manuj & Mentzer, 2008; Miller, 1992).

2.7.1 Risk management framework

Due to multi-dimensional and mutually dependence of risk behaviours, companies have difficulty understanding and identifying risks in their supply chains. (Ghadge et al., 2013) suggests that a combination of risk management framework and supply chain risk model can benefit companies to have better understanding of risks. A framework consisting risk identification, risk assessment and risk mitigation stages is presented by (Ghadge et al., 2013). In the first stage, risks are categorized and the sources associated with risks are later recognized. Moreover, the total risk impacts are studied in risk modelling stage which elaborates risk features and its pattern. The impacts of risk can be high or low relying on reinforcements. The necessity of knowing variation in the model and decreasing mistakes require to have a sensitivity analysis. Before making any mitigation decisions, strategic planning is taken into consideration based on the risk trends and sensitivity analysis. In regards to past and current events, risk mitigation strategy is taken to diminish risk effect based on the nature of each risk. Besides, (Bandaly et al., 2012; Ghadge et al., 2013) present a framework for supply chain risk management consisting of two stage risk categorization and risk management approaches. The first stage is comprised of identifying the risk domain, risk source and specific risks. Internal processes, external stakeholders, marketplace and environment are defined as risk domains by (Bandaly et al., 2012) . Similarly, in the framework, the sources pertaining to risk domains should be detected and differentiated from identified risks. As an example, although delivery delays and poor quality are both emanating from untrustworthy supplier, the risk management methods in dealing with each risk are thoroughly distinctive. Therefore, risks should be examined individually in spite of similar risk sources.

(Ritchie & Brindley, 2007) present a supply chain framework which is comprised of five stages: risk sources and profile, risk and performance drivers, risk and performance consequences, risk management responses, risk and performance outcome. In the first stage, different risk derivatives are defined as a function of environment, industry, organisational strategy, decision-maker, supply chain configuration and supply chain members sources. In the second stage, these sources decisively influence the organization's performance. In the third stage, after risk detection and assessment are conducted, the performance outcomes are subsequently scrutinized. In fourth and fifth stages, in response to risk occurrence, the implementation of information sharing, risk consciousness, connection improvement, collaboration strategies and risk insurance are all regarded as risk management responses. Risk measurement of risk sources and the state of being responsive play important roles in risk management strategy (Ritchie & Brindley, 2007).

2.7.2 Risk management approaches

In addition to risk categorization, risk management approaches dealing with various risks are classified into three categories of avoidance, mitigation and prevention approaches (Bandaly et al., 2012).

2.7.2.1 Avoidance approaches

This method decreases the probability of a business confronting risks remarkably (e.g. the Disney theme parks locations are considered to be constructed in warm regions to diminish the possibility of adverse effect of cold weather) (Bandaly et al., 2012). Retaining high buffer stock or special incentive payment to suppliers are both considered to avoid having supply disruptions during a given period (Zsidisin & Ritchie, 2008). Although these actions fail to bring in profit for a company, customer satisfaction is attained. Due to financially unstable suppliers, changing to secure suppliers or having better supplier selections is resulted in decreasing supplier default risk (Zsidisin & Ritchie, 2008). Insurance companies offer different types of insurance such as transportation insurances, inventory-related insurances (e.g.) or natural disaster or environmental risk insurances (Zsidisin & Ritchie, 2008).

2.7.2.2 Preventative approach

Firms that are geographically spread are more prone to exchange rate risk. Therefore, financial hedging supports firms against the likelihood of exchange rate exposure (Gleason, Kim, & Mathur, 2005). Additionally, employing TQM and Six Sigma principles can mitigate supply chain risk probability (Zsidisin & Ritchie, 2008). The Container Security Initiative (CSI) which is quality check of all containers at the origin before sending them to U.S is the example of applying TQM principle to mitigate terrorist attack (Zsidisin & Ritchie, 2008).

2.7.2.3 Mitigation approach

The negative effect of risks would be lessened or even be removed in some cases by the mitigation approaches. If mangers of small or medium enterprise realise the influence of variables such as information sharing, aligning incentives, risk sharing and corporate social responsibility, risks are remarkably reduced in the supply risk management (Chopra & Sodhi, 2012; Spekman & Davis, 2004). Furthermore, supply chain risk can be decreased by employing strategies such as information technology, risk pooling, multiple suppliers, increasing flexibility and responsiveness and having productive connections with customers and suppliers (Chopra & Sodhi, 2012). Postponement is another strategy which is applied to delay in fulfilling customer's demands, whereas speculation has an opposite meaning of postponement. Decisions made based on expected customer's demand is called speculation which is not suggested to apply in electronics Company due to high risk of obsolescence and high holding cost (Manuj & Mentzer, 2008). Risk mitigation is classified in to proactive and reactive approaches (Ghadge et al., 2012). For proactive approach, in product and process management, postponement strategy and in supplier relationship management, supplier collaboration, cultural adaptation and continuous coordination strategies are recommended. For reactive approach, in contingency planning, strategic event management plan and in disaster management, robust recovery and scenario analysis approaches are suggested. In addition to disaster management, dynamic pricing, operational rerouting and shifting customer demand methodologies are proposed. However, in order to have more generic approach, agility, flexibility and preparedness are proposed strategies (Ponomarov & Holcomb, 2009).

Although a large number of studies have been conducted to properly address risks involved in supply chains, a more generic risk management framework encompassing all required tools and techniques which is applicable in any area is lacking. In some studies, risk management strategies were implemented to reduce risk exposure whereas it might boost the possibility of subjecting to other risks. Therefore, ignoring risk relations may have severe consequences. Other studies mainly focused on presenting their own industry-specific risk frameworks which were limited to specific tools and techniques.

In order to enhance risk consciousness, we present a conceptual risk management framework in the following chapter that assists in finding risk sources and applying suitable risk strategies.

3 Methodology

3.1 Introduction

In this chapter, we present the risk framework based on the extensive literature review and on Bandaly et al's (2012) work conducted in the previous chapter. A conceptual generic risk management framework is presented in Figure 3-1. We attempt to set an exhaustive framework, which is practical for managers, decision makers and operating managers. The framework consists of the following stages:

i. Risk identification: The primary step in this framework is to recognize risks stemming from different sources.
ii. Risk mapping: The potential risk sources are mapped to visualize risk magnitudes.
iii. Risk assessment: Once risks are identified and mapped, the impact and the probability of the risks on the system should be identified and assessed either subjectively or objectively.
iv. Risk interactions: In order to ascertain whether or not there is an interaction among risks, we propose approaches to assess risk interactions either collectively or individually.
v. Risk prioritization: The higher risk factors among other risks should be identified.
vi. Risk management strategies: An appropriate risk management strategy in dealing with reducing risk likelihood should be applied.
vii. Risk control: There should be consistent observance over existing risk as well as emerging risks within supply chains.

This framework notably encompasses a recurring loop, which means that upon the identification of an emerging risk, the steps of analysis will start over again.

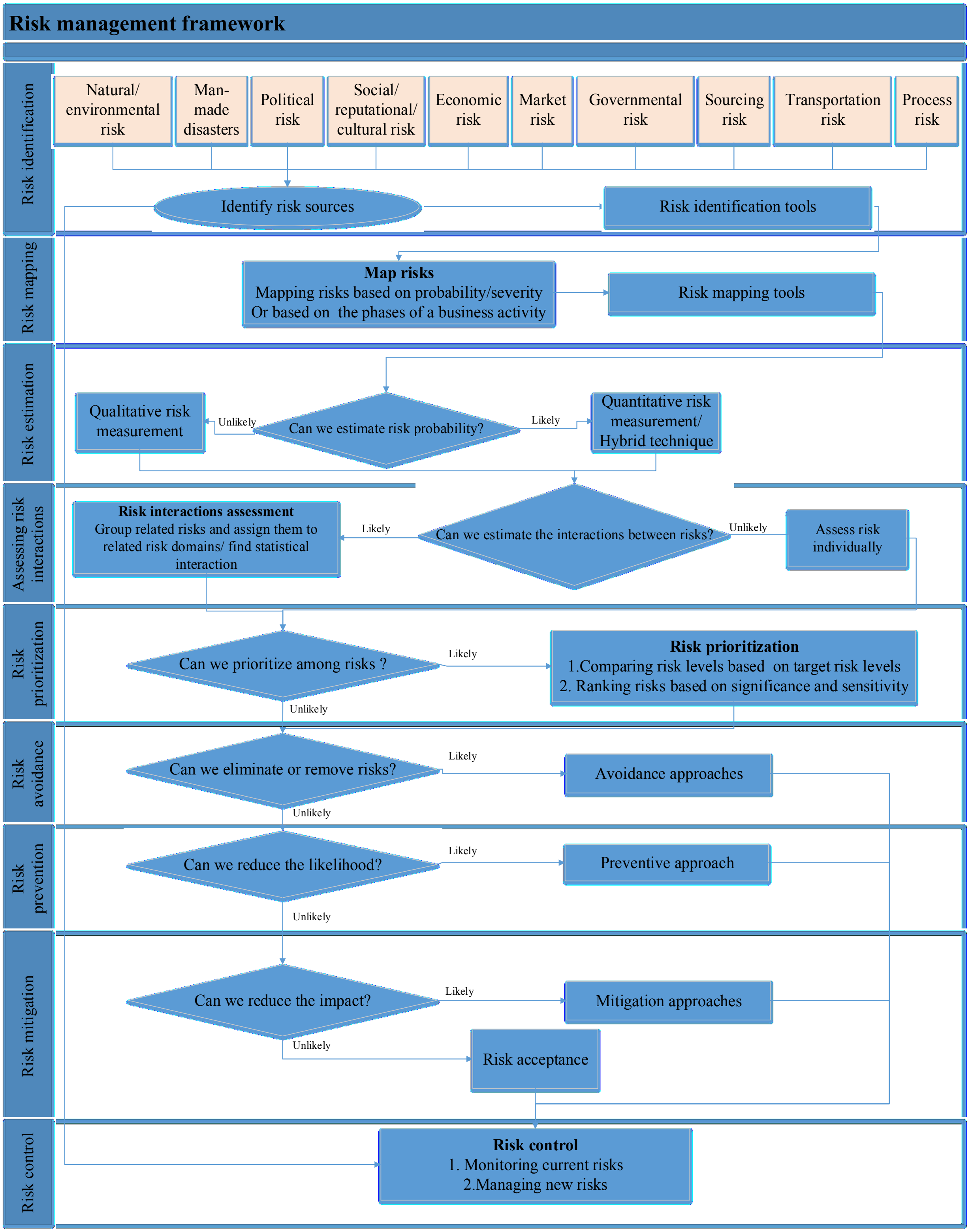


Figure 3-1 Risk management framework

3.1.1 Risk identification

As previously stated in the literature review, risks are classified into two main groups: external and internal risks. External risk encapsulates risks from environmental and human-made disasters, governmental risks, political risks, cultural and social risks to market as well as economical risks. On the other hand, internal risk incorporates those associated with any disruptions in the internal processes, systems or machines. Table 3-1 presents a number of risk identification tools and techniques tools and techniques with different characteristics to assist in finding the main causes of risks.

Table 3-1 Risk identification tools and technique

Risk identification tools and techniques		
Hazard and Operability Study (HAZOP)	(Rogers, 2000)	Applicable in identifying risk in design as well as operational issues
Sneak analysis	(Rogers, 2000)	Beneficial especially for batch plants
DEFI	(Rogers, 2000)	Useful in finding errors and failuers assoicated with equipment and operations
Reliability Block Diagram (RBD)	(Rogers, 2000)	Helpful diagram in showing risks and reliability of a system
Goal Oriented Failure Analysis (GOFA)	(Rogers, 2000)	Advantageous in errors or failures determination of a system causing unsatisfactory outcomes
Concept Safety Review (CSR)	(Rogers, 2000)	Practical applications in risk determination specifically within chemical industry where enhancements rely on risk detection conditions
Hazard Identification and Ranking Analysis (HIRA)	(F. I. Khan & Abbasi, 1998; F. Khan & Abbasi, 1997)	Employed in chemical industry to find chemical and process units with great risk potential
Preliminary Hazard Analysis (PHA)/Preliminary	(Rogers, 2000)	Beneficial in finding risk factors an early stage especially in complicated products leading to safe design

Consequence Analysis (PCA)		
Concept Hazard Analysis (CHA)	(Rogers, 2000)	Useful in identifying major risk factors leading to safe design
Maintenance Analysis (MA)	(Rogers, 2000)	Practical in detecting maintenanace risks
Sequentially Timed Event Plotting (STEP)	(Hendrick & Benner, 1986)	Efficient in recognising factors assoicuated with procedure failures
Structural Reliability Analysis (SRA)	(Rogers, 2000)	Effective risk detection technique which is employed in finding out the safety margin and the impact of probable failure in general Used in measuring the offshore oil safety or gas platforms under distinct weather conditions
Hierarchical Holographic Modeling (HHM)	(Haimes, Kaplan, & Lambert, 2002)	Advantageous as an identification method where subsystems and their connections are depicted to find risk triggers (the overall assessment is highly reliant on subsystem evaluation)
Safety Audits	(Reniers, Dullaert, Ale, & Soudan, 2005)	Beneficial in detection of defective parts or loss in outcome due to procedural or machinery circumstances achieved by audit or auditors' team
Task Analysis/ Action Error Analysis/ Human Reliability Analysis	(Rogers, 2000);(Brauchler & Landau, 1998; Doytchev & Szwillus, 2009; Kirwan, 1994; Kontogiannis, 1999a; Landau, Rohmert, & Brauchler, 1998)	• Applied in recognition of human-related risks • Appeared due to lack of training, communication among staff, practical forecasting and management inability to make modifications in processes, risk awareness and ergonomic related rules • Used to analyze operators' performance and their

		involvement with system and other co-workers

3.1.2 Risk mapping

In order to have a better understanding of risks as well as their magnitudes and consequences, we use risk mapping. A risk map can be a simple illustration of risk likelihood and severity or it can be based on phases of business activities. Risk mapping benefits companies by demonstrating the drivers of potential risk leading to disruptions. A series of risk mapping tools exist as illustrated in Table 3-2.

Table 3-2 Risk mapping tools

Risk mapping tools		
Risk heat map	(Cox Jr, Louis Anthony Tony, 2012; Dominguez-Chicas & Scrimshaw, 2010)	Depiction of risk likelihood and its impact in different risk levels (low, medium, high levels)
Risk matrix	(Markowski & Mannan, 2008)	Illustration of risk probability and its impact which is beneficial in finding and assessing critical risks
Vulnerability risk map or sensitivity map	(Nelson, 2000; Tortell, 1992) (MacDonald, Little, Eno, & Hiscock, 1996)	Presentation of the parts or areas which are subject to stress (for example, authorities can benefit from an oil sensitivity map in such a way that they react precisely to any oil spills)
Risk value map	(http://ww2.cfo.com/risk-management/2013/02/how-to-map-your-risks/)	Demonstration
Risk Breakdown Structure (RBS)	(Cagliano et al., 2012; Hillson, 2003)	Illustration
Supply	(Cagliano	Presentation

Contamination risk map/ Exposure risk map/ Hazard map	(Huber, Bach, & Frede, 1998; Probst, Berenzen, Lentzen-Godding, & Schulz, 2005; Lahr & Kooistra, 2010;Wang, He, & Chen, 2012)	• Depiction of how a region might be affected by risk and compares evaluated exposure to the standard values (for example, water contamination by pesticides across Canada) • Application of hazard risk mapping in different areas (e.g. assessment of metals in river sediments, environmental quality, and soils in a mining area)
Process map	(Hunt, 1996)	• Depiction of process overview which is advantageous in reducing service development cost, system integration failures and better process comprehension • Application of this tool in areas such as banking, manufacturing (auto or aerospace industry), insurance, pharmaceutical and service enterprises

3.1.3 Risk assessment

In

Table

Quantitative		
Fault-Tree Analysis (FTA)	(Marhavilas, Koulouriotis, & Gemeni, 2011)	Illustration of cause-and-effect relationship where the connection and logic behind human, system and other failures are simply displayed
Event Tree Analysis (ETA)	(Marhavilas et al., 2011)	Demonstration of primary triggers for a series of events (both negative and positive aspects of each step are pointed out)
Quantitative Assessment of Domino Scenarios (QADS)	(F. I. Khan & Haddara, 2003)	Application of this technique depending on set of actions (e.g. identification, frequency estimation, outcome evaluation and outcome analysis of domino scenarios consisting all mixed of secondary events)
Clinical Risk and Error Analysis (CREA)	(Trucco & Cavallin, 2006; Vincent, Taylor-Adams, & Stanhope, 1998)	• Consisting of five main stages, namely, process identification, process description, error identification, risk assessment and influential factor analysis

		• Measuring both error mode and crucial factors
Risk Based Maintenance (RBM)	(Hillson et al., 2006;F. I. Khan & Haddara, 2003)	• Consisting of risk measurement, evaluation and eventually maintenance planning to adjust risks to acceptable levels • Encompassing three major stages, namely risk identification, estimation and subsequent support actions
Predictive Epistemic Approach (PEA) /Decision Matrix Risk-Assessment (DMRA) and Proportional Risk Assessment Technique (PRAT)	(Ayyub, 2014; Fine, 1971; Marhavilas et al., 2011)	Analyzing, assessing and forecasting risks
Fuzzy set	(Durkin & Durkin, 1994)	Identifying relationships between risk factors and their effects on project performance measures with the use of fuzzy set methodology and risk cause and effect
Genetic algorithm/ Rough set	(Varetto, 1998)	• Identifying insolvency risk and analyzing it • The integration of a rough set and GA are used in order to assess credit risk in commercial banks
Analytic Hierarchy Process (AHP)	(Y. Wu, 2006)	• Building a hierarchy of hazards based on experts' opinion, knowledge and experience • Implementation of this technique in order to assist managers to assign

		importance to risks with weights and likelihood
Analytic Network Process (ANP)	(Ergu, Kou, Shi, & Shi, 2014)	Assessing risk factors interactions and analyzing their impacts (the complementary technique of AHP)
Simulation	(Kim, Jeong, Park, & Baik, 2006; Singhal et al., 2011; Talluri, Kull, Yildiz, & Yoon, 2013; T. Wu et al., 2007)	• Detecting complexities within supply chains and resolving them (in healthcare, manufacturing and other fields) • Producing a real model of current processes which provides a deep insight into process performance with the use of computer simulation • Addressing any external or internal hazards (e.g. human-related issues and bottle necks in manufacturing lines) by computer simulation model • Monitoring static and dynamic behavior of supply chains
Optimization	(Ben-Haim, 2012; L. Li, Porteus, & Zhang, 2001; Luna-Reyes & Andersen, 2003; Popovic, Vasic, Rakicevic, & Vorotovic, 2012; Tomlin, 2006; D. D. Wu, Chen, & Olson, 2014; Y. Wu, 2006; Zhang, 2006)	• Having various functionalities in risk prediction, evaluation, monitoring and improvement areas by using optimization approaches (e.g. linear programming, nonlinear programming and dual optimization)
Supply Chain Risk Structure Model and Supply Chain Risk Dynamics Model	(Oehmen, Ziegenbein, Alard, & Schönsleben, 2009)	• Capturing risks factors and their influences in supply chains by Supply Chain Risk Structure Model • Observing and modeling risk behaviors in various situations with the use of Supply Chain Risk Dynamics Model
Value-at-risk (VaR)	(Rockafellar & Uryasev, 2000; D. D. Wu & Olson, 2013)	Measuring the extent of losses and profits in investments to improve portfolio

Real option	(Mun, 2002)	• Providing useful visions of project assessment in financial terms • Taking advantage of uncertainty (for example, with the use of real option, postponement and modification in portfolios and processes account as decision-making under uncertainty)
Game theory	(Zhao & Jiang, 2009;Gnyawali & Park, 2009; Lin, Ke, & Whinston, 2012; Merrick & Parnell, 2011; Nash, 1950)	• Making effective decisions in project risk management • Implementation of this tool in distinct areas (e.g. online advertising, small and medium-sized enterprise (SMEs) and counterterrorism)
Weighted Risk Analysis (WRA)	(Suddle, 2009)	• Accounting for other risk domains including economic, environmental, psychological, political and societal factors • Obtaining weighted risk based on the integration of different elements (for example, political, social, environmental and quality) in financial terms
Two-stage stochastic model	(Goh, Lim, & Meng, 2007)	Assisting firms to model decisions by meeting risk minimization and profit maximization objectives
Stochastic	(Wallace & Ziemba, 2005)	• Considering all uncertainty parameters comprising constraints, issues with regards to structure and risk related decisions • Reducing total transportation costs, inventory prices and location cost in supply chain by implementation of stochastic location model with risk pooling
Modified projection model	(Nagurney & Nagurney, 2010)	Implementation

Human Error Analysis Techniques (HEAT)/ Human Factor Event Analysis (HFEA)	(Attwood, Khan, & Veitch, 2006a; Attwood, Khan, & Veitch, 2006b; Baysari, McIntosh, & Wilson, 2008; Hollywell, 1996; Kontogiannis, 1999b; Kontogiannis & Malakis, 2009) Bellamy, Geyer, & Wilkinson, 2008; Doytchev & Szwillus, 2009b; J. W. Kim & Jung, 2003; Mackieh & Cilingir, 1998)	• Considering *human involvement* and its impact in process, design and support of complicated systems in order to avoid unexpected events • Factors affecting human actions, such as "work-related" factors (e.g. training, operators' ability and task hardships and work environment), or complicated systems

Table

Qualitative		
Brainstorming	(Chapman & Ward, 1996; Hallikas et al., 2002; Raj Sinha, Whitman, & Malzahn, 2004b; Rogers, 2000)	Comprising of experts raising questions (e.g. what should or could be achieved regarding the safety system), detecting potential risk factors and their effects
Delphi technique	(Berg, 2010; Dey & Ogunlana, 2004; Guide, 2001; MacGillivray, Sharp, Strutt, Hamilton, & Pollard, 2007)	Providing method, comments, results and feedback in a brainstorming group to achieve an agreement
Expert judgement/ Expert interviews	(Del	• Considering the experts' exceptional knowledge of systems and techniques as the prime qualitative source of risk estimation • Improving an expert's judgment by providing some training
Analogy process	(Savci & Kayis, 2006	Information extraction technique relying on previous risk realizations
What if? Analysis/ Checklists	(Ayyub, 2014; Doerr, 1991; Mullai, 2006; Reniers et al., 2005; Rogers, 2000)	• Raising questions regarding to equipment or design purpose • Boosting the effectiveness of risk identification remarkably by the integration of What if? Analysis with checklists

3.1.4 Risk interaction assessment

Before

Table

Risk interaction assessment tools		
Bow-tie diagram	(Deloitte & Touche LLP)	The integration of fault tree and an event tree indicating a complicated risk occurrence from risk factors to consequences
Risk interaction maps	(Deloitte & Touche LLP)	• Capturing risk interactions • Demonstration of risks on x and risks relations
Correlation matrix/ Statistical analysis	(Deloitte & Touche LLP)	• Indicating any interactions among risks quantitatively based on historical data

3.1.5 Risk prioritization

The

Table

Risk		
Failure Mode and Effect Analysis (FMEA)/ Failure Mode and Effect Criticality Analysis (FMECA)	(Rogers, 2000; Lipol & Haq, 2011)	Advantageous in configuring the cause and effect of hazards
Method Organised Systematic Analysis of Risks (MOSAR)/ TOPSIS	(Rogers, 2000; Kutlu & Ekmekçioğlu, 2012)	• Employed particularly for system safety and frequency risk analysis • Represented potential failure modes of product or operation and the impact of each failure mode • Used to Rank failures are according to how crucial they are and the probability of occurrence

Short Cut Risk Assessment (SCRA)	(Rogers, 2000)	• Estimated risks where a quantitative result, in terms of occurrence and severity, is derived from qualitative evaluation and the results would be achieved in terms of occurrence and severity
Rapid Ranking (RR)	(Tweeddale et al., 1992)	• Prioritized risks based on severity and probability of occurrence after risks detection • Informed about risks occurrences, • Created a base for comparing various risks and helpful in inspecting risks with high and low significance

3.1.6 Risk management strategies

According

Table

Avoidance approaches		
Insurance with high coverage and low deductibles	(Ritchie & Brindley, 2007)	• Avoiding risk likelihood by implementation of insurance in different areas such as transportation, inventory-related, natural disaster and environmental risk ensuring safety against relevant risks
High buffer stock	(Zsidisin & Ritchie, 2008)	Avoiding supply disruptions
Multi supplier/ Better supplier selection	(Zsidisin & Ritchie, 2008)	Decreasing

Preventive

Table

Preventive approaches		
Financial hedging	(Gleason et al., 2005)	Diminishing the likelihood of exchange rate exposure
TQM and Six Sigma principles	(Zsidisin & Ritchie, 2008)	Reducing supply chain risk probability

In

Table

Mitigation approach		
Risk sharing/ Aligning incentives/Corporate social responsibility	(Chopra & Sodhi, 2012; Spekman & Davis, 2004)	Reducing risk impact remarkably
Information technology/Risk pooling/Multiple suppliers/ Increasing flexibility/ responsiveness	(Chopra & Sodhi, 2012)	Implementing in small or medium enterprise
Agility/Flexibility/Prepa redness	(Ponomarov & Holcomb, 2009)	Decreasing risk influence remarkably
Postponement	(Manuj & Mentzer, 2008)	Diminishing risk effect by delaying customer's demand
Speculation	(Manuj & Mentzer, 2008)	Mitigating risk impact by making decision in regarding to customer's demand expectation
Proactive approach	(Ghadge et al., 2012)	Consisting of supplier management (such as supplier collaboration, cultural adaptation and continuous coordination strategies) and process management (for instance, postponement strategy)
Reactive	(Ghadge	Encompassing

3.1.7 Risk control

Existence

3.1.8 Use of the framework

The application of the proposed risk management framework can be modified according to industry features. A company can adjust and adapt to the framework based on its requirements. In the experiment section, since company ABC deals with specific risk, those approaches and tools which properly manage these risks are employed to diminish risk likelihood and its impact.

4 An application of the risk management framework developed: A case study in a mattress manufacturer

In this chapter, in order to evaluate the practicality of the framework, it is applied to a case company. This company, which we will call ABC for confidentiality, produces organic mattresses and pillows. Company ABC is a small company located in North America, employing 20 people. The company outsources its main material, namely latex, from Asia, due to low costs. More details are provided in the upcoming sections.

Since

4.1 Methods and techniques used in the experiment

The initial issue that the company deals with is regarding the outsourcing risk. In accordance with this issue, the company's process map is required in order to obtain a detailed overview of the entire process. With the use of this map, we can have better understanding of the activities, inefficiencies, delays, excessive activities and rework. The objectives of the process map within this context are to:

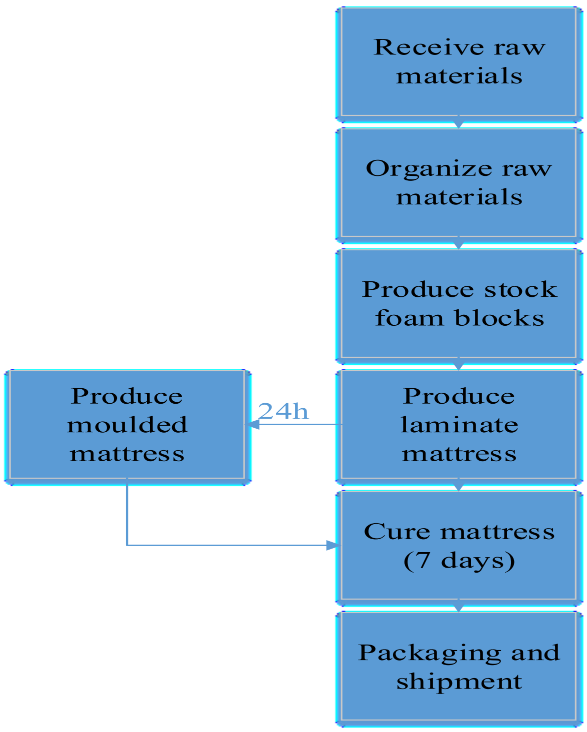
i. Detect rework

ii. Recognize delays and non-value added activities.

Once

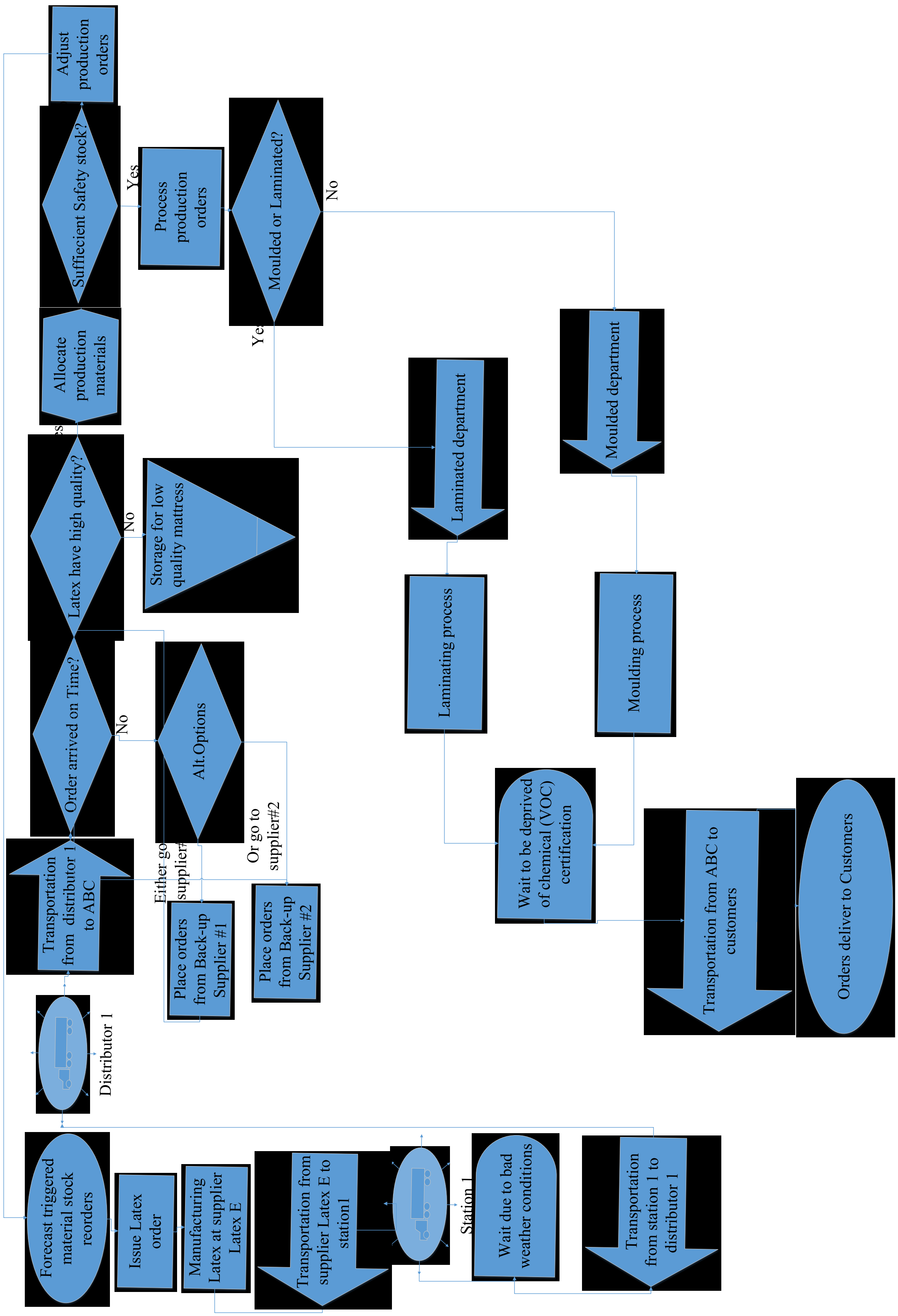
4.1.1 Process

The



Figure

The


Adjust production orders
Sufficient Safety stock?
Yes
Process production orders
Moulded or Laminated?
No
Yes
Allocate production materials
Latex have high quality?
No
Storage for low quality mattress
Laminated department
Moulded department
Order arrived on Time?
No
Alt.Options
Laminating process
Moulding process
Either go supplier#
Or go to supplier#2
Transportation from distributor 1 to ABC
Place orders from Back-up Supplier #1
Place orders from Back-up Supplier #2
Wait to be deprived of chemical (VOC) certification
Transportation from ABC to customers
Orders deliver to Customers
Distributor 1
Forecast triggered material stock reorders
Issue Latex order
Manufacturing Latex at supplier Latex E
Transportation from supplier Latex E to station1
Station 1
Wait due to bad weather conditions
Transportation from station 1 to distributor 1

Figure

As

4.1.2 Problem description

Since

4.1.2.1 Simulation model description

A simulation model with the use of Arena software is designed to model the number of lost sales and define inventory level for the company. Process Analyzer is a software tool that enables Arena simulation runs and analyzes results in different scenarios. The model logic is presented in Figure 4-3. The simulation uses the (R, Q) inventory model. Once inventory level falls below reorder point, an order of q batch size is placed based on (R, Q) inventory policy. The entire system is triggered by customers' demand arrivals and runs for 18 weeks, 2 weeks of warm-up and 25 replications of model runs by using Arena software. The reason why simulation model runs for this specific period is that we have access to customers' demands information during this time period. When customers' demands take place (based on weekly basis), the on hand inventory is checked: If it is sufficient, the demand will be satisfied as shown in Figure 4-3. Otherwise, demand is backordered and has high priority to be served for next week while upcoming demand occurs. $L*D$) + Safety stock Equation 4-1, initial inventory level is equal to reorder point number (ROP). The reorder point is calculated by the following formula which both lead time and demand are variables:

$$R = (\overline{L} * \overline{D}) + \text{Safety stock} \qquad \text{Equation 4-1}$$

$$Safety\ stock = z\sigma_{DLT}$$

$$\sigma_{DLT} = L\sigma_D^2 + d^2\sigma_{LT}^2$$

Notations:
R= reorder point
$\overline{L}$ = average lead time
$\overline{D}$ = average demand
Z = number of standard deviations needed to achieve the cycle-service level
σ_D= stand deviation of demand
σ_{DLT}= stand deviation of demand during lead time

Those demands that are satisfied earlier in the system are deducted from inventory level. Therefore, it is clearly understood that current inventory level is less than the initial inventory. If the current inventory level is less than reorder point and no order has taken place yet; therefore, ABC initiates ordering from supplier latex E. The reason that we accentuate on placing one order at the time is multiple simultaneous ordering leading to high buffer and holding cost. Since ABC has a backup supplier, supplier S.A., control variable is defined to allow system to choose between supplier E and supplier S.A.

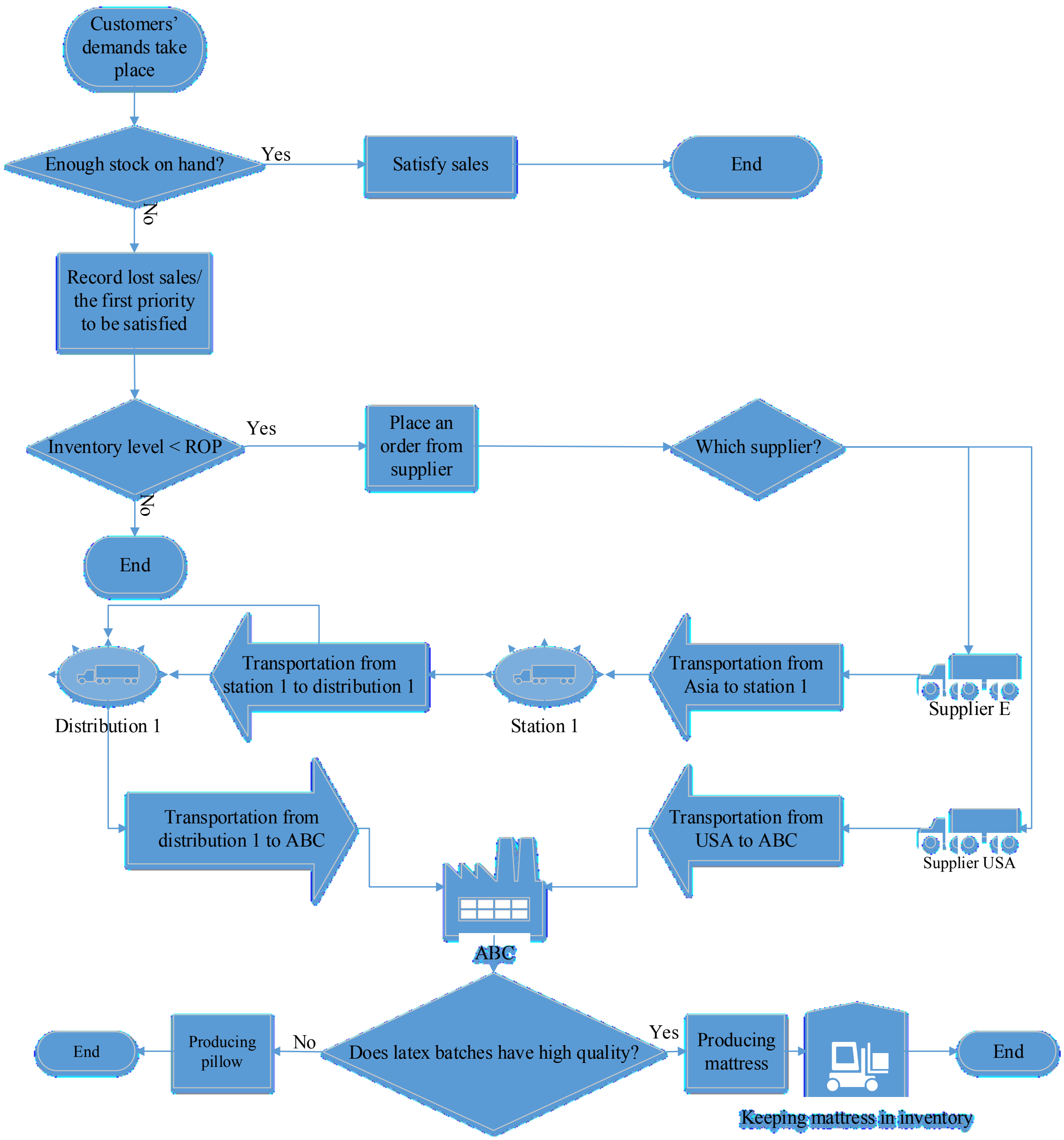
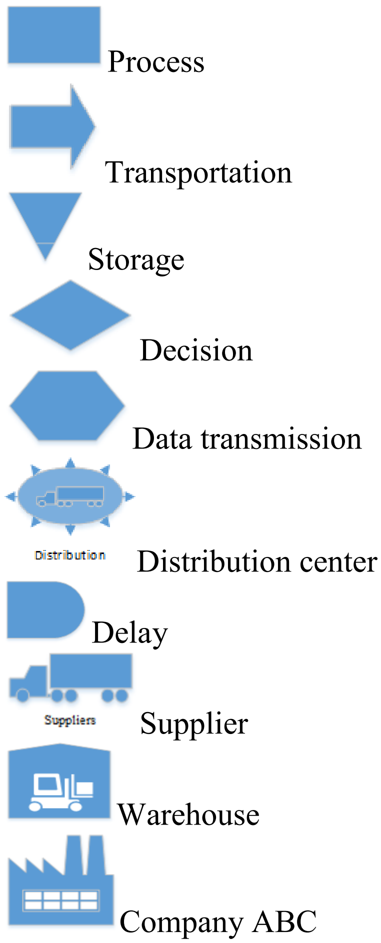


Figure 4-3 Simulation model logic

Legend:

Start/End



When an order is placed by company from supplier E, latex units are transferred from origin to station 1 and from station 1 to distribution 1, as depicted in Figure 4-3. Latex units are delivered from distribution 1 to ABC.

On the other hand, if ABC decides to order the latex batches from supplier S.A, batches will be directly delivered from USA to the company.

Once latex batches are received, the company carries out a thorough inspection on the quality of batches. Those poor quality batches are used in manufacturing pillows whereas high quality batches are used in mattress production (either in moulded or laminated forms based on the customer's demands). Later, mattresses are kept in inventory to fulfill future demand. The entire supply chain of mattress manufacturing from the upstream level to downstream level is illustrated in Figure 7-1 in Appendix A in terms of the simulation model.

Simulation model assumptions:

i. Quality constraint: ABC raises an issue which is the inclusion of quality constraints in received batches. Since on average 40% of latex batches have poor quality, we consider a quality measure variable accounting for the poor quality batches in order to compensate and optimize the required batches.

ii. The existence of lead time variation for each month requires defining the month variable to allow the system to identify the current time. For instance, if the system is running during December and January, it will take longer in comparison to the spring season to receive latex batches. Severe weather conditions result in long lead time of raw material and correspondingly delays in mattress production and in some cases losing customers.

The inputs and outputs of the model are given below for a simulation period of 18 weeks. All values are provided in Appendix B.

Inputs:

i. forecast demand (for 18 weeks)

ii. real demand (based on actual customers' demand obtained from the company for 1 weeks in mattress units)

iii. lead time (including all the means and variances of transit entities in weeks)

iv. reorder point (which is entered as primary inventory in mattress units)

v. average of real demand (which is used in order quantity formula in mattress units)

vi. holding cost (H in 1 ($)/unit/week)

vii. ordering cost (K in $s/orders)

viii. shortage cost (R in $s/unit short/week)

Outputs:

iii. lost sales (in mattress units)

iv. latex quantities from supplier E (in kg units)

v. mattress quantities (in kg units)

vi. real demand (in mattress units)

vii. defective latex for pillows (in pillow units)

4.1.2.2 Supplier comparison

In addition to supplier E, ABC has a secondary backup supplier, supplier S.A, to avoid having delays in raw materials shipment or having poor quality of raw materials. Although the ordering cost (K in $s) may seem overpriced at first glance in Table 4-1 in comparison to supplier E, it takes only 2 weeks to receive the latex batches directly from USA. On the other hand, on the positive side, there are no more intermediaries in between and the lead time is more manageable and changes less. A detailed comparison is made between two suppliers to see how much company ABC benefits more in each case in terms of shortage cost and overall total costs.

In this model, the comparison between two suppliers is made with the use of Process Analyzer, shown in Figure 9-1 in Appendix C. We run the simulation model for supplier E while considering all previously mentioned inputs and an ordering cost of 100$. However, for the supplier S.A, we run the model for the ordering cost of 200$. Since the second supplier requires much less lead time of the first supplier, we have fewer lost sales and the shortage cost is relatively small.
Since different ordering costs are estimated for two suppliers, we take ordering cost into consideration as our control variable to observe changes in response values. Moreover, we are able to detect the impact of different ordering costs of both suppliers on shortage and total costs. As shown in Table 4-1, the costs of ordering latex from supplier E is 100$ while it would cost twice as much to order from supplier S.A. Also, it is apparent that shortage cost of first scenario is higher in comparison to the second scenario so as the average total cost.

Table 4-1 A comparison with two suppliers with different ordering costs and its impact on response values

Scenario	Supplier	Simulation model replications	Ordering cost (K in $s/orders)	Shortage cost($)/unit short/week	Average total cost
1	Supplier E	25	100	12298.665	12440.081
2	Supplier S.A	25	200	6761.401	6853.735

As shown in Table 4-1, although ordering cost associated with the first supplier is half of the second supplier, resulting shortage cost is considerably higher due to long lead time of raw material resulting in high lost sales numbers.

4.1.2.2.1 Findings

Table 4-1 illustrates the scenarios of supplier E and supplier S.A under different circumstances. Scenario 1: The initial inventory is estimated based on the average lead time of 5 weeks and standard deviation of 2 weeks to reduce lost sales numbers.

Scenario 2: The primary inventory estimation is based upon the average lead time of 2 weeks and standard deviation of 0.2 week. Although the ordering cost is doubled with the second supplier, the shortage cost and total average cost are as low as the first supplier illustrated in Table 4-1.

It is highly suggested to provide the required quantity of raw materials from the second supplier despite higher ordering cost. The reason is clearly indicated from Table 4-1 that, overall, the company incurs fewer expenses in raw material provision from the second supplier.

4.2 Experimental design

Factorial design

Experimental design is conducted to study the relationships between factors and detect any of their probable impact on response values. We used full factorial design to investigate the relation between independent factors and potential effects on dependent value on different levels. We run the simulation model with these parameters as our main factors:

i. mean lead time (weeks)
ii. lead time variance (weeks)
iii. demand variance (times std. dev. of current demand)

Since there is a considerable variation in latex transportation from supplier to manufacturer (upstream level), we take into account both mean lead time and lead time variance as our critical factors. Moreover, demand variability signifies the variability of customers' requests (downstream level). Table 4-2 demonstrates three levels used for mean lead time, lead time variance and demand variance. Mean lead time and lead time variance are represented in weeks, whereas demand variance is given in terms of number of standard deviation from the mean demand.

Table 4-2 Experimental design factors with three levels

	Level		
Mean lead time (weeks)	3	4	5
Lead time variance (weeks)	0.6	0.9	1.2
Demand variance (times std. dev. of current demand)	0.75	1	1.25

Simulation model replications

As we consider three factors at three levels, we end up running the simulation model for 27 combinations. The simulation model outputs are as follows:

i. lost sales (in mattress units)
ii. latex quantities from supplier E (in kg units)
iii. mattress quantities (in kg units)
iv. real demand (in mattress units)
v. defective latex for pillows (in pillow units)

Among all the predefined output factors, we narrow down our study to lost sales from which company ABC suffers most. Response values are achieved by running the simulation model based on predefined input values summarized in Table 4-3.

Table 4-3 Response values for each set of input values

Lead time (Mean)	Lead time (Variance)	Demand (Variance)	Lost sales
3	0.6	0.75	22
3	0.9	0.75	259
4	0.6	0.75	318
3	0.6	1	378
3	1.2	0.75	444
3	0.9	1	448
3	0.6	1.25	478
4	0.9	0.75	554
3	0.9	1.25	563
4	1.2	0.75	563
5	0.6	0.75	563
5	0.9	0.75	567
4	0.6	1	656
5	1.2	0.75	714
3	1.2	1	779
4	0.6	1.25	781
4	0.9	1	889
4	1.2	1	898
5	0.6	1	898
5	0.9	1	898
5	1.2	1	927
3	1.2	1.25	956
4	0.9	1.25	1066
4	1.2	1.25	1075
5	0.6	1.25	1075
5	0.9	1.25	1075
5	1.2	1.25	1104

4.2.1 Findings

Table 4-3 reveals longer lead time mean and variance result in higher number of lost sales. As demand variation increases, the number of lost sales likewise rise. The findings are summarized in the following:

i. Lost sales go up for the same mean lead time and lead time variance as demand variation increases.
ii. Lost sales numbers ascend for the same lead time and demand variation, as mean lead time increases.
iii. Lost sales rise for the same mean lead time and demand variation as lead time variation increases.

Statistical analysis

We conduct statistical analysis to study simulation model performance under three different levels to come up with a risk management suggestion to company ABC. In order to do so, Minitab software is used to perform design of experiments with three factors and three levels. From the data in Figure 4-4, it is apparent that mean lead time, lead time variance and demand variance have all significant effects on lost sales. Moreover, the two-way interaction of mean lead time and lead time variance has a considerable impact on lost sales.

Multilevel Factorial Design

Factors:	3	Replicates:	1
Base runs:	27	Total runs:	27
Base blocks:	1	Total blocks:	1

Number of levels: 3, 3, 3

General Linear Model: Lost sales versus Lead time me, Lead time va, ...

Factor	Type	Levels	Values
Lead time mean	fixed	3	3, 4, 5
Lead time variance	fixed	3	0.6, 0.9, 1.2
Demand variance	fixed	3	0.75, 1.00, 1.25

Analysis of Variance for Lost sales, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Lead time mean	2	717267	717267	358633	156.85	0.000
Lead time variance	2	291595	291595	145797	63.76	0.000
Demand variance	2	1000091	1000091	500045	218.69	0.000
Lead time mean*Lead time variance	4	145902	145902	36476	15.95	0.001
Lead time mean*Demand variance	4	4956	4956	1239	0.54	0.710
Lead time variance*Demand variance	4	3600	3600	900	0.39	0.808
Error	8	18292	18292	2287		
Total	26	2181703				

S = 47.8174   R-Sq = 99.16%   R-Sq(adj) = 97.28%

Figure 4-4 Design of experiments with three factors and three levels

The residual plots for lost sales versus mean lead time, lead time variance and demand variance are depicted in Figure 4-5. The residual plot shows a random pattern. Moreover, the points and data on the normal probability and histogram plot indicate that the data set is relatively normally distributed. Overall, these plots display that the output (lost sales) is approximately normally distributed.

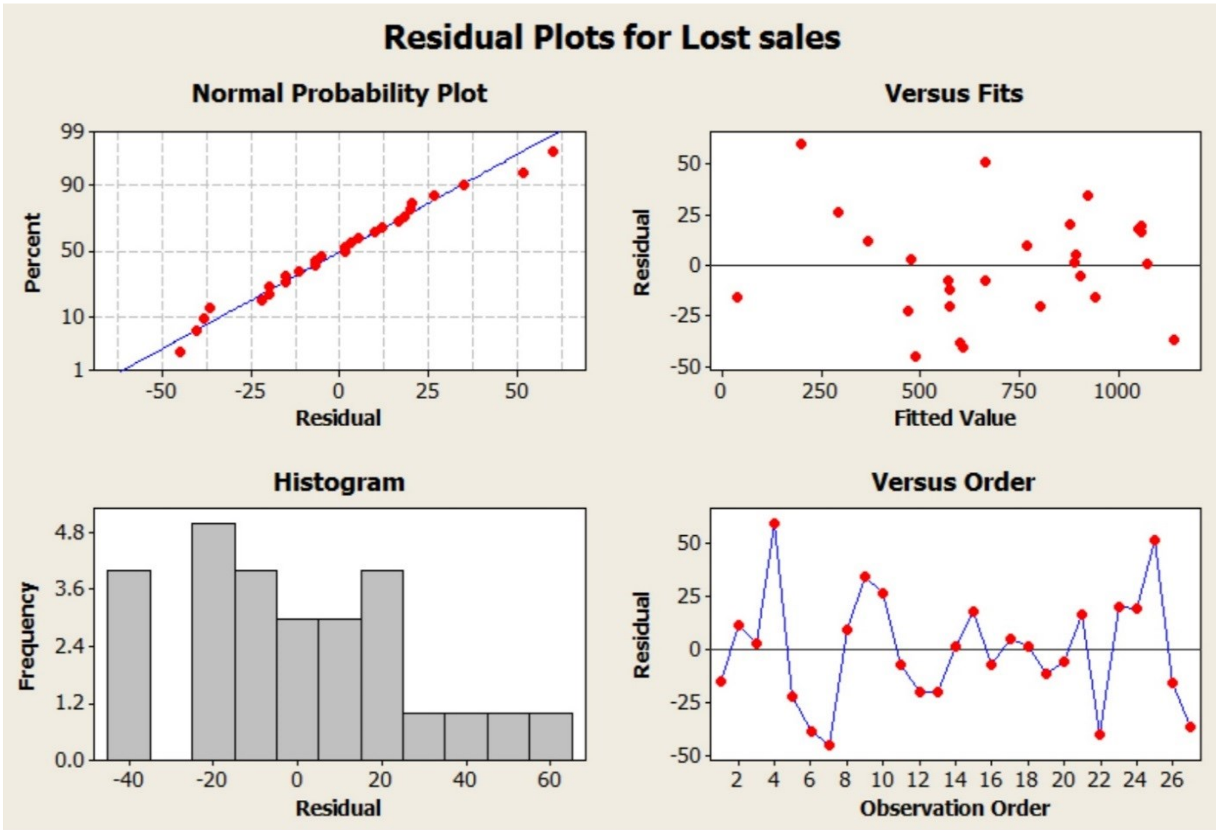


Figure 4-5 Residual plots for lost sales versus mean lead time, lead time variance and demand variance

Figure 4-6 exhibits the significant interactions of mean lead time and lead time variance on lost sales. Figure 4-7 and Figure 4-8 show that there are no interactions among lead time variance and demand variance as well as between lead time and demand variance on lost sales. As is apparent from Figure 4-7 and Figure 4-8, all response graphs have parallel lines, employing lack of interaction among the aforementioned factors.

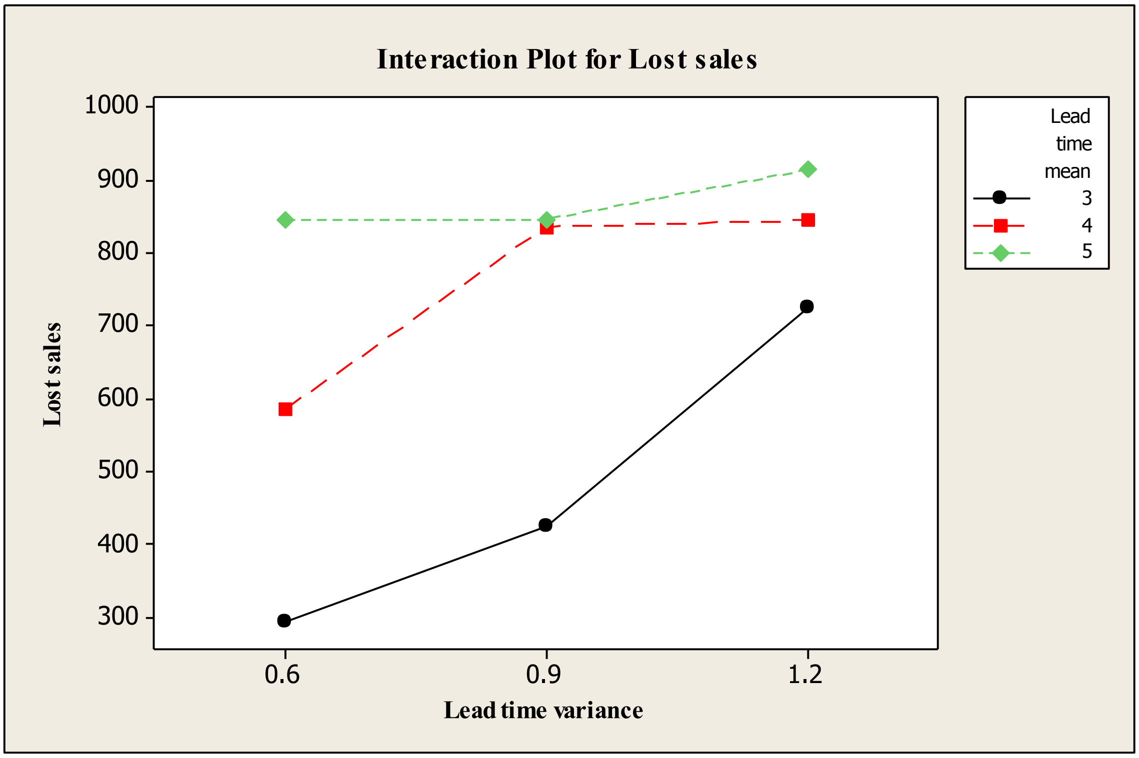


Figure 4-6 Lost sales at given lead time variance levels for various levels of lead time demand

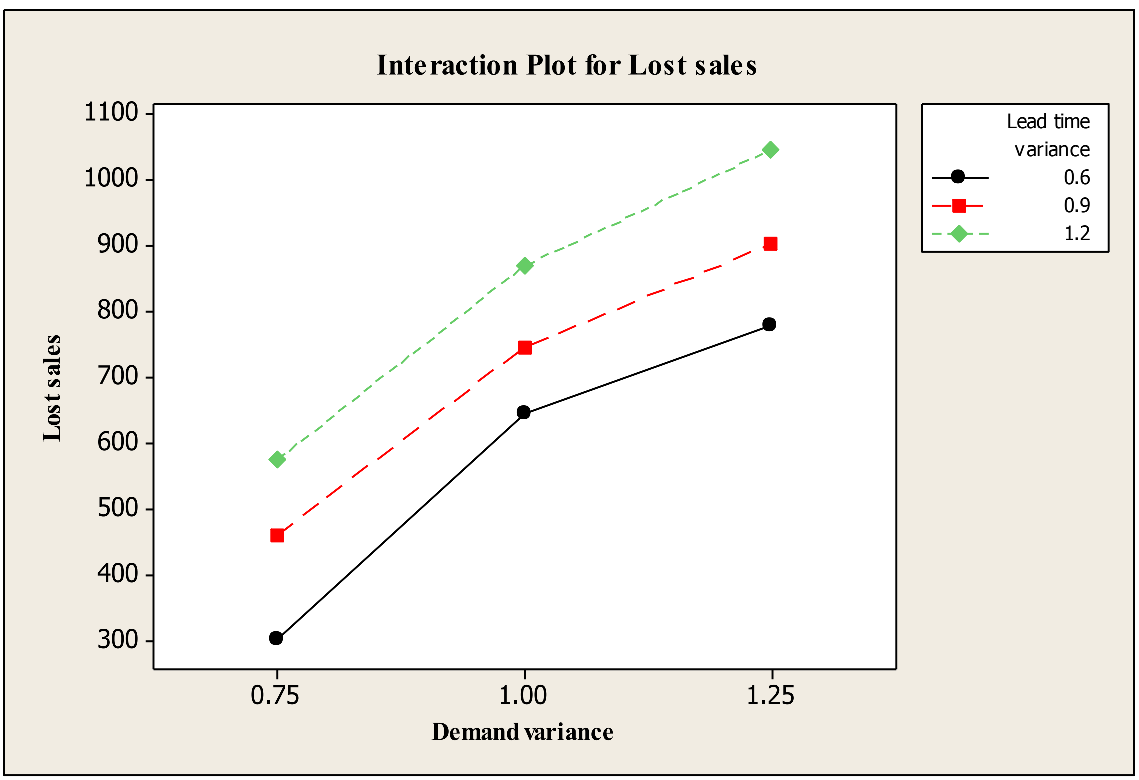


Figure 4-7 Lost sales at given demand variance levels for various lead time variance levels

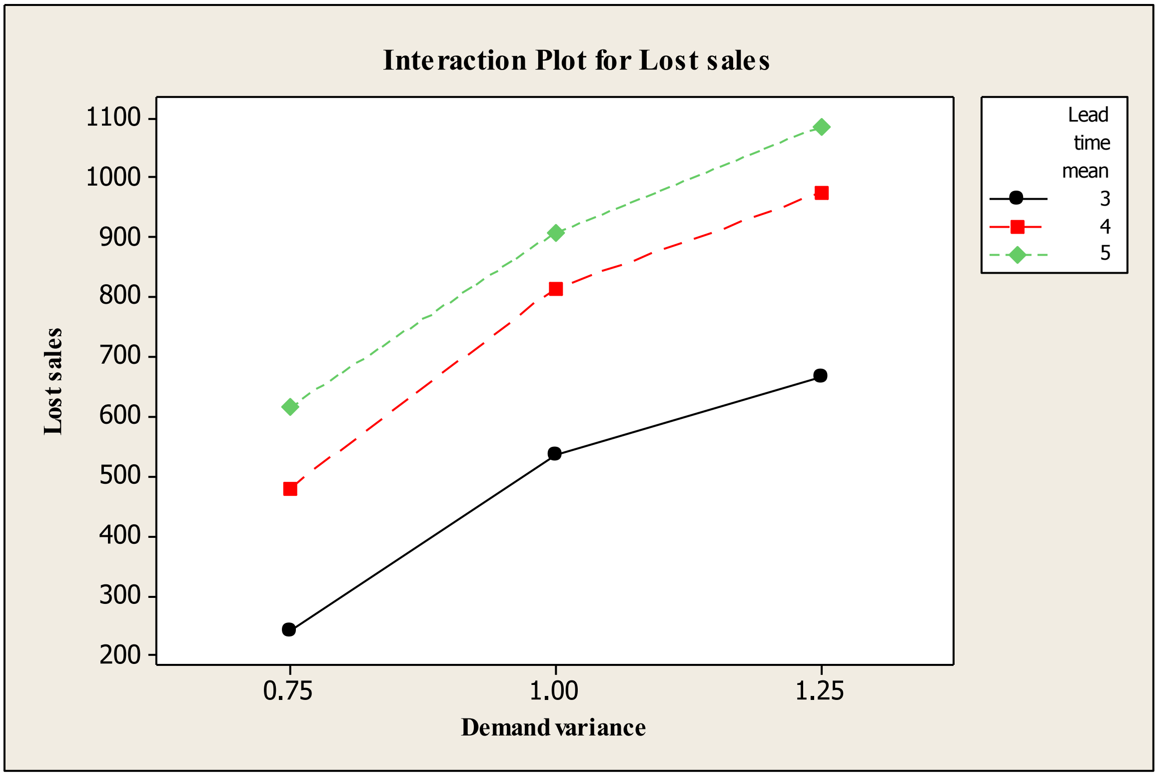


Figure 4-8 Lost sales at given demand variance levels for various mean lead time levels

As can be observed from Table 4-3, shorter lead times and small lead time variances result in less lost sales and hence less shortage cost. The achievement of good supply chain management practices in this company is therefore highly reliant on collaboration among suppliers, distributors and manufacturer.

Although the findings reported are intuitive, for different numbers of lost sales number, company ABC should expect various risk appetite levels. For instance, if ABC estimates to have approximately 300 of lost sales, the risk appetite levels that the company anticipates to have in terms of demand variance would be between 0.75 to 1, as illustrated in Figure 4-7 and Figure 4-8.

5 Conclusions

With the knowledge that risk occurrence is an inevitable phenomenon in supply chains, the main goal of this thesis is to investigate risk, evaluate risk magnitude and deploy risk management strategies.

In order to do so, we provide a generic conceptual risk management framework to verify risks and control them from the beginning. Even though several studies have developed supply chain risk management frameworks and approaches to deal with risks, they each have limitations. Some studies implement a risk management strategy to diminish certain risk exposure. However, this increases the probability of being exposed to other risks, which will subsequently lead to an underestimation in risk interactions.

It may however be noted that most studies were aimed at a more industry specific risk management framework and a rigorous study for a more generic framework has not been attempted. According to risk management strategies, risks stemming from different sources are categorised into internal and external sources and are further carefully studied and measured either quantitatively or qualitatively. We stress the importance of studying the risk interactions and risk prioritization before employing any risk management strategy. In order to avoid risk occurrence and to reduce risk impact and likelihood, different risk management strategies are provided in the present framework.

We studied a small mattress manufacturing company as a case to implement the defined framework. We can detect the causes of risk occurrence from suppliers using the risk management framework. Primarily, delay in the shipment process of raw materials is detected with the use of a risk map. Therefore, we design a stochastic simulation model to estimate the likelihood and impact of risk. Since the company does not set any specific inventory, we use the (R, Q) inventory model to prevent having a large number of lost sales and gain information regarding the stock level and reordering level. As customer's demand fluctuates from month to month, we know that the demand uncertainty has an effect on the number of lost sales. In order to explore the impact of any potential risk factor on lost sales, we conducted an experimental design with three factors at three levels using the Minitab software. We found out that mean lead time, lead time variance and demand variance all have considerable effects on lost sales. Since the p-value of each of the three factors are significant, all three factors have a high impact on the output (lost sales). Moreover, the significant two-way interaction of mean lead time and its variance illustrates critical importance of the lead time factor on lost sales. Hence, in order to reduce risk likelihood of lost sales, better supplier selection is suggested in line with the risk management framework. Company ABC can also define penalty costs for delays in raw material delivery to reduce risk impact. Moreover, proper demand forecasting would enable the company to order its requirements in advance, which possibly would contribute to a higher level of customer satisfaction.

Furthermore, we demonstrate the efficiency of supplier S.A. (ABC's backup supplier) in raw material provision by implementing a process analyzer software. Company ABC has the potential of benefiting more by ordering from supplier S.A. This advantage is attributable to more controllable and shorter lead time (less mean, less variance) despite high ordering costs.

Limitations of our study can be argued in terms of the following:

i. Due to limited access to the company's data, the simulation model is created for 18 weeks with 2 weeks of warm-up. Using demand data over much longer periods would contribute to a more reliable demand forecasting, stock level, holding cost and overall cost. In such a case, we would have a better understanding of the actual monthly customer demand operational responses.

ii. Since the company has no estimated inventory, an (R, Q) inventory model is employed to calculate the initial stock level.

For future studies, each stage in the framework can be further detailed. For instance, risk management strategies such as risk sharing, cultural adaptation, continuous coordination strategies, increasing flexibilities and responsiveness can further detailed in the framework. Moreover, defining appropriate metrics to assist decision-makers in investigating more about the impact of risk on their company's performance would be useful. Also, instead of using binary indices in the risk management framework, the branching of such framework can be further detailed by using probabilities of various scenarios. In regards to the experiment section, more advanced techniques such as response surface methodology can be used for analysing the experimental design findings. Furthermore, in experimental design, more risk factors (such as mean demand) can be experimented with 4 or 5 levels.

6 References

Attwood, D., Khan, F., & Veitch, B. (2006a). Occupational accident models—Where have we been and where are we going? *Journal of Loss Prevention in the Process Industries, 19*(6), 664-682.

Attwood, D., Khan, F., & Veitch, B. (2006b). Offshore oil and gas occupational accidents—What is important? *Journal of Loss Prevention in the Process Industries, 19*(5), 386-398.

Ayyub, B. M. (2014). *Risk analysis in engineering and economics* CRC Press.

Bandaly, D., Satir, A., Kahyaoglu, Y., & Shanker, L. (2012). Supply chain risk management–I: Conceptualization, framework and planning process. *Risk Management, 14*(4), 249-271.

Basel Committee. (2003). Sound practices for the management and supervision of operational risk. *Bank for International Settlements: Basel Committee Publications,* (96), 14.

Baysari, M. T., McIntosh, A. S., & Wilson, J. R. (2008). Understanding the human factors contribution to railway accidents and incidents in australia. *Accident Analysis & Prevention, 40*(5), 1750-1757.

Ben-Haim, Y. (2012). Doing our best: Optimization and the management of risk. *Risk Analysis, 32*(8), 1326-1332.

Berg, H. (2010). Risk management: Procedures, methods and experiences. *Risk Management, 1*(17), 79-95.

Blackhurst, J. V., Scheibe, K. P., & Johnson, D. J. (2008). Supplier risk assessment and monitoring for the automotive industry. *International Journal of Physical Distribution & Logistics Management, 38*(2), 143-165.

Brauchler, R., & Landau, K. (1998). Task analysis: Part II–: The scientific basis (knowledge base) for the guide1The recommendations provided in this guide are based on numerous publishe. *International Journal of Industrial Ergonomics, 22*(1), 13-35.

Burke, G. J., Carrillo, J. E., & Vakharia, A. J. (2007). Single versus multiple supplier sourcing strategies. *European Journal of Operational Research, 182*(1), 95-112.

Burnes, B., & Dale, B. (1998). Working in partnership. *Gower, Aldershot,*

Cachon, G. P. (2004). The allocation of inventory risk in a supply chain: Push, pull, and advance-purchase discount contracts. *Management Science, 50*(2), 222-238.

Cagliano, A. C., De Marco, A., Grimaldi, S., & Rafele, C. (2012). An integrated approach to supply chain risk analysis. *Journal of Risk Research, 15*(7), 817-840.

Chapman, C., & Ward, S. (1996). *Project risk management: Processes, techniques and insights* John Wiley.

Childerhouse, P., Hermiz, R., Mason-Jones, R., Popp, A., & Towill, D. R. (2003). Information flow in automotive supply chains-identifying and learning to overcome barriers to change. *Industrial Management & Data Systems, 103*(7), 491-502.

Chiles, T. H., & McMackin, J. F. (1996). Integrating variable risk preferences, trust, and transaction cost economics. *Academy of Management Review, 21*(1), 73-99.

Chopra, S., & Sodhi, M. (2012). Managing risk to avoid supply-chain breakdown. *MIT Sloan Management Review (Fall 2004),*

Cohen, M. A., & Kunreuther, H. (2007). Operations risk management: Overview of paul kleindorfer's contributions. *Production and Operations Management, 16*(5), 525-541.

Cousin, P., Lamming, R., & Bowen, F. (2004). The role of risk in environment-related initiatives. *International Journal of Operation and Production Management, 24*(6), 554-565.

Cox Jr, Louis Anthony Tony. (2012). Evaluating and improving risk formulas for allocating limited budgets to expensive Risk-Reduction opportunities. *Risk Analysis, 32*(7), 1244-1252.

Cox, A., & Townsend, M. (1998). Strategic procurement in construction: Towards better practice in the management of construction supply chains.

Davies, J., Finlay, M., McLenaghen, T., & Wilson, D. (2006). Key risk indicators–their role in operational risk management and measurement. *ARM and RiskBusiness International, Prague,* , 1-32.

Dey, P. K., & Ogunlana, S. O. (2004). Selection and application of risk management tools and techniques for build-operate-transfer projects. *Industrial Management & Data Systems, 104*(4), 334-346.

Doerr, W. W. (1991). What-if analysis. *Risk Assessment and Risk Management for the Chemical Process Industry,* , 75.

Dominguez-Chicas, A., & Scrimshaw, M. D. (2010). Hazard and risk assessment for indirect potable reuse schemes: An approach for use in developing water safety plans. *Water Research, 44*(20), 6115-6123.

Doytchev, D. E., & Szwillus, G. (2009). Combining task analysis and fault tree analysis for accident and incident analysis: A case study from bulgaria. *Accident Analysis & Prevention, 41*(6), 1172-1179.

Durkin, J., & Durkin, J. (1994). Expert systems: Design and developmentPrentice hall. *Englewood Cliffs, New Jersey,*

Ergu, D., Kou, G., Shi, Y., & Shi, Y. (2014). Analytic network process in risk assessment and decision analysis. *Computers & Operations Research, 42*, 58-74.

Faisal, M. N. (2009). Prioritization of risks in supply chains. *Managing supply chain risk and vulnerability* (pp. 41-66) Springer.

Fine, W. T. (1971). *Mathematical Evaluations for Controlling Hazards,* Froot, K. A., Scharfstein, D. S., & Stein, J. C. (1994). A framework for risk management. *Harvard Business Review, 72*(6), 91-&.

Gaonkar, R. S., & Viswanadham, N. (2007). Analytical framework for the management of risk in supply chains. *Automation Science and Engineering, IEEE Transactions On, 4*(2), 265-273.

Ghadge, A., Dani, S., Chester, M., & Kalawsky, R. (2013). A systems approach for modelling supply chain risks. *Supply Chain Management: An International Journal, 18*(5), 523-538.

Ghadge, A., Dani, S., & Kalawsky, R. (2012). Supply chain risk management: Present and future scope. *The International Journal of Logistics Management, 23*(3), 313-339.

Gleason, K., Kim, Y. S., & Mathur, I. (2005). The operational and financial hedging strategies of US high technology firms. *Documento De Trabajo, Florida Atlantic University,*

Gnyawali, D. R., & Park, B. R. (2009). Co-opetition and technological innovation in small and medium-sized enterprises: A multilevel conceptual model. *Journal of Small Business Management, 47*(3), 308-330.

Guide, A. (2001). Project management body of knowledge (PMBOK® GUIDE). *Project Management Institute,*

Haimes, Y. Y., Kaplan, S., & Lambert, J. H. (2002). Risk filtering, ranking, and management framework using hierarchical holographic modeling. *Risk Analysis, 22*(2), 383-397.

Hallikas, J., Virolainen, V., & Tuominen, M. (2002). Risk analysis and assessment in network environments: A dyadic case study. *International Journal of Production Economics, 78*(1), 45-55.

Han, M., & Chen, J. (2007). Managing operational risk in supply chain. *Wireless Communications, Networking and Mobile Computing, 2007. WiCom 2007. International Conference On,* 4919-4922.

Hendrick, K., & Benner, L. (1986). *Investigating accidents with STEP* CRC Press.

Hillson, D. (2003). *Effective opportunity management for projects: Exploiting positive risk* CRC Press.

Hillson, D. (2006). Integrated risk management as a framework for organisational success. *PMI Global Congress Proceedings,*

Hillson, D., Grimaldi, S., & Rafele, C. (2006). Managing project risks using a cross risk breakdown matrix. *Risk Management,* , 61-76.

Hillson, D., & Murray-Webster, R. (2007). *Understanding and managing risk attitude* Gower Publishing, Ltd.

Hollywell, P. D. (1996). Incorporating human dependent failures in risk assessments to improve estimates of actual risk. *Safety Science, 22*(1), 177-194.

Huang, S. H., Sheoran, S. K., & Keskar, H. (2005). Computer-assisted supply chain configuration based on supply chain operations reference (SCOR) model. *Computers & Industrial Engineering, 48*(2), 377-394.

Huber, A., Bach, M., & Frede, H. (1998). Modeling pesticide losses with surface runoff in germany. *Science of the Total Environment, 223*(2), 177-191.

Hunt, V. D. (1996). *Process mapping: How to reengineer your business processes* John Wiley & Sons.

Hyneman, F. (1971). *Risk, uncertainty and profit* University Press.

Jüttner, U. (2005). Supply chain risk management: Understanding the business requirements from a practitioner perspective. *The International Journal of Logistics Management, 16*(1), 120-141.

Jüttner, U., Peck, H., & Christopher, M. (2003). Supply chain risk management: Outlining an agenda for future research. *International Journal of Logistics: Research and Applications, 6*(4), 197-210.

Kaplan, S., & Garrick, B. J. (1981). On the quantitative definition of risk. *Risk Analysis, 1*(1), 11-27.

Kara, S., Kayis, B., & Gomez, E. (2008). Managing supply chain risks in multi-site, multi-partner engineering projects. *Communications of the IBIMA, 5*(1), 100-112.

Kaya, M., & Özer, Ö. (2009). Quality risk in outsourcing: Noncontractible product quality and private quality cost information. *Naval Research Logistics (NRL), 56*(7), 669-685.

Kelle, P., & Miller, P. A. (2001). Stockout risk and order splitting. *International Journal of Production Economics, 71*(1), 407-415.

Ketikidis, P. H., Lenny Koh, S., Gunasekaran, A., Cucchiella, F., & Gastaldi, M. (2006). Risk management in supply chain: A real option approach. *Journal of Manufacturing Technology Management, 17*(6), 700-720.

Khan, F. I., & Abbasi, S. (1998). Techniques and methodologies for risk analysis in chemical process industries. *Journal of Loss Prevention in the Process Industries, 11*(4), 261-277.

Khan, F. I., & Haddara, M. M. (2003). Risk-based maintenance (RBM): A quantitative approach for maintenance/inspection scheduling and planning. *Journal of Loss Prevention in the Process Industries, 16*(6), 561-573.

Khan, F., & Abbasi, S. (1997). Accident hazard index: A multi-attribute method for process industry hazard rating. *Process Safety and Environmental Protection, 75*(4), 217-224.

Khan, O., & Burnes, B. (2007). Risk and supply chain management: Creating a research agenda. *The International Journal of Logistics Management, 18*(2), 197-216.

Kim, Y., Jeong, D., Park, S., & Baik, D. (2006). Simulation of risk propagation model in information systems. *Computational Intelligence and Security, 2006 International Conference On, , 2* 1555-1558.

Kirwan, B. (1994). *A guide to practical human reliability assessment* CRC Press.

Kiser, J., & Cantrell, G. (2006). 6 steps to managing risk. *Supply Chain Management Review, 10*(3)

Kleindorfer, P. R., & Saad, G. H. (2005). Managing disruption risks in supply chains. *Production and Operations Management, 14*(1), 53-68.

Knemeyer, A. M., Zinn, W., & Eroglu, C. (2009). Proactive planning for catastrophic events in supply chains. *Journal of Operations Management, 27*(2), 141-153.

Kontogiannis, T. (1999). User strategies in recovering from errors in man–machine systems. *Safety Science, 32*(1), 49-68.

Kontogiannis, T., & Malakis, S. (2009). A proactive approach to human error detection and identification in aviation and air traffic control. *Safety Science, 47*(5), 693-706.

Kutlu, A. C., & Ekmekçioğlu, M. (2012). Fuzzy failure modes and effects analysis by using fuzzy TOPSIS-based fuzzy AHP. *Expert Systems with Applications, 39*(1), 61-67.

Lahr, J., & Kooistra, L. (2010). Environmental risk mapping of pollutants: State of the art and communication aspects. *Science of the Total Environment, 408*(18), 3899-3907.

Landau, K., Rohmert, W., & Brauchler, R. (1998). Task analysis: Part I–: Guidelines for the practitioner1The recommendations provided in this guide are based on numerous published and unpublished sci. *International Journal of Industrial Ergonomics, 22*(1), 3-11.

Li, J., & Hong, S. (2007). Towards a new model of supply chain risk management: The cross-functional process mapping approach. *International Journal of Electronic Customer Relationship Management, 1*(1), 91-107.

Li, L., Porteus, E. L., & Zhang, H. (2001). Optimal operating policies for multiplant stochastic manufacturing systems in a changing environment. *Management Science, 47*(11), 1539-1551.

Lin, M., Ke, X., & Whinston, A. B. (2012). Vertical differentiation and a comparison of online advertising models. *Journal of Management Information Systems, 29*(1), 195-236.

Lipol, L. S., & Haq, J. (2011). Risk analysis method: FMEA/FMECA in the organizations. *International Journal of Basic & Applied Sciences IJBAS-IJENS, 11*(05), 74-82.

Lockamy III, A., & McCormack, K. (2010). Analysing risks in supply networks to facilitate outsourcing decisions. *International Journal of Production Research, 48*(2), 593-611.

Lowrance, W. W. (1980). The nature of risk. *Societal risk assessment* (pp. 5-17) Springer.

Luna-Reyes, L. F., & Andersen, D. L. (2003). Collecting and analyzing qualitative data for system dynamics: Methods and models. *System Dynamics Review, 19*(4), 271-296.

MacDonald, D. S., Little, M., Eno, N. C., & Hiscock, K. (1996). Disturbance of benthic species by fishing activities: A sensitivity index. *Aquatic Conservation: Marine and Freshwater Ecosystems, 6*(4), 257-268.

MacGillivray, B. H., Sharp, J., Strutt, J., Hamilton, P. D., & Pollard, S. J. (2007). Benchmarking risk management within the international water utility sector. part I: Design of a capability maturity methodology. *Journal of Risk Research, 10*(1), 85-104.

Manuj, I., & Mentzer, J. T. (2008). Global supply chain risk management. *Journal of Business Logistics, 29*(1), 133-155.

March, J. G., & Shapira, Z. (1987). Managerial perspectives on risk and risk taking. *Management Science, 33*(11), 1404-1418.

Marhavilas, P., Koulouriotis, D., & Gemeni, V. (2011). Risk analysis and assessment methodologies in the work sites: On a review, classification and comparative study of the scientific literature of the period 2000–2009. *Journal of Loss Prevention in the Process Industries, 24*(5), 477-523.

Markowski, A. S., & Mannan, M. S. (2008). Fuzzy risk matrix. *Journal of Hazardous Materials, 159*(1), 152-157.

Merrick, J., & Parnell, G. S. (2011). A comparative analysis of PRA and intelligent adversary methods for counterterrorism risk management. *Risk Analysis, 31*(9), 1488-1510.

Miller, K. D. (1992). A framework for integrated risk management in international business. *Journal of International Business Studies,* , 311-331.

Moore, P. G. (1983). *The business of risk* Cambridge University Press.

Mullai, A. (2006). *Risk management system-risk assessment frameworks and techniques* DaGoB (Safe and Reliable Transport Chains of Dangerous Goods in the Baltic Sea Region) Project Office, Turku School of Economics, Turku, Finland.

Mun, J. (2002). *Real options analysis: Tools and techniques for valuing strategic investments and decisions* John Wiley & Sons.

Nagurney, A., & Nagurney, L. S. (2010). Sustainable supply chain network design: A multicriteria perspective. *International Journal of Sustainable Engineering, 3*(3), 189-197.

Narasimhan, R., & Talluri, S. (2009). Perspectives on risk management in supply chains. *Journal of Operations Management, 27*(2), 114-118.

Nash, J. F. (1950). Equilibrium points in n-person games. *Proceedings of the National Academy of Sciences, 36*(1), 48-49.

Nelson, P. (2000). Australia's national plan to combat pollution of the sea by oil and other noxious and hazardous Substances–Overview and current issues. *Spill Science & Technology Bulletin, 6*(1), 3-11.

Norrman, A., & Jansson, U. (2004). Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. *International Journal of Physical Distribution & Logistics Management, 34*(5), 434-456.

Oehmen, J., Ziegenbein, A., Alard, R., & Schönsleben, P. (2009). System-oriented supply chain risk management. *Production Planning and Control, 20*(4), 343-361.

Paulsson, U. (2004). Supply chain risk management. *Supply Chain Risk: A Reader,* , 79-96.

Peck, H. (2006). Reconciling supply chain vulnerability, risk and supply chain management. *International Journal of Logistics: Research and Applications, 9*(2), 127-142.

Ponomarov, S. Y., & Holcomb, M. C. (2009). Understanding the concept of supply chain resilience. *The International Journal of Logistics Management, 20*(1), 124-143.

Popovic, V. M., Vasic, B. M., Rakicevic, B. B., & Vorotovic, G. S. (2012). Optimisation of maintenance concept choice using risk-decision factor–a case study. *International Journal of Systems Science, 43*(10), 1913-1926.

Probst, M., Berenzen, N., Lentzen-Godding, A., & Schulz, R. (2005). Scenario-based simulation of runoff-related pesticide entries into small streams on a landscape level. *Ecotoxicology and Environmental Safety, 62*(2), 145-159.

Raj Sinha, P., Whitman, L. E., & Malzahn, D. (2004). Methodology to mitigate supplier risk in an aerospace supply chain. *Supply Chain Management: An International Journal, 9*(2), 154-168.

Reniers, G., Dullaert, W., Ale, B., & Soudan, K. (2005). Developing an external domino accident prevention framework: Hazwim. *Journal of Loss Prevention in the Process Industries, 18*(3), 127-138.

Ritchie, B., & Brindley, C. (2007). Supply chain risk management and performance: A guiding framework for future development. *International Journal of Operations & Production Management, 27*(3), 303-322.

Ritchie, B., & Marshall, D. V. (1993). *Business risk management* Chapman & Hall.

Rockafellar, R. T., & Uryasev, S. (2000). Optimization of conditional value-at-risk. *Journal of Risk, 2*, 21-42.

Rogers, R. (2000). Methodology for the risk assessment of unit operations and equipment for use in potentially explosive atmospheres. *EU RASE Project no SMT4eCT97.Library Area SAFETYNET, Inburex GmbH Hamm, Allemagne,*

Rowe, W. D. (1980). Risk assessment approaches and methods. *Society, Technology and Risk Assessment, Academic Press, London,* , 343.

Royal Society. (1992). *Risk: Analysis, perception and management*. London: Royal Society.

Ryding, A., & Sahlin, J. (2013). Improving supply chain risk management by introducing performance measurement systems.

Sachdeva, A., Sharma, V., Arvind Bhardwaj, D., Kayis, B., & Dana Karningsih, P. (2012). SCRIS: A knowledge-based system tool for assisting manufacturing organizations in identifying supply chain risks. *Journal of Manufacturing Technology Management, 23*(7), 834-852.

Scandizzo, S. (2005). Risk mapping and key risk indicators in operational risk management. *Economic Notes, 34*(2), 231-256.

Sheffi, Y., & Rice Jr, J. B. (2005). A supply chain view of the resilient entreprise. *MIT Sloan Management Review, 47*(1)

Singhal, P., Agarwal, G., & Mittal, M. L. (2011). Supply chain risk management: Review, classification and future research directions. *International Journal of Business Science and Applied Management, 6*(3), 15-42.

Spekman, R. E., & Davis, E. W. (2004). Risky business: Expanding the discussion on risk and the extended enterprise. *International Journal of Physical Distribution & Logistics Management, 34*(5), 414-433.

Stephens, S. (2001). Supply chain operations reference model version 5.0: A new tool to improve supply chain efficiency and achieve best practice. *Information Systems Frontiers, 3*(4), 471-476.

Suddle, S. (2009). The weighted risk analysis. *Safety Science, 47*(5), 668-679.

Talluri, S. S., Kull, T. J., Yildiz, H., & Yoon, J. (2013). Assessing the efficiency of risk mitigation strategies in supply chains. *Journal of Business Logistics, 34*(4), 253-269.

Tang, C. S. (2006). Perspectives in supply chain risk management. *International Journal of Production Economics, 103*(2), 451-488.

Tang, C., & Tomlin, B. (2008). The power of flexibility for mitigating supply chain risks. *International Journal of Production Economics, 116*(1), 12-27.

Tang, C., & Tomlin, B. (2009). How much flexibility does it take to mitigate supply chain risks? *Supply chain risk* (pp. 155-174) Springer.

Tang, O., & Musa, S. N. (2011). Identifying risk issues and research advancements in supply chain risk management. *International Journal of Production Economics, 133*(1), 25-34.

Thun, J., & Hoenig, D. (2011). An empirical analysis of supply chain risk management in the german automotive industry. *International Journal of Production Economics, 131*(1), 242-249.

Tomlin, B. (2006). On the value of mitigation and contingency strategies for managing supply chain disruption risks. *Management Science, 52*(5), 639-657.

Tortell, P. (1992). Coastal zone sensitivity mapping and its role in marine environmental management. *Marine Pollution Bulletin, 25*(1), 88-93.

Trucco, P., & Cavallin, M. (2006). A quantitative approach to clinical risk assessment: The CREA method. *Safety Science, 44*(6), 491-513.

Tweeddale, H. M., Cameron, R. F., & Sylvester, S. S. (1992). Some experiences in hazard identification and risk shortlisting. *Journal of Loss Prevention in the Process Industries, 5*(5), 279-288.

Varetto, F. (1998). Genetic algorithms applications in the analysis of insolvency risk. *Journal of Banking & Finance, 22*(10), 1421-1439.

Vincent, C., Taylor-Adams, S., & Stanhope, N. (1998). Framework for analysing risk and safety in clinical medicine. *BMJ (Clinical Research Ed.), 316*(7138), 1154-1157.

Wagner, S. M., & Bode, C. (2006). An empirical investigation into supply chain vulnerability. *Journal of Purchasing and Supply Management, 12*(6), 301-312.

Wagner, S. M., & Bode, C. (2008). An empirical examination of supply chain performance along several dimensions of risk. *Journal of Business Logistics, 29*(1), 307-325.

Wallace, S. W., & Ziemba, W. T. (2005). *Applications of stochastic programming* Siam.

Wang, J., He, J., & Chen, H. (2012). Assessment of groundwater contamination risk using hazard quantification, a modified DRASTIC model and groundwater value, beijing plain, china. *Science of the Total Environment, 432*, 216-226.

Womack, J., Jones, D., & Roos, D. (1990). The machine that changed the world, rawson associates, new york, NY. *Acknowledgements: This Project was Completed with the Great Help and Efforts of Mr SM Vijayan, and Mr E.Soedjatmiko,*

Wu, D. D., Chen, S., & Olson, D. L. (2014). Business intelligence in risk management: Some recent progresses. *Information Sciences, 256*, 1-7.

Wu, D. D., & Olson, D. L. (2013). Computational simulation and risk analysis: An introduction of state of the art research. *Mathematical and Computer Modelling, 58*(9), 1581-1587.

Wu, T., Blackhurst, J., & O'grady, P. (2007). Methodology for supply chain disruption analysis. *International Journal of Production Research, 45*(7), 1665-1682.

Wu, Y. (2006). Robust optimization applied to uncertain production loading problems with import quota limits under the global supply chain management environment. *International Journal of Production Research, 44*(5), 849-882.

Xie, C., Anumba, C. J., Lee, T., Tummala, R., & Schoenherr, T. (2011). Assessing and managing risks using the supply chain risk management process (SCRMP). *Supply Chain Management: An International Journal, 16*(6), 474-483.

Yates, J. F., & Stone, E. R. (1992). The risk construct.

Yu, H., Zeng, A. Z., & Zhao, L. (2009). Single or dual sourcing: Decision-making in the presence of supply chain disruption risks. *Omega, 37*(4), 788-800.

Zhang, F. (2006). A note on supply risk and inventory outsourcing. *Production Planning & Control, 17*(8), 796-806.

Zhao, L., & Jiang, Y. (2009). A game theoretic optimization model between project risk set and measure set. *International Journal of Information Technology & Decision Making, 8*(04), 769-786.

Zsidisin, G. A. (2003). Managerial perceptions of supply risk. *Journal of Supply Chain Management, 39*(4), 14-26.

Zsidisin, G. A., Ellram, L. M., Carter, J. R., & Cavinato, J. L. (2004). An analysis of supply risk assessment techniques. *International Journal of Physical Distribution & Logistics Management, 34*(5), 397-413.

Zsidisin, G. A., Panelli, A., & Upton, R. (2000). Purchasing organization involvement in risk assessments, contingency plans, and risk management: An exploratory study. *Supply Chain Management: An International Journal, 5*(4), 187-198.

Zsidisin, G. A., & Ritchie, B. (2008). *Supply chain risk: A handbook of assessment, management, and performance* Springer Science & Business Media.

Tixier, J., Dusserre, G., Salvi, O., & Gaston, D. (2002). Review of 62 risk analysis methodologies of industrial plants. *Journal of Loss Prevention in the process industries*, *15*(4), 291-303.

7 Appendix A

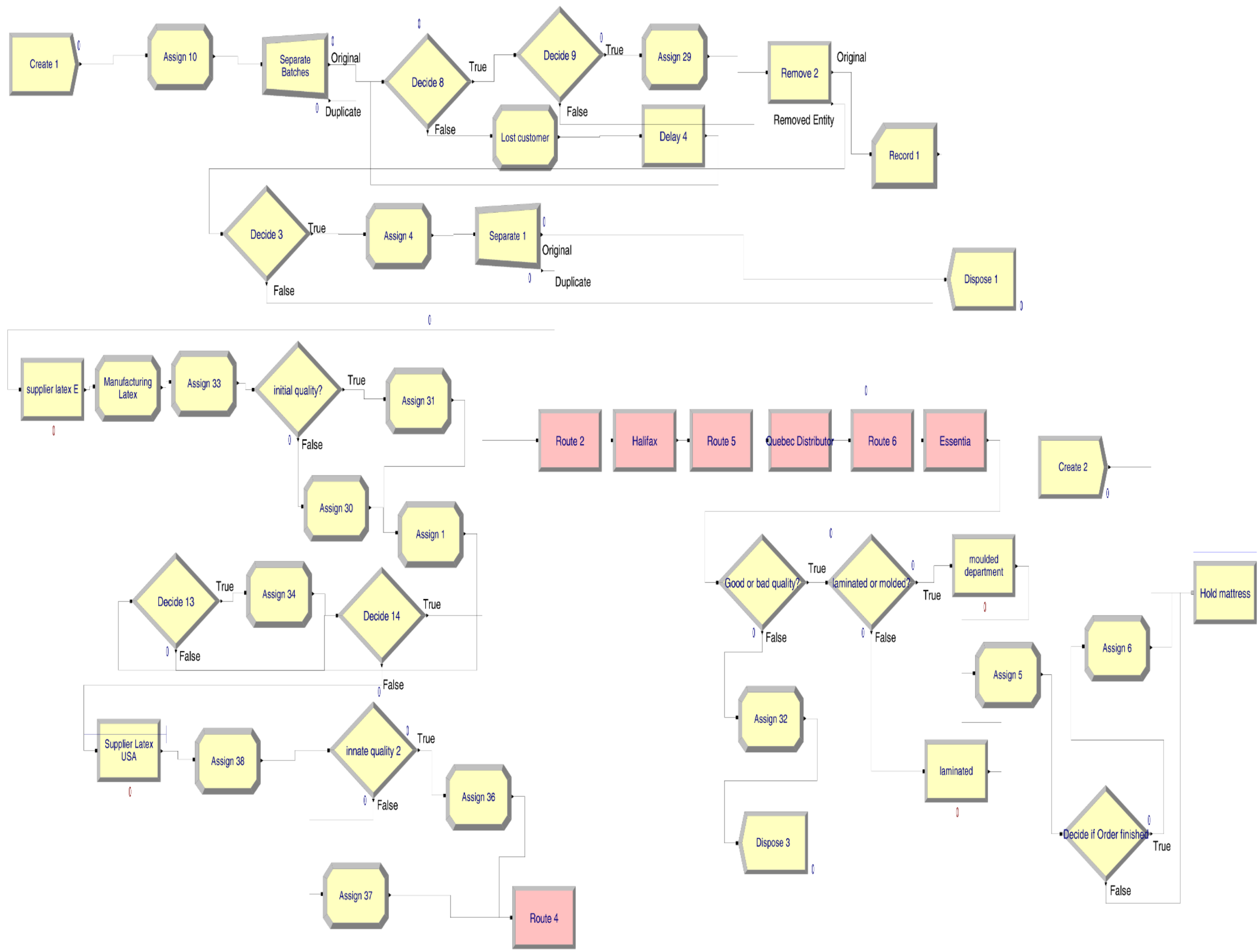
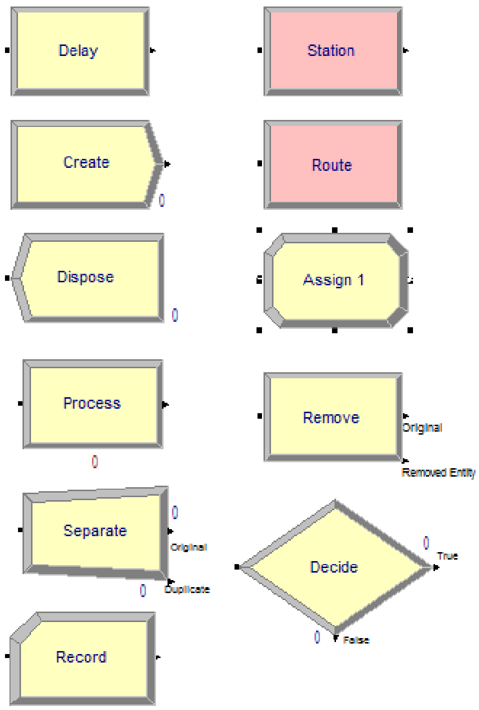


Figure 7-1 The supply chain of mattress manufacturing from upstream level to downstream level

Legend:



8 Appendix B

Inputs:

i. forecasted demand (which is used in calculating ROP)

1	91
2	131
3	60
4	161
5	46
6	246
7	91
8	202
9	80
10	216
11	94

12	250
13	45
14	270
15	150
16	235
17	95
18	200
19	320
20	137
Average lead time	5
St deviation lead time	2
Average Projected demand	156
St deviation Projected demand	81.82008504
ROP	1376.68
StandeviationD.LT	361.6858189

ii. real demand (for 20 weeks)

week	Real demand
1	146
2	111
3	122
4	139
5	150
6	120
7	140
8	200
9	186
10	100
11	186
12	179
13	200
14	215

15	155
16	114
17	171
18	163
19	151
20	188

iii. fixed costs

Ordering cost	200($)/orders
Shortage cost	20 ($)/unit short/week
Holding costs	1 ($)/unit/week

Outputs

Secondary output measure:

Lead time (Mean)	Lead time (STD)	Demand (STD)	Lost sales	Latex	Mattress	Pillow	Real demand
3	0.6	0.75	22	3233	5558	925	3069
3	0.6	1	378	2841	5368	811	3405
3	0.6	1.25	478	2841	5512	811	3714
3	0.9	0.75	259	2477	5365	707	3069
3	0.9	1	448	2418	5212	690	3405
3	0.9	1.25	563	2418	5356	690	3714
3	1.2	0.75	444	2335	4425	667	3069
3	1.2	1	779	2335	4376	667	3405
3	1.2	1.25	956	2335	4520	667	3714
4	0.6	0.75	318	2508	5396	717	3069
4	0.6	1	656	2507	5245	716	3405
4	0.6	1.25	781	2507	5389	716	3714
4	0.9	0.75	554	2450	4417	701	3069
4	0.9	1	889	2450	4368	701	3405

4	0.9	1.25	1066	2450	4512	701	3714
4	1.2	0.75	563	1980	4052	564	3069
4	1.2	1	898	1980	4003	564	3405
4	1.2	1.25	1075	1980	4147	564	3714
5	0.6	0.75	563	2363	4187	675	3069
5	0.6	1	898	2363	4138	675	3405
5	0.6	1.25	1075	2363	4282	675	3714
5	0.9	0.75	567	1745	3968	498	3069
5	0.9	1	898	1745	3919	498	3405
5	0.9	1.25	1075	1745	4063	498	3714
5	1.2	0.75	714	1671	3929	477	3069
5	1.2	1	927	1671	3880	477	3405
5	1.2	1.25	1104	1671	4024	477	3714

9 Appendix C

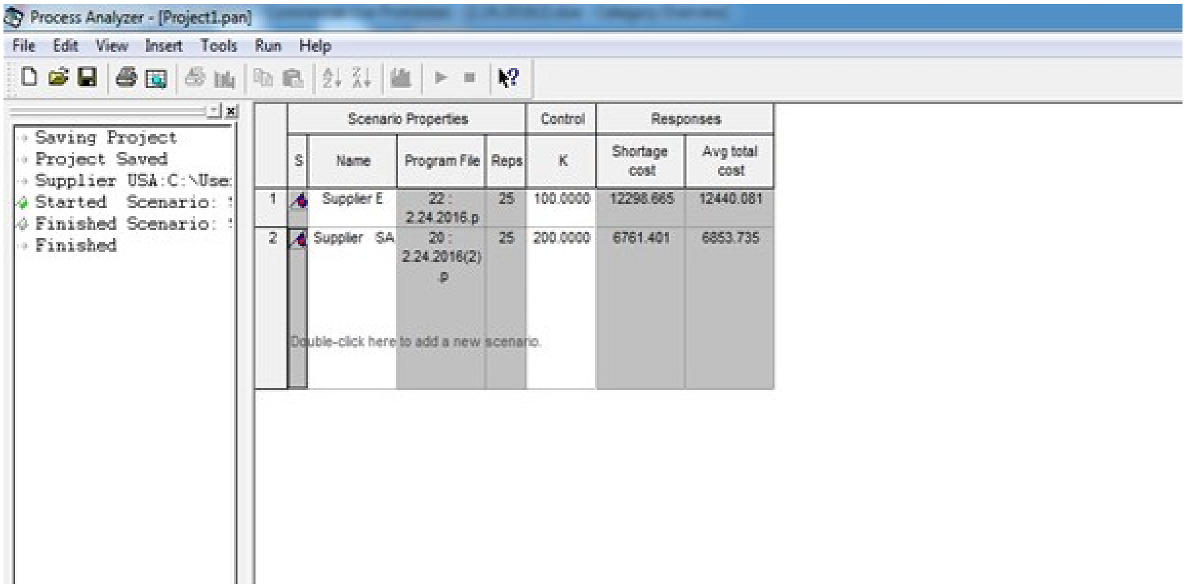


Figure 9-1 A comparison with two suppliers with different ordering costs and its impact on response values