ANALYZING SUPPLY CHAIN RISKS THROUGH MULTI-TIER SUPPLIER NETWORKS

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Abstract

As firms establish their global supply chains, the risks increase dramatically due to increased complexity of the supply chains, which could result in lowering their market and financial performances. Natural disasters become major threats and often create significant negative impacts to supply chains. In this paper, an in-depth interview with a supply chain executive of an auto manufacturer reveals that when a natural disaster occurred, single sourcing at a tier-3 supplier and lack of location diversification for suppliers were weaknesses of the automaker's supply chain. To assess supply chain risks we propose to build a supplier information system and construct multi-tier supplier networks to analyze them from different risk perspectives. This study offers the unique value of establishing a supplier database which not only includes tier-1 supplier, but also includes tier-2 and tier-3 suppliers which often have more hidden risks.

Keywords: Supply Chain Risk, Supplier Network, Single Sourcing, Disruption Risk

INTRODUCTION

Risks from uncertainty have been extensively researched in various business fields such as finance, operations, and marketing. Supply chain risks have recently been given increased attention by practitioners and researchers since they have significant negative impacts on a firm's market and financial performances (Fortune, 2011; Tang, 2006). For instance, the estimated costs of natural disasters for Japan in 2011 are $210 billion (Fortune, 2011). There are two types of supply chain risks, which are operational risks and disruption risks (Kleindorfer and Sadd, 2005). Operational risks are caused by normal uncertainties from supply, demand, and cost, such as equipment malfunction, customer demand change, and technology shifts. Disruption risks are caused by natural or man-made disasters, and examples include earthquake, terrorism, and

bankruptcy. Generally, the impact by disruption risks is much greater than that caused by operational risks (Kleindorfer and Sadd, 2005; Tang, 2006).

We performed an in-depth interview with a director from a Japanese automaker. The director revealed two incidents (a flood in Thailand and Tsunami in Japan) which struck the company's supply chain exposing the weaknesses of its supply network. We propose to build a supplier information system collecting information from suppliers not only at the tier-1, but from multiple tiers. Using the data in the system, we construct supplier networks and perform various risk analyses. To illustrate, we perform risk analysis from the perspectives of the two weaknesses in our case, single sourcing and location diversification.

The paper is organized as follows: Section 2 is a literature review followed by a description of a case and its findings in Section 3. We introduce our approach and perform risk analysis for supplier networks in Section 4. Section 5 includes conclusions and discussions of the study. Section 6 concludes the study, addresses limitations, and highlights future research directions.

LITERATURE REVIEW

Risk has been an important issue in supply chain management. Supply chain risk results not only from natural disasters, flood, and fire but also from ill supply chain design strategies. A series of recent events-Japanese earthquake and tsunami, the floods in Thailand, volcanic eruption in Iceland - made supply chain managers realize that supply chains are fragile and they can no longer focus solely on cost reduction, but they also need to focus on risk mitigation. Therefore it became a necessity to identify threats facing supply chains and applying effective risk management strategies. That is why a number of papers have shown a recent interest in studying supply chain risks and risk mitigation strategies.

In 1987, in a study by March and Shapira (1987) supply chain risk is defined as "a variation in the distribution of possible supply chain out-comes, their likelihood, and their subjective values". Vanany, Zailani, and Pujawan (2009) defined supply chain risk management as a set of activities aimed at reducing supply chain risks. These activities often include identifying supply chain risks, assessing the probabilities and the severity of impacts, prioritizing the risk event to be dealt with and developing actions for mitigating risks or planning backup actions. In a study by Manuj, Esper, and Stank (2014), two types of supply chain risks are identified: Supply-side risks and demand side risks. Supply side risks are "associated with availability of material supply from upstream suppliers that affect the ability of the focal firm to meet customer demand" and demand-side risks are "associated with availability of finished product to meet customer demand within anticipated cost and time requirements". Based on the interviews conducted with supply chain managers from various companies, the appropriate

risk management approach is identified as hedging or assuming. Demand-side risk approaches included postponement or speculation.

A group of researchers studied supply chain risk in various industries. As an example, Diabat, Govindan, and Panicker (2012) studied the risks involved in the food supply chain of a leading producer of food products in south India. Five categories of risk were identified, namely product/service management risk, macro level risk, demand management risk, supply management risk, and information management risk. Strategies for mitigating these risks were also proposed. In another study, Thun, Druke, and Hoenig (2011) have conducted an empirical investigation of supply chain risk management in small and medium-sized enterprises. Data from 67 manufacturing plants from the German automotive industry are used, differences between large-scale enterprises and small and medium-sized enterprises are identified and the key drivers of supply chain risks are analyzed.

In addition to studying supply chain risks, risk mitigation strategies have been extensively proposed. Chen, Sohal, and Prajogo (2013) examined supply chain collaboration as a risk mitigation strategy. Three types of risks, namely supply risk, demand risk and process risk are studied in relation to three types of collaboration, namely supplier collaboration, customer collaboration and internal collaboration, as a mechanism to mitigate those risks. Data are collected from 203 manufacturing companies in Australia. The authors found out that each area of collaboration effectively reduces its respective supply chain risk, but only the mitigation of process risk and demand risk have a direct effect on supply chain performance. In addition, both supply risk and demand risk increase process risk. Giannakis and Louis (2011) developed a framework for the design of a multi-agent based decision support system for the management disruptions and mitigation of risks in manufacturing supply chains. Talluri, Kull, Yildiz, and Yoon (2013) carried out a comprehensive evaluation of supply chain risk mitigation strategies in the presence of a variety of risk categories, risk sources, and supply chain configurations. The study utilized two main risk mitigation strategy types: redundancy and flexibility. They concluded that the more efficient strategies focus on flexibility rather than on redundancy for supply chain failures. Rodger (2014) developed a mechanism that could be embedded in the requisition process to identify items with a potential to become backordered, before orders are even placed. That particular tool helped military personnel to address the problem of backorder creation in supply chains. The paper describes the structure of a Bayesian network from a real-world supply chain data set and then determines a posterior probability distribution for backorders using a stochastic simulation based on Markov blankets. In another study, Rodger, Pankaj, and Gonzalez (2014) investigated the challenge of identifying the major risk triggers of backordered items. Risk factors were identified, the impact importance and probability metric performance ratings were determined via induced linguistic

ordered weighted averaging, and a risk mitigation strategy was used to identify and predict supply chain backorder risk triggers.

Supply chain risks have been studied in different countries. A study by Lavastre, Gunasekaran, and Spalanzani (2012) conducted an empirical study of 142 general managers and logistics and supply chain managers in 50 different French companies. Their study showed that supply chain risk management is an operational management tool demonstrating that effective supply chain risk management is based on collaboration. Cagliano, De Marco, Grimaldi, and Rafele (2012) presented a risk identification and analysis methodology that integrates well-established supply chain and risk management tools, such as the Supply Chain Operations Reference Model, the Risk Breakdown Structure, the Risk Breakdown Matrix (RBM) and performance indicators. The proposed approach is applied to a hypothetical manufacturing supply chain to increase corporate awareness on supply chain risk by providing a structured approach to identify, assess and communicate sources and consequences of risky event.

Our literature search also focused on supplier information systems. For instance, Goswami, Engel, and Krcmar (2013) proposed a framework that can be used to evaluate supply chain information systems and their contribution towards information visibility in supply chains. The paper compared two different supply chain information systems to assess the extent to which these systems meet the information visibility needs within supply chains and networks.

A recent survey conducted by Accenture (2014) revealed that while a vast majority of executives believe supply chain risk management is a priority, only a small group of companies employ practices to mitigate risk. So our study attempts to build a supplier information system and to construct multi-tier supplier networks to analyze supply chain risks based on Kleindorfer and Sadd (2005)'s proposed (SAM) framework (specifying, assessing, and mitigating). We are hoping the proposed model will help companies to understand and analyze their supply chain risks in a better way.

CASE

Data Source

A senior director of supply chain at a major Japanese auto manufacturer was interviewed to collect first-hand information to identify major supply chain risks for the company. In the study, the name of the company is kept confidential. This senior director has worked with the company in the supply chain management division for more than 10 years and is qualified as a major information source on supply chain management and supply chain risk management of the company. The interview questions are listed in the Appendix. In addition, we performed internet searches for relevant information.

Findings

The director provided basic information regarding the current status of the company's supply chain, and described procedures the company has taken to reduce risks associated with the supply chain.

What the company has done to prevent risks is all with their tier-1 suppliers. First, they tried their best to decrease the single sourcing problem. The focal company has diversified its tier-1 suppliers by choosing two different suppliers for some key components so that the two suppliers could back up each other for the same key component. In addition, for different models of the same part, the company has selected different suppliers. Assuming a Part X is used by models Alpha, Beta, and Gamma, supplier A is selected to produce Part X for Model Alpha vehicle, supplier B is responsible for Model Beta, and supplier C for Model Gamma. When the company introduces a new model, Model Delta, each of the three suppliers is asked to bid for the Part X contract for the new model. This system not only enjoys economies of scale by offering the Part X contract for one model to a single supplier, but also encourages competition among Part X suppliers as well, because each supplier has pressure from peer suppliers that make the same part for different models. Moreover, if there is a quality problem or price issue with one supplier, one of the other suppliers can become a backup. Secondly, the auto maker also encourages their single source supplier to mitigate its risk. If for some reason there is only one supplier for all models of a part, the buyer company encourages the supplier to have backup lines for some key manufacturing processes. By using the self-backup system, the operational risk of a single supplier is largely decreased.

However, risks associated with tier-2 and tier-3 suppliers were not on the radar of the automaker. In addition, geographic vicinity of suppliers was not paid attention to by the manufacturer from a risk standpoint although it is generally considered from a JIT perspective. The director explained two incidents that disturbed the operations of the company's supply chain. Next we briefly describe them.

Single Sourcing. Single Sourcing refers to a method whereby a purchased part is supplied by only one supplier. For example, Motorola buys many of its high-volume handset components from multiple vendors in order to lower the risk of disruption and also to preserve economies of scale at its suppliers (Chopra and Sodhi, 2004). On the other hand, a fire in one of the Philips plants caused serious damages to Ericsson because of single sourcing (Trkman and McCormack, 2009). Yu, Zeng, and Zhao (2009) examine single sourcing and dual sourcing in the presence of supply chain disruptions. They find that depending on the magnitude of the disruption probability either single sourcing or dual sourcing might be effective, however, dual sourcing is much better when the probability of disruptions is high. Even after taking a series of procedures to reduce risks, however, the automobile manufacturer does not have a systematic way to collect

some necessary information for tier-2 and further higher-tier suppliers along the upstream of its supply chain, thus single sourcing at the tier-2 or higher-tier suppliers can hurt the company's supply chain. According to the director, one problem was due to single sourcing of tier-2 suppliers. Specifically, the Thailand flood struck a tier-3 supplier which is a sole supplier for two tier-2 suppliers making the same part, and in turn impacted the focal company although it has diversified many of its tier-1 suppliers.

Location Dispersion. A principle stated by Kleindorfer and Sadd (2005) to reduce risks is diversification. For disruption risk management, diversification should include facility locations, sourcing options, logistics, and operational modes (Kleindorfer and Sadd, 2005). The second vulnerability for the focal company's supply chain is related to the location dispersion. If located at the same or nearby region, all suppliers can be affected by the same natural disaster, such as an earthquake. Specifically, a recent major disruption for the focal company's supply chain was due to the Japanese Tsunami in March 2011. This incident exposed another weakness of its supply network in terms of supplier diversification by location.

The impact of the above two weaknesses with the supply chain of the manufacturer is huge. One occurrence of the single sourcing of a tier-3 supplier caused a significant amount of loss for the manufacturer, compared to the yearly profit of the manufacturer. The manufacturer is looking for solutions for these two sources of supply chain risks, single sourcing from lower tier suppliers and geographical vicinity. To help reducing the risks associated with the two sources, this study adopts Kleindorfer and Sadd's (2005) SAM (specifying, assessing, and mitigating) model to mitigate the risks associated with the two sources. Both of the sources are linked to either being lack of sufficient information or not performing analysis with available information. This study proposes to build a supplier information system and performance analysis system in the following section.

PROPOSED APPROACH

In the following, we present how to collect suppliers' information to build a supplier information system, and then we use examples to demonstrate how to analyze supplier networks for risks.

Information Collection

In order to further mitigate supply chain risks for the auto manufacturer, we propose to build a supplier information system by including supplier's information from multiple tiers instead of only the tier-1 suppliers. We propose the following steps to collect data:

1. The OEM creates a supplier information system which has a Web interface as a front end for user interactions and a database at the back end for data storage.
2. The OEM enters all necessary information for its tier-1 suppliers to the system. The collected information may include but is not limited to the following: location, part name, part number, criticality of the part, model number, strategic importance of the supplier, supplier's current assets, current liabilities, capability to rapidly increase production volumes. If needed, the OEM should inquire about significant unknown information from the supplier.
3. The OEM requires each of its tier-1 suppliers to provide all the necessary information for its own suppliers which are the tier-2 suppliers for the OEM.
4. Each of the tier-2 suppliers is required to provide its own suppliers (i.e., tier-3 suppliers for the OEM) information.
5. Repeat the above step as necessary to include suppliers from a higher tier if needed.
6. Each supplier is responsible for the timely update of the information it entered.

Network Construction and Analysis

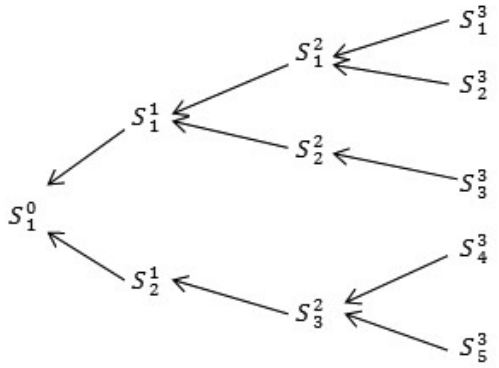
For the supplier information system, the database is truly the fundamental part since it contains all the data. On the basis of different demands, the focal company can develop application programs to extract different pieces of the data from the database, construct appropriate supplier networks, and produce output in text or graphs. Next we illustrate how to construct supplier networks, and check for the problem of a single supplier and the problem of location diversification.

1. To analyze the single sourcing problem, a supplier network is constructed such that each node represents a unique company (it does not matter if the same supplier is located in one or multiple locations). A directed link between two nodes represents a supplier and customer relationship, and the link points to the customer from the supplier. Typically in a directed network (a network where a link/edge has a direction), an in-degree of a node reflects the flow into the node. In this supplier network, the in-degree of a node represents the number of its suppliers. Thus, nodes with in-degree of one are the companies with single sourcing. Besides text output, the single sourcing problem can also be easily identified in a graph.

   Figure 1 illustrates a supplier network with a focal company, two tier-1, three tier-2, and five tier-3 suppliers, and shows the supplier and customer relationships. Notation: S_i^j denotes the ith supplier at tier j. So S_2^1 is the second supplier at tier 1, and S_2^2 is the second supplier at tier 2. We use S_1^0

to denote the focal company. In this figure, S_2^1 and S_2^2 are suppliers with single sourcing.

FIGURE 1
Supplier Network

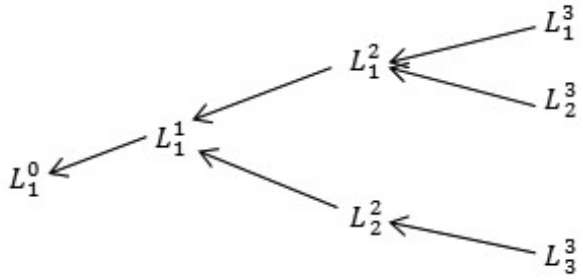


2. To analyze supplier diversification by location, first we should choose a granularity for location analysis, such as at the granularity level of a street, zip code, city, county, state, or country. Then we could reuse the same supplier network constructed before and let programs calculate for any company, how many different locations its suppliers have and generate output in text. Since in this network, each node represents a unique company not a unique location, graphically it looks unintuitive for people to examine location diversification. So we could reconstruct a network such that each node represents a location for a company at a specific tier. If two companies are at the same location (such as the same zip code) and at the same tier (such as tier 1), then there will be just one node for the two companies in the network. If two companies are at the same location (such as the same zip code) but at different tiers (such as tier 1 and tier 2), then there will be two different nodes for the two companies in the network. Note that we could use one node to represent two companies at the same location no matter if they are at the same tier or not. This change only affects the look of the graphical output but not the way we analyze the problem in this approach. A directed link between two nodes represents a supplier and customer relationship and the link points to the customer from the supplier. In this supplier network, the in-degree of a node represents the number of different locations for suppliers, not the number of suppliers.

   Figure 2 illustrates such a location-based supplier network in which all tier-1 suppliers are in one location (such as the same state), tier-2 suppliers are in two different locations, and all tier-3 suppliers are in three locations.

Notation: L_i^j denotes the location for the i[th] supplier at tier-j. In this figure, L_2^2suffers the problem of location diversification for suppliers.

FIGURE 2
Location-Based Supplier Network



The information and the analysis models proposed above provide a foundation for supply chain risks associated with a supply network including different tiers of suppliers. The location information is specifically important when it is linked to natural disaster information of each location. This can provide more information on the level of natural disaster risks associated with one manufacturer's supply network.

CONCLUSIONS

We interviewed a senior supply chain director of a major Japanese automotive manufacturer to understand the company's supply chain management and to identify its weaknesses. We also conducted an Internet search to collect information about supply chain risks caused by natural disasters. Two major factors for the supply chain risks were identified: location diversification and single sourcing. We present an approach to build a supplier information system which is based on necessary information collected across multi-tier suppliers. On the basis of information from both suppliers and external sources, such as geographic and weather data, we constructed various supplier networks, and analyzed different risks associated with the suppliers in the supply chain. Our supplier network can be based on suppliers for a critical part, a component, an assembly, or a complete product. The risk analysis can be for a single risk factor, such as earthquake, or for multiple factors by applying the portfolio theory. This study adopts the SAM (i.e., specifying, assessing, and mitigating) model to systematically analyze the supply chain disruption risk under natural disasters (Kleindorfer and Sadd, 2005). Our proposed approach is aligned with the Information Management approach according to Tang (2006). Our work helps managers to realize negative impacts of natural disasters on their supply chain and suggests actions for mitigating risks.

LIMITATIONS AND FUTURE RESEARCH

The limitations of this study include the limited information from a single case in one industry. The conclusions from a single case may have concerns with generalizability of this study. However, during this study, we have also searched related information and found that similar cases happened with other manufacturers in the same industry. The interview conducted by us allows us to get in-depth understanding of the risks from a manufacturer's standpoint.

Our future studies will focus on collecting more information about the supply chain risk caused by different types of sources with several different industries in different countries. Another research direction is to link natural disaster database with the supplier database proposed by this study and to conduct further quantitative analysis.

REFERENCES

Accenture. 2014. http://www.accenture.com accessed March 16, 2014.

Cagliano, A.C., De Marco, A., Grimaldi, S., and Rafele, C. 2012. An Integrated Approach to Supply Chain Risk Analysis. *Journal of Risk Research* (15:7), 817-840.

Chen, J., Sohal, A.S., and Prajogo, D.I. 2013. Supply Chain Operational Risk Mitigation: A Collaborative Approach. *International Journal of Production Research* (51:7), 2186-2199.

Chopra S., and Sodhi, M.S. 2004. Managing Risk to Avoid Supply-Chain Breakdown. MIT Sloan Management Review (46:1), 53-61.

Diabat, A., Govindan, K., and Panicker, V. V. 2012. Supply chain risk management and its mitigation in a food industry. *International Journal of Production Research* (50:11), 3039-3050.

Fortune. 2011. http://tech.fortune.cnn.com/2011/12/12/supply-chain-distasters-disruptions/

Giannakis, M., and Louis, M. 2011. A Multi-Agent Based Framework for Supply Chain Risk Management. *Journal of Purchasing and Supply Management* (17), 23-31.

Goswami, S., Engel, T., and Krcmar, H. 2013. A Comparative Analysis of Information Visibility in Two Supply Chain Management Information Systems. *Journal of Enterprise Information Management* (26:3), 276-294.

Kleindorfer P.R., and Saad G.H. 2005. Managing Disruption Risks in Supply Chains. Production and Operations Management (14:1), 53–68.

Lavastre, O., Gunasekaran, A., and Spalanzani, A. (2012). Supply Chain Risk Management in French Companies. Decision Support Systems (52), 828-838.

Manuj, I., Esper, T.L., and Stank, T.P. 2014. Supply Chain Risk Management Approaches under Different Conditions of Risk. *Journal of Business Logistics* (35:3), 1-42.

March, J.G., and Shapira, Z. (1987). Managerial Perspectives on Risk and Risk Taking. Management Science (33:11), 1404-1418.

Rodger, J.A. 2014. Application of a Fuzzy Feasibility Bayesian Probabilistic Estimation of Supply Chain Backorder Aging, Unfilled Backorders, and Customer Wait Time Using Stochastic Simulation With Markov Blankets. Expert Systems with Applications (41:16), 7005-7022.

Rodger, J., Pankaj P., and Gonzalez, S.P. 2014, Decision Making Using a Fuzzy Induced Linguistic Ordered Weighted Averaging Approach for Evaluating Risk in a Supply Chain. *International Journal Advanced Manufacturing Technology* (70:1), 711–723.

Talluri, S., Kull, T.J., Yildiz, H., and Yoon, J. 2013. Assessing the Efficiency of Risk Mitigation Strategies in Supply Chains. *Journal of Business Logistics* (34), 253-269.

Tang, C. S. 2006. Perspectives in Supply Chain Risk Management. *International Journal of Production Economics* (103), 451-488.

Thun, J.H., Druke, M., and Hoenig, D. 2011. Managing Uncertainty - an Empirical Analysis of Supply Chain Risk Management in Small and Medium-sized Enterprises. *International Journal of Production Research* (49:18), 5511-5525.

Trkman, P., and McCormack, K. 2009. Supply Chain Risk in Turbulent Environments: A Conceptual Model for Managing Supply Chain Network Risk. *International Journal of Production Economics* (119), 247-258.

Vanany, I., Zailani, S., and Pujawan, N. (2009). Supply chain risk management: literature review and future research. *International Journal of Information Systems and Supply Chain Management* (2:1), 16-33.

Yu, H., Zeng, A.Z., and Zhao, L. 2009. Single or Dual Sourcing: Decision-Making in the Presence of Supply Chain Disruption Risks. Omega (37), 788-800.

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APPENDIX: INTERVIEW QUSTIONS

1. Would you please describe the current supply chain structure of your company?
2. What is your view on supply chain risk?
3. What have your company done to mitigate supply chain risk?
4. What are some important parts which are missing in terms of supply chain risk?
5. Could you please describe those missing parts with examples?