Modeling and Mitigating Global Supply Chain Risk Management

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Abstract
As many companies have outsourced production to oversea manufacturers, supply chains have been extended, and the complexities of the chains have increased exponentially. Managing risk in the supply chain has never been as challenging as it is today. This paper develops a comprehensive quantitative risk evaluation and mitigation model in global supply chains from several disciplines – logistics, supply chain management, operation management, economics and international business. A case study is provided based on a real company whose products are manufactured in China and sold in U.S. Firstly, four main risks including supply risk, operational risk, demand risk and financial risk, are identified and modeled as probabilistic distributions of the outcome of adverse events associated with the components throughout the supply chain. These risks are further incorporated into a simulation model, and quantitatively evaluated using @Risk 5.0. Furthermore, some risk mitigation strategies such as hedging and speculation are implemented and integrated with the simulation model for further investigation.

Keywords
Supply chain management, Risk management, Modeling and simulation, Risk mitigation.

1. Introduction
Supply chain networks are global in nature, comprising of complex interactions and flows of goods, information and funds between companies and facilities geographically distributed across countries and continents. Most manufacturing supply chains are structurally similar. The member companies in a typical manufacturing supply chain network include the suppliers and their customers, assembly plants, distributors, retailers, inbound and outbound logistics providers and financing institutions. [1]

With the economy globalization, today's supply chains are becoming not only more efficient, but also riskier, due to the tight interconnectedness of numerous chain links that are prone to breakdowns, disruptions, bankruptcies, and disasters. These risks might prevent deliveries, lead to delays, damage goods, or somehow affect smooth operations. Although supply chain risks have always been presented, they are being exacerbated by two forces: the move to leaner supply chains holding fewer inventories and the move to increased outsourcing. According to a survey of 110 risk management professionals conducted in January and February 2008 [2], nearly three-quarters of them report that their company's risk levels have increased since 2005, while only 2% say it declined. Moreover, the C-level at companies – the CEO, CFO and COO – are increasingly recognizing the danger of supply chain risks.

In terms of directly relevant work in the area of supply chain risk management, Paulsson [3] provides a good survey of the recent literature in the field. Some of the commonly studied supply chain risks are disruption risk, terrorism risk and the risk from natural disasters.

With reference to disruption risks, Handfield *et al.* [4] identify sources of disruption risk, and provide some high level approaches to minimize the effects of disruption risk. In the area of terrorism risk there has been a great deal of interest especially after the September 11, 2001 terrorist attack, Sheffi [5] studies supply chain management under the threat of international terrorism and proposes some methods such as setting certain operational redundancies. Martha and Subbakrishna [6] also analyze supply chains under terrorist attacks and propose a so-called targeting a just-in-case supply chain strategy to face the inevitable next disaster.

Another area of particular interest in supply chain risk management is that of managing risks emanating from natural disasters. Svensson [7] and Walters [8] establish conceptual frameworks to analyze the vulnerability in supply chains. Manju [1] also provides a more comprehensive risk management and mitigation framework for global supply chains.

Despite these publications, there are limited researches on quantitative identification the effects of risks on the dynamic supply chains, although some provide static optimization models to minimize costs or maximize profits in the presence of risks. In this paper, we will provide a comprehensive quantitative risk evaluation and mitigation simulation model based on a real company whose products are manufactured in China and sold in the U.S. in the context of supply risk. In Section 2, we identify the risks in supply chains, and then in Section 3, we build a simulation model to quantitatively represent these risks. In Section 4, we present our results and corresponding strategies to mitigate the risks in supply chains. Finally we make our conclusion.

2. Identification of Risks in Supply Chains

Companies' brand reputation and earnings consistency increasingly rely on how well risks are managed in their supply chains. Media headlines are filled with accounts of supply chain risks: food and toy safety, product quality recalls, natural hazard disruptions, supplier delays, logistics unpredictability, supply chain security, and so on. According to a survey [2], Figure 1 shows the risk areas of greatest concern to study participants. As we can see, natural disasters, e.g., hurricanes or floods are not the biggest issues. The most concerning risk issues are labor issues, raw material costs, import/export restrictions, and risks involving shifting production from plant to plant or country to country.

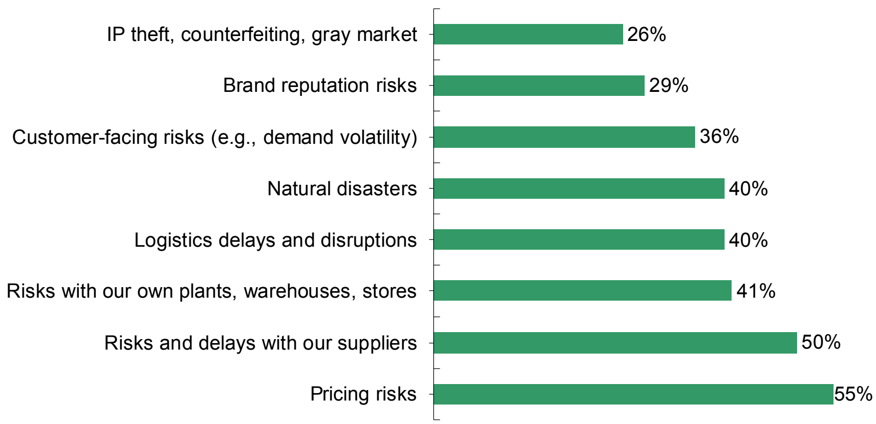

Figure 1: Risk Areas of Greatest Concern to Companies

Based on Figure 1, the source of supply chain risks are classified into supply risks, operations risks, demand risks and financial risks. More detailed discussions about the source of risks can be referred to the international business literatures [9][10]. We must notice that most of these risks are overlapping and do not exist in isolation. In the following sections we will discuss them in detail.

Supply risk is the possibility of loss occurring from unavailability of the necessary raw material from the suppliers (www.businessdictionary.com). Supply risks include the reliability of the suppliers, the availability of the raw material, the supply lead time, the supply delivery problems (disruption), etc. From Figure 1, about 50% of the companies are concerning on the risks due to supply delay, while about 40% are worry about the supply disruption.

The operational risk is the possibility of loss resulting from inadequate or failed internal processes, people and systems, or from external events (www.riskglossary.com). The operational risks include the reliability of equipment, loss of an IT system, human errors and quality issues, etc. They also arise from directly from managers' decisions, such as the choice of batch sizes, safety stock level. From Figure 1, about 41% of the companies are concerning on the operational risks.

The demand risk is the possibility of loss associated with outbound flows that may affect the likelihood of customers placing orders, or variance in the volume and assortment desired by the customer [1]. Sources of demand risks include variance of demand due to seasonality or new product introduction, brand and reputation damage due to product quality or company's scandals, or problems with the order processing, etc.

The financial risk is the possibility of loss with the flow of money [1] which includes risks to payments, price, economy condition, cash flow, investments, etc. These risks appear as poor returns on investment, excessive costs, unreasonable high product price, unpaid bills, shortage of cash, etc. As we can see in Figure 1, about 55% of companies are concerning on the pricing risks.

There are many types of quantitative analysis about risk, but they are all based on two factors: 1) the likelihood of a risky event occurring; and 2) the consequences when the event does occur. Therefore we can define the risk as follows [1]:

$$\text{Risk} = \text{P(event)}*\text{L(consequence)} \tag{1}$$

where P(event) is the likelihood of the event occurring, and L() is the loss resulting from the event occurring. So the essence of risk analysis is to define the possibilities of each possible risk and evaluate possible impacts corresponding to each risk, then give a prioritized list based on Eq. 1. For the most significant risks, we need to pay positive attentions and provide corresponding mitigations.

Uncertainties are sources of risk. The higher uncertainties, the greater risks, and more variability in supply chain performance. Deviation is associated with uncertainty all the time. A deviation is said to have occurred when one or more parameters, such as cost, demand, lead-time, etc, within the supply chain system stray from their expected or mean value. In this paper, we present the likelihood, or uncertainty of an event with expected value and deviations. Section 3 defines the deviations in supply, demand, production and logistics cost, and transportation and production lead-times.

3. Case Study – Modeling of Supply Chain Risk Management

FunLogo Company sells college football logos to NCAA universities, and mainly focuses on Big10 and SEC conferences. For example, the logo of the University of Tennessee is “T”, the logo of University of Michigan is “M”. FunLogo designs the models of these logos and has the Intelligence Property (IP). A Chinese manufacturer produces these logos when they receive orders from FunLogo, and ship the products to the distribution center of U.S. FunLogo rents a distribution center in Knoxville, Tennessee. When FunLogo receives orders from NCAA schools, it will ship the orders via a 3PL – UPS. Since the manufacturing and transportation lead time from China to U.S. is too long (i.e. 70 days), FunLogo selects another manufacturer in Mexico as a backup whose manufacturing cost is much higher than that in China. The supply chain of FunLogo has some risks such as supply disruption due to the hurricanes or financial crisis. Moreover, the demands are uncertain since the performance of each school during the football season has a huge impact, while it is unpredictable. For example, it is surprising that the No.3 Pennsylvania State University lost to the unranked University of Iowa. We integrate these risks into a simulation model and investigate risk management for FunLogo Company.

To simplify the simulation model, we aggregate the logos to Big10 conference to one product: Big1 although there are 11 different products. Similarly, we model the product to SEC conference to one product: Sec2. We also aggregate the customers of Big10 to one customer (C1) locating at Cleveland, Ohio, and that of SEC to one customer (C2) locating at Atlanta, Georgia. The distribution center (DC) is based in Knoxville, Tennessee. There is one supplier each in China (S1) and in Mexico (S2). Both suppliers – S1 and S2 – can supply the two products (Product Big1 and Product Sec2). Figure 2 shows the supply chain network.

Risk events serve as the independent variables for this event-driven model. For the supply risks, we include the order processing risk and transportation risk. Financial risk at the suppliers leads to a permanent disruption, while hurricanes result in a 45 days supply disruption. For demand risks, all supply chain customers are based in the U.S. Since the football season is from September to December, a seasonal demand is also considered.

Table 1 provides a list of all independent variables, their definitions and values. Supply risks are divided into manufacturing lead time variability, transportation lead time variability, and cost variability. Demand risk is manifest by demand variability.

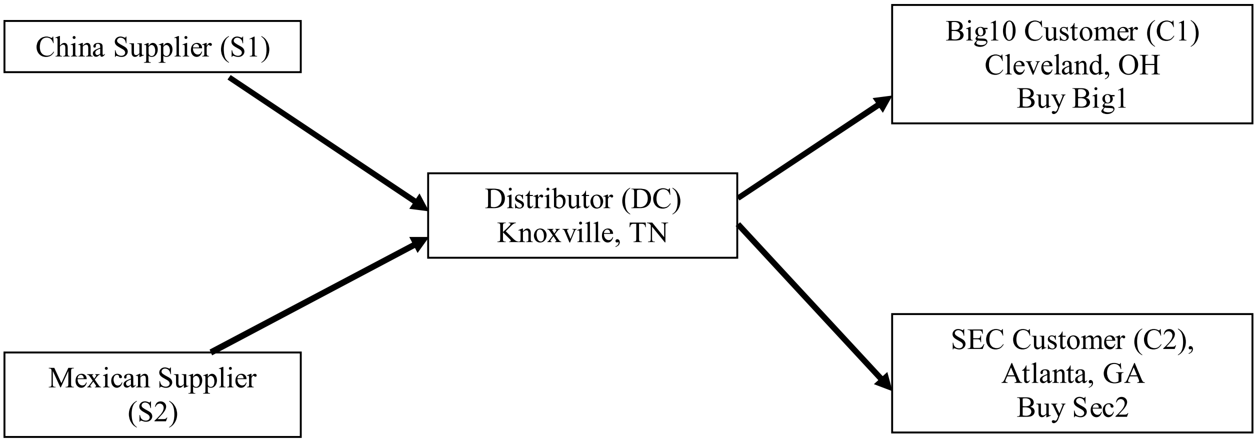

Figure 2: Simulation Supply Chain. Both supplies can produce products Big1 and Sec2.
C1 buys Big1 and C2 buys Sec2

The model flow for this study can be divided into the following five stages:

1. Demand generated at the customer location
2. Order received and processed at the distributor
3. Order placed on the supplier(s)
4. Order shipped from supplier to the distributor
5. Order shipped from distributor to the customers

Table 1. Independent Variables

Parameters	Definition		Low Risk	High risk	Mexico	Remarks
1. Supplier Order Processing Time Variability	Time from order placement to replenishment at the supplier facility	Manufacturing	N(35,3.5) days	N(35,10.5) days	N(10,1) days	Normal Distribution
		Transportation	T(30,35,40)days	T(30,40,50) days	T(4,5,6) days	Triangular Distribution
2. Cost Variability	Product Big1 Product Sec2 ($)		T(2.5,3,3.5)	T(3.5,4.5,5.5)	5	T(min,mean,max)
Demand Risk Events						
3. Variability of demand	Average variation in daily demand	For Customer 1 For Customer 2	N(20,2) N(40,4)	N(20,6) N(40,12)	NA	Jan. – Aug.
		For Customer 1 For Customer 2	N(50,5) N(70,7)	N(50,15) N(70,21)	NA	Sep. – Dec. Football Season
Disruption						
4. Disruption	Closure of US port for 45 days					

Stage 1: Demand generated at the customer location

Demand is generated daily at both customer sites. The average demands at non-football season (Jan. to Aug.) for products Big1 and Sec2 are different from that at football season. The demands are normal distribution with the coefficient of variation 0.1 for low risk and 0.3 for high risk. These values were validated during conceptual validation with FunLogo Company.

Stage 2: Order received and processed at the distributor

Customer orders are received and placed instantaneously at the distributor. The minimal order quantity is 24 units. The order processing begins as soon as being received. The processing at distributor takes place 8 hours a day, 5 days a week, and 365 days a year.

Stage 3/4: Order placed on the supplier(s) and shipped to the distributor

Chinese supplier takes an average of 35 days to manufacture the products. The manufacturing lead time is a normal distribution with the coefficient of variation 0.1 for low risk and 0.3 for high risk. Mexican supplier takes 10 days to manufacture. The transportation lead time from China to U.S. is a triangular distribution, with T(30,35,40) for low risk and T(30,40,50) for high risk. It takes Mexican supplier T(4,5,6) days to ship products to the distributor.

The two suppliers follow "demand flow" inventory management policy, with initial inventory 1000 units for both products, which means only when the suppliers receive orders from the distributor, they begin to produce the exact quantity units in the order. The distributor takes a (R,Q) inventory management policy. The reorder point and order up to point are (1000,4000) for product Big1 and (2000,6000) for product Sec2. The order review period is 2 months.

Stage5: Order shipped from the distributor to the customers
It takes T(3,5,7) days via UPS from the distributor to the customers.

We build this model by using @Risk 5.0 from Palisade Corp. (www.palisade.com) embedded with VBA. Another software-Supply Chain Guru (www.llamasoft.com) is also excellent and dedicatedly designed for supply chain simulation. However, we cannot control the background simulation flows because it works as a black box. @Risk 5.0 uses Monte Carlo simulation for risk evaluation and can be controlled by VBA macros. Therefore, we select @Risk to build our simulation model.

4. Results and Strategies

We incorporate high supply risks with high variances at manufacturing, transportation and cost, and high demand risk with high variances from the two customers' daily demands. Regarding to supply disruption, we assume the U.S. port is closed for 45 days. We adopt a "Tree and Branch" diagram to illustrate the possible combinations of risks and mitigation strategies. The evaluation metric is based on the profits gained after one year's simulation run.

4.1 Supply Risk and Hedging Strategy

When Chinese supplier has high supply risk, a hedging strategy is used to mitigate this risk. Hedging is a transfer of risk without buying insurance policies. Basically, it takes equal and opposite positions in two different markets (such as cash and future markets) to protect one's capital against financial risks (www.businessdictionary.com). In supply chain context, Hedging is undertaken through a globally dispersed portfolio of suppliers, customers and facilities such that one single risk can not jeopardize the whole supply chain. In this case study, two global suppliers (China and Mexico) are used as a hedge against risk of supply risks, and each replenishment order has an equal probability being assigned to either Chinese supplier or Mexican Supplier

With the high supply risk and low demand risk, hedging strategy greatly decreases the risk and increases the profit. In our simulation, when Chinese manufacturer has high supply risk, hedging strategy selects Mexican supplier and gains $49,414 profit. If the simulation continues using the old logistics network, the profit is about $6,845. On the other hand, with the low supply risk and high demand risk, the old logistics network shows a higher profit. In our simulation, old supply chain has a profit $76,771, while hedging strategy using Mexican supplier has a profit of $44,816.

4.2 Demand Risk and Speculation Strategy

The original reorder point and order up to point for non-football season are (1000,4000) for product Big1 and (2000, 6000) for product Sec2. The review period is 2 months. During the football season, the average demand and demand risk are high, we set the reorder point and order up to point (3000,15000) for product Big1 and (5000,20000) for product Sec2. The review period is set to 1 month. The corresponding high and low daily customers' demands are listed in Table 1.

Speculation is to take large risks, especially with respect to trying to predict future in the hope of making quick large gains (www.investowords.com). In supply chain context, speculation is to make decisions based on anticipated customer demands with a high frequency. For example, FunLogo company predicts the demand from SEC conference will increase while from Big10 conference will decrease based on this year's football performance of each school. Therefore, FunLogo orders more products Sec2 from suppliers in order to make more profit. In our simulation, when supply chains face high demand risk, speculation strategy has a higher profit of $117,213, while non-speculation strategy has a profit of $85,538.

4.3 Disruption Risk and Strategies

Disruption can manifest themselves in a variety of forms including transportation delays, port closures, accidents, natural disasters, quality problems. In our simulation, we test all possible combination of supply risks and demand risks, strategy on supply and demand sides, respectively under conditions of disruption. We argue that hedging strategy is always better under corresponding environmental conditions and demand side strategy.

5. Conclusion

In this paper, we develop a quantitative risk evaluation and mitigation model in global supply chains. A case study is provided based on a real company whose products are manufactured in China and sold in the U.S. Main risks including supply risk, demand risk and financial risk, are identified and modeled as probabilistic distributions. We quantify these risks in a simulation model using @Risk 5.0 and provide the corresponding risk mitigation strategies such as hedging and speculation. Our model justifies that the mitigation strategies are applicable to these risks and can gain more profits compared with non-strategy-used scenarios. However, this model is too simple to model such a complex global supply chain because we ignore the product manufacturing process. Also, a further investigation about the risk mitigation strategies, such as postponement, will be conducted for our future research.

References

1. I. Manuj and J. T. Mentzer, "Global Supply Chain Risk Management," *Journal of Business Logistics*, Vol. 29, No. 1, 2008.
2. B. Enslow, Marsh Corp., www.marsh.com.
3. U. Paulsson, "Management Risks in Supply Chains – An Article Review", *Presented at NOFOMA*, 2003, Oulu, Finland, 12-13, June 2003.
4. R. B. Handfield, and K. McCormack, "Supply Chain Risk Management: Minimizing Disruptions in Global Sourcing", Taylor & Francis Group, New York, USA, ISBN-13: 978-0-8493-6642-0, 2007
5. Y. Sheffi, "Supply Chain Management under the Treat of International Terrorism", *The International Journal of Logistics Management*, Vol. 12, No. 2, 2001.
6. J. Martha and S. Subbakrishna, "Targeting a Just-in-case Supply Chain for the Inevitable Next Disaster", *Supply Chain Management Review*, Sep/Oct, 18–23, 2002.
7. G. Svensson, "A Typology of Vulnerability Scenarios towards Suppliers and Customer in Supply Chains Based upon Perceived Time and Relationship Dependencies", *International Journal of Physical Distribution & Logistics Management*, 32, 168–187, 2002.
8. D. Waters, "Supply Chain Risk Management: Vulnerability and Resilience in Logistics," *MPG Books Ltd., Bodmin, Cornwall*, ISBN-13:978-0-7494-4854-7, 2007.
9. S. Chopra and P. Meindl, "Supply Chain Management: Strategy, Planning and Operations", 2nd Edition, Pearson Prentice Hall, ISBN 0-13-101028-X, 2004.
10. S. Ghoshal, "Global Strategy: An Organizing Framework", *Strategic Management Journal*, Vol. 8, No. 5, pp. 425-440, 1987.