Competitive Risks and Information Sharing Scheme Impacts on Supply Chain Performance using System Dynamics

WANG CAOXU

(B.Eng., Nanjing University)

A THESIS SUBMITTED

FOR THE DEGREE OF MASTER OF ENGINEERING

DEPARTMENT OF INDUSTRIAL & SYSTEMS ENGINEERING

NATIONAL UNIVERSITY OF SINGAPORE

2014

DECLARATION

I hereby declare that this thesis is my original work and it has been written by me in its entirely. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

Wang Caoxu

22 November 2014

ACKNOWLEDGEMENTS

The 2-year master study in National University of Singapore is an unforgettable journey for me. During this period, I have been fully trained as a research student, learned lots of academic knowledge and also met lots of friends. At the end of my master study, I would like give my regards to all the people that cared about me and supported me.

First I would like to express my profound gratitude to my supervisor Assistant Prof. Chen Nan and Assoc. Prof. Lee Loo Hay for their guidance, assistance and support during my whole master candidature. Not only they guided me all the way through my academic study, but also taught me lots of things that benefit my entire life.

Besides, I would like to thank National University of Singapore for providing well-constructing facility and Department of Industrial and Systems Engineering for its nice and helpful staff. I would like to thank all the faculty members and staff at the Department for their support. My thanks extend to all my friends Peng Rui, Deng Peipei, Ren Xiangyao, Chao Ankuo, Tang Mucheng, Zhong Tengyue, Jiang Jun and Tao Yi for their help.
Last but not least, I present my full regards to my parents, Cao Fayi and Wang, Liangfang, and my girlfriend, Miranda Li, for their love, support and encouragement in this endeavour.

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SUMMARY

In the context of this study, we are looking at competitive risk which is interacted and derived from its competitor's advantage. From there, we will investigate and validate how information sharing scheme could affect supply chain performance by simulating different interruption scenarios using system dynamics model. At the fast pacing and changing environment, a lot of factors will affect supply-manufacturing relationship. Standing at manufacturer side, it needs cope with downstream customer demand by providing first class product in terms of quality and cost. It also has to maintain its suppliers effectively in order to reduce its total product cost and increase its service level to its customer. In a globalized business environment, supply chain is becoming more and more complex. How to mitigate the risk of supply chain? How to develop a strategy to manage its suppliers? How to understand customer requirement to better position itself in a competitive business environment? All those questions are kept coming into business and research industry as a relentless topics for us to explore.

In this research paper, we have identified 3 different levels of risks that are risks at supply chain level, industry level and macro level. Furthermore, a qualitative approach was introduced to understand competitive risk and a system dynamics modeling based method to study information sharing scheme impacts on supply chain performance was established.

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CHAPTER I INTRODUCTION

The vulnerability of global supply chain has definitely driven more attention since the terrorist attacks on the World Trade Centers in 2001, even though managing potential risks and setting up more flexible networks have always been a critical topic within supply chain management area. The severe Bangkok flood and Japan tsunami in 2011 have a widely and largely impact on global supply chain performance across different industries like hardware production, automobile, aerospace and logistics etc. Risks encountered by global supply chain are quite diversified and hardly well predicted and managed. All those hassles on supply chain overall performance contain production disruptions, delivery delays, information and networking fluctuation, forecasting variance, intellectual property vulnerability, procurement difficulties, customers dissatisfaction, inventory level increment, and capacity constraints. (Chopra & Sodhi, 2004) Supply chain disruptions or temporary termination due to some unexpected risks are costly and may trigger different results which are hardly control. That's why we need to understand what kind of risks may happen and what impacts can be expected on global supply chain performance. Meanwhile, what risk management tools and techniques can be used to analyze these risks and developed to mitigate risks. Strategically, this study will potentially study what competitive advantages can help achieve overall better supply chain performance and mitigate supply chain disruption impact. Also, to what level and scenario that implementing information sharing scheme with their suppliers can help optimize supply chain performance.

1.1 Background

1.1.1 Supply Chain Management

Supply chain management (SCM) is the management of an interconnected or interlinked between network, channel and node businesses involved in the provision of product and service packages required by the end customers in supply chain. (Harland, 1996) Supply chain management spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point of point of construction. At the same time, there is another definition provided by APICS dictionary when it defines SCM as the “design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand and measuring performance globally.”

1.1.2 Supply Chain Risk Management

Supply chain risk management (SCRM) is the implementation of strategies to manage both every day and exceptional risks along the supply chain based on continuous risk assessment with the objective of reducing vulnerability and ensuring continuity. (Wieland & Wallenburg, 2012) SCRM attempts to reduce supply chain vulnerability via a coordinated holistic approach, involving all supply chain stakeholders, which identifies and analyses the risk of failure points or disruption events within supply chain networks. Mitigation strategies to manage these risks can involve logistics, planning, finance, human resources and risk management disciplines. The ultimate goal being to ensure supply chain continuity in the event of scenario which otherwise have interrupted normal business and thereby profitability.

1.1.3 Supply Chain Performance Measurement and Metrics

SCM has been a major component of competitive strategy to enhance organizational productivity and profitability. Performance measurement and metrics have an important role to play in setting objectives, evaluating performance, and determining future courses of actions. (Gunasekaran, Patel, & McGaughey, 2004) Learn performance measurement or metrics for global supply chain performance improvements should always be concerned by companies with their fierce competition. Today’s marketplace is shifting from individual company performance to supply chain performance: the entire chain’s ability to meet end-customer needs through product availability and responsive, on-time delivery. The ability to fill customer orders faster and more efficiently than the competition has been agreed as the ultimate supply chain goal for company’s operation and business running. To achieve that, performance measurement or metrics should be proposed, designed and monitored in an appropriate way for global supply chain performance improvements. Generally speaking, supply chain measurement and metrics must show not only how well you are providing for your customers (service metrics) but also how you are handling your businesses (speed, asset, inventory and financial indicators).

1.2 Motivation of the Study

Risk management techniques are prevalent in financial field for quite a long time. Risks with respect to supply chain have been collecting attention from the researchers recently as industries have faced several supply chain disruptions due to different unforeseen events. The affected companies reported, on average, 14% increase in inventory, 11% increase in cost and 7% decrease in sales during the year following the disruption. (Hendricks & Singhal, 2005) Various events in the business environment may cause serious effects to product availability and service delivery. In the operational scope, a manufacturing facility may be damaged by an accidental fire or flood, the transportation system may be disrupted due to union strike or typhoon, and spare parts may run out of stock for supplier's sudden insolvency. In the economic scope, the decline in demand may happen due to some disruptive innovation, the supplier may go to bankruptcy during financial crisis, and additional trade barriers may imposed by some states in conflict. In the natural scope, natural disasters such as flood, storm, earthquake, and tsunami etc. may totally overwhelm an industrial sector. The huge impact of supply chain disruption has been discussed and emphasized not only in industrial debate but also in academic research. However, there is no clear or well-constructed research based on how information sharing within supply chain could help achieve better performance and protect against unexpected disruptions.

When a disruptive event comes to reality, not only a single business entity suffers from the loss, but the whole supply chain or the whole industrial network may also be seriously affected. For this reason, inter-organizational cooperation in mitigating risks is very critical to minimize the impact of these catastrophic events and to allow for continuity in their businesses. Furthermore, due to global sourcing, the adoption of lean supply chain, and the complex supply chain networks, almost all the business entities in the world are dependent on other supply chain partners. Once a catastrophic event happens, the shock wave more or less will cause impacts to all the business entities around the world. Normally, a company should have its own contingent plan in response to these risky events and a business will attempt to control the damage and restore its capacity according its private internal information and available public information.

This paper aims to study a multi-echelon supply chain, where there are multiple players in one echelon and are susceptible to risks on the supply side. It will investigate the possibility of sharing information across supply chain players in order to mitigate such risks and reduce the effect of them on the customer satisfaction, and costs that are incurred during the time of disruption. At the same time, a survey based research was conducted with 10 companies' supply chain designer or supply chain project manager to understand about what they believe are most critical to their business success when supply chain is disrupted and here in this paper we summarized such critical success factors are competitive advantages.

1.3 Objectives and Scopes

Due to the aforementioned inadequacies of the existing literature in supply chain risk identification and impact research and serious results occurred after a disruptive event happens in supply chain networks, we believe there is a need to conduct our research. This thesis intends to achieve the following specific objectives:

(1) To conduct a preliminary study on supply chain risk identification and categorization in there different levels which are supply chain level, industry level and macro level, and help the organizations or companies have a better framework or tools to redefine their respect potential supply chain risks and implement relevant mitigation strategies so as to achieve their overall competitive and supply chain strategy.

(2) To develop a mathematical model using system dynamics to tackle the 4-echelon supply chain networks, in other words, to simulate and compare the continuous performance of supply chain with and without embedding competitive risks after a disruptive event happens in one of the upstream common raw material suppliers.

(3) To analyze the impact of competitive risk in a 2-echelon supply chain network to aid the decision making process and supply chain risks mitigating strategy development.

It should be noted that, the mathematical model developed in this thesis to address the impact of competitive risk on a 2-echelon supply chain networks which includes two raw material suppliers, two manufacturers (focal part of competitive risk's impact), two warehouses and end-customers. Besides, in our study, we only focus on when one of the suppliers shut down their operation facility, what kind of impacts will incurred to both of the manufacturers based on their market share, sales date and total revenue. Different marketplace of each manufacturer may result different cost when they try to shift to another raw material supplier and that is the competitive risk which is going to affect each entities' risk mitigation strategy.

CHAPTER II LITERATURE REVIEW

Risk is the potential that chosen action or activity will lead to a loss or undesired outcome. (Hansson & Sven, 2007) Furthermore, it is a probability or threat of damage, injury, liability, loss or any other negative occurrence that is caused by external internal vulnerabilities. (Holton & Glyn, 2004) From all those definitions, we can see that risk has a key impact on designated actions or operations especially when it occurred without fully preparation and reaction towards it. (Proske, 2008)

Hence, we will do literature review on supply chain risk identification, supply chain risks impacts evaluation techniques, competitive risks and information sharing within supply chain.

2.1 Supply Chain Risk Identification

Risk identification is the first step in managing disruptions in supply chains. The purpose of risk identification is to identify all knowable disruptions. This step is especially important because a supply chain disruption can be well managed only under condition that it is first identified. (Chopra & Sodhi, 2004) categorized nine types of Supply Chain Risks and their drivers in order to develop risk mitigation strategies. (Chopra & Sodhi, 2004)

Category of Risk	Drivers of Risk
Disruptions	1. Natural disaster 2. Labor dispute 3. Supplier bankruptcy 4. War and terrorism 5. Dependency on a single source of supply as well as the capacity and responsiveness of alternative suppliers
Delays	1. High capacity utilization at supply source 2. Inflexibility of supply source 3. Poor quality or yield at supply source 4. Excessive handling due to broader crossing or to change in

	transportation model
Systems	1. Information infrastructure breakdown 2. System integration or extensive systems networking 3. E-commerce
Forecast	1. Inaccurate forecasts due to long lead times, seasonality, product variety, short life-cycles, small customer base 2. Bullwhip effect or information distortion due to sales promotions, incentives, lack of supply chain visibility and exaggeration of demand in times of product shortage
Intellectual Property	1. Vertical integration of supply chain 2. Global outsourcing and markets
Procurement	1. Exchange rate risk 2. Percentage of a key component or raw material procured from a single source 3. Industry wide capacity utilization 4. Long-term versus short-term contracts
Receivables	1. Number of customers 2. Financial strength of customers

Inventory	1. Rate of product obsolescence 2. Inventory holding cost 3. Product value 4. Demand and supply uncertainty
Capacity	1. Cost of capacity 2. Capacity flexibility

Table 1 – Category and drivers of risk

At the same time, Kleindorfer and Saad propose another concept which divide supply chain risk into two broad categories: (1) risks arising from the problems of coordinating supply and demand, and (2) risks arising from disruptions to normal activities. (Kleindorfer & Saad, 2005) The literature on supply chain risk management has discussed two important issues on risk identification. Firstly, different risk identification techniques have been discussed and secondly, different risk classification schemes are presented to support a more structured risk identification process.

2.1.1 Risk Identification Techniques

To facilitate the risk identification, a wide range of techniques are presented in literature. Some of common methods are presented in table 2.

Risk Identification Method		Reference
Generic Approaches	Expert view -Brainstorming	Norrman & Jansson (2004)
	Expert view - Survey	Thun & Hoening (2009), Yang (2010)
	Literature review	Wu et al. (2006), Canbolat et al. (2008), Yang (2010)
	Action Research and AHP	Schoenherr et al. (2008)
Speficific Approaches	Ishikawa Diagrams	Wiendahl et al. (2008)

	HAZard and Operability (HAZOP)	Adhitya et al. (2009)

Table 2 – Risk identification method

One of the most frequently used approaches for risk identification in the supply chains is expert view which can be in different forms like survey (Thun & Hoenig, 2009) or brainstorming (Norrman & Jansson, 2004). Historical data for past events and the review of literature or reports of similar companies can support experts in a better-informed risk identification process. It is also recommended to involve a cross-functional team of employees and diverse group of experts in the process. (Hallikas et al., 2004; Norrman & Jansson, 2004) This is beneficial both for the variety of perspectives such a group can provide and to build the commitment to risk management process in the whole company. Among more systematic methods, Schoenherr et al. (2008) used Analytical Hierarchy Process (AHP) to identify the risk factors related to the offshoring decision in a US manufacturing company. For this purpose, they have identified three sourcing characteristics related to the product, the partner and the environment as main decision objectives. Next, they subdivided the main objectives into sub-objectives and finally to 17 risk factors. Adhitya et al. (2009) discussed the application of HAZard and Operability (HAZOP) method to supply chain risk identification. The HAZOP method is one of the most widely-used techniques for hazard identification in the process plants. Based on the similarities between supply chains and the chemical plants, Adhitya et al. (2009) suggested adapting the methods and concepts from chemical process risk management to supply chains. Similar to HAZOP study for a process plant that is performed around process flow diagram (PFDs), they defined a supply chain flow diagram (SCFD) and work-flow diagram (WFD) to represent the supply chain structure and the sequence of tasks. Subsequently, the risk identification can be performed by systematically generating deviations in different supply chain parameters and identifying their possible causes, consequences, safeguards, and mitigating actions. For example, “High” or “Low” can be combined with a flow “Demand” to indicate the deviation “High Demand” or

"Low Demand" respectively and its possible causes and consequences can be identified by tracing the flows in the diagram.

The other method mentioned in the literature is Ishikawa Diagram which is used by Wiendahl et al. (2008) to identify the logistic risks for a case study of a forging company. They started with an objective and the possible negative consequences like low output rate etc. A list of possible events that may lead to each adverse effect in five main actuating variables-material, machine, method, human and environment is also presented and developed.

Although a wide spectrum of methods is available for companies to identify risks, the choice of the risk identification method is different for different cases. Some factors which may influence the chosen method are the time availability, experience and the complexity of supply chain. In general, the basic expert-based methods for risk identification (like brainstorming or survey) are fast; however, they need a level of expertise which might not be available inside the company. Of course, a company may ask external experts and consultants to perform the risk identification which itself is a costly and more time-consuming process. More systematic risk and discipline approaches can facilitate a more comprehensive risk identification process. Moreover, as in most cases the outputs of these methods are repeatable; the results of risk identification process can be easily evaluated and also extended in future.

2.1.2 Risk Classification Schemes

To support a systematic and comprehensive risk identification process, several classification schemes are presented in the table 3. Categorizing risks not only improve the effectiveness and quality of the risk identification but also supports better communication among actors involved in the process. (Stecke & Kumar, 2009)

Risk Classification	Reference

Location-based classification	Internal/External	Christopher & Peck (2004), Wu et al. (2006),Cucchiella & Gastaldi (2006), Bogataj & Bogataj(2007), Oehmen et al. (2009), Thun and Hoenig(2009), Trkman & McCormack (2009), Kumar et al.(2010), Dani & Deep (2010), Olson & Wu (2010)
	Supply chain view	Wagner & Bode (2006), Sodhi & Lee (2007), Tangand Tomlin (2008), Oke & Gopalakrishnan (2009),Tomlin (2009)
Scale-based clssification		Kleindorfer & Saad (2005), Gaonkar &Viswanadham (2007), Lodree & Taskin (2008), Okeand Gopalakrishnan (2009), Knemeyer et al. (2009),Huang et al. (2009), Ravindran et al. (2010)
Other classification		Cavinato (2004), Chopra & Sodhi (2004), Peck(2005), Sheffi (2005), Tang (2006b), Cheng & Kam(2008), Blos et al. (2009), Matook et al. (2009), Tangand Musa (2010)

Table 3 – Risk classification

For location-based classification scheme, supply chain risks are classified based on where the source of disruption is located. Christopher & Peck (2004) considered three categories of risk sources which are further sub-divided to five categories: risk sources "Internal to the firm" which are subcategorized into "process risks" and "control risks"; risk sources which are "external to the firm but internal to the supply chain network" and include "demand" and "supply" risks; and, finally, risk sources "external to the network" or "environment risks" which are exemplified by natural disasters, terrorist attacks and regulatory changes. The term "Interaction Risks" is also used for the last group as they arise due to the interaction between a supply chain and its environment. (Kumar et al. 2010) Similarly, Thun & Hoenig (2009) made a distinction between "internal company risk" and "cross-company based risks". The cross-company based risks are further divided into purchasing risk (upstream risk) and demand risk (downstream risk). The external supply chain risks are also subcategorized into sociopolitical, economical, technological, or geographical disruptions. This classification is especially useful as internal risks are generally within the boundary of the system, company or supply chain, and the actors have more control on the cause of disruption. (Trkman & McCormack 2009) External risks, however, are more difficult and sometimes even uncontrollable. (Wu er al. 2006)

For scale-based classification scheme, supply chain disruptions can be generally classified into:

- Low-likelihood, High-impact disruptions: the disruptions with very low probability of occurrence but significantly consequences if they occur.
- High-likelihood, Low-impact disruptions: the events that might happen more frequently with less damage to the supply chain operation.

The first class is termed Value-at-Risk (VaR) type disruptions by Ravindran et al. (2010). It is also called catastrophes or catastrophic events. (Lodree & Taskin, 2008; Knemeyer et al., 2009; Huang et al., 2009) The second class is frequently called the operational disruptions or day-to-day disruptions. (Kleindorfer & Saad, 2005; Huang et al., 2009) Miss-the-Target (MtT) is another term suggested by Ravindran et al. (2010).

For the other risk classification scheme, there are several approaches have been discussed. The multi-level classification of Peck (2005) has driven lots of attention. In his conceptual framework, the sources for supply chain risks are presented in four main levels of value stream or product/process, assets and infrastructure dependencies, organizations and inter-organizational networks and environment. With a similar idea, Cavinato (2004) discussed that identifying risks and uncertainties in supply chains must focus on five sub-networks in every supply chain: physical, financial, informational, relational and innovational networks.

In addition to categorization approaches discussed here, a lot of works in the literature discuss only particular risks or tied with some certain conditions. A more general and through way of identifying potential supply chain risks should be raised to a higher level of attention.

2.2 Supply Chain Risk Impacts Evaluation Techniques

Supply chain risks impacts evaluation is the process for evaluating the disruptions that have been identified and developing the basis for making decision on the relative importance of each disruption. (Zsidisin, Ellram, Carter, & Cavinato, 2004) The risk level of disruptions is mostly quantified in two dimensions: the likelihood or frequency of the disruptions occurrence and the impacts of disruption on the performance of supply chain.

2.2.1 Likelihood Estimation Approach

Appropriate methods to estimate the probability of supply chain disruptions have received little attention from research so far and they are mostly neglected in the literature. Some approaches for probability estimation of catastrophic events are discussed in Knemeyer's (2009) work. For some type of disruptions, such as aircraft accidents, the historical data is available for estimation of similar events occurrence probability. For cases the historical data is limited or unknown as the only source of estimation, combining the available data with expert estimates (like Delphi Method) can give the insight on disruption likelihood. Simulation is the other approach might be used when the factors that might cause a disruption is very-well known. As an example, Knemeyer et al. (2009) discussed a hurricane simulator which uses input like central pressure, maximum wind radius, etc. from government and private sources to generate probability distributions for the number, intensity and location of hurricane activity in a given year. In another effort for disruption likelihood estimation, Mohtadi and Murshid (2009) developed a dataset of terrorist attacks that have involved chemical and biological. Based on these data, they estimated the likelihood of such a catastrophic event using extreme value theory.

2.2.2 Impacts Estimation Approach

Systematic methods for assessing the disruption impact have gained more attention in the supply chain risk management literature. A summary of relevant methods and reference is shown in the following table:

Risk Impacts Evaluation		Reference
Qualitative/Semi-qualitative	AHP	Wu et al. (2006), Gaudenzi & Borghesi (2006),Levary (2007), Levary (2008), Schoenherr et al.(2008), Enyinda et al. (2010), Kull & Talluri(2008)
	Expert group rating	Norrman & Jansson (2004), Blackhurst et al.(2008), Matook et al. (2009)
	Expert opinion	Thun & Hoenig (2009), Yang (2010)
	Failure mode and effect analysis (FMEA)	Sinha et al. (2004), Pujawan & Geraldin (2009)
Quantative (modeling and simulation)	Petri net	Wu et al. (2007), Tuncel & Alpan (2010)
	System Dynamics	Wilson (2007)
	Discrete event simulation	Munoz & Clements (2008)
	Markov chain modeling	Ross et al. (2008)
	Inoperability input-output modeling (IMM)	Wei et al. (2010)

Table 4 – Risk impacts evaluation

2.3 System Dynamics Modeling

System dynamics (SD) is a methodology and mathematical modeling technique for framing, understanding and discussing complex issues and problems over time. It deals with causal loops and delays that affect the behavior of the entire system. (Forrester, 1995) SD was created during the mid-1950s by Professor Jay Forrester (1995). After decades of development, SD is widely applied to solve corporate and non-corporate problems. With the help of computer simulations, SD is found very effective in policy design and organization framework building compared to the conventional methodologies. (Radzicki & Taylor, 1997)

2.3.1 Feedback Thinking and Casual-Loop Thinking

Feedback concept is at the heart of the system dynamics approach. Diagrams of loops of information feedback and circular causality are tools for conceptualizing the structure of a complex system. There are two types of feedback loop: (Forrester, 1995)

(1) Reinforcing feedback loop

(2) Negative or balancing feedback loop

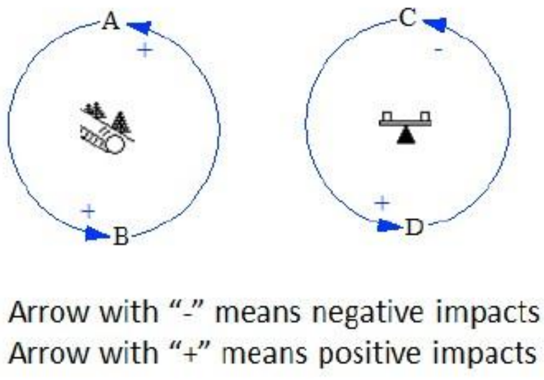

Figure 1 - Reinforcing Loop and Balancing Loop

Based on the two basic feedback loops and delay, some typical dynamic causal loop structures are developed, such as goal-seeking structure and oscillation structure. (Forrester, 1995) These dynamics structures can help us better understand the complex system.

2.3.2 System Dynamics and its Application in Supply Chain Management

The primary modeling and analysis tool used in this research is system dynamics (SD) methodology. Forrester J. (1971) introduced SD in the early 60's as a modeling and simulation methodology for long-term decision making in dynamic industrial management problems. Since then, SD has been applied to various business policy and strategy problems. There are already few publications using SD in supply chain modeling. Forrester J. (1971) introduces a model of supply chain as one of his early examples of the SD methodology. Leckcivilize, A. (2012) uses SD in supply chain redesign to provide added insights into SD behavior and particularly into its underlying casual relationships. The outputs of proposed model in his work are industrial dynamics model of supply chains. Minegishi and Thiel (2005) take SD as an effective method to improve the understanding of the complex logistic behavior of an integrated food industry. They present a generic model and then provide practical simulation results applied to the field of poultry production and processing. Sanghwa and Maday (2005) investigate effective information control of a production-distribution system by automatic feedback control techniques. Sterman (2005) presents tow case studies where SD is used to model reverse logistic problems. In the first one, Zamudio-Ramirez (2003) analyzes part recovery and material recycling in the US auto industry to provide insights about the future of enhanced auto recycling. In the second one, Taylor (2006) concentrates on the market mechanisms of paper recycling, which usually lead to instability and inefficiency in flows, prices, etc. Georgiadis and Vlachos (2007) use SD methodology to estimate stocks and flows in a reverse supply chain, while providing specific paradigms with a fixed remanufacturing capacity change per year.

The SD methodology, which is adopted in this research, is a modeling and simulation technique specifically designed for long-term, chronic, dynamic management problems. (Vlachos, D., Georgiadis, P., & Iakovou, E. 2007) It focuses on understanding how the physical processes, information flows and managerial policies interact so as to create the dynamics of the variables of interest. The totality of the relationships between these components defines the structure of the system. Hence, it is said that the structure of the system, operating over time, generates its “dynamic behavior patterns”. It is most crucial in SD that the model structure provides a valid description of the real processes. The typical purpose of a SD study is to understand how and why the dynamics of concern are generated and then search for policies to further improve the system performance.

CHAPTER III SUPPLY CHAIN RISK IDENTIFICATION AND CATEGORIZATION

Risk identification is the first step to manage the abnormal situations or potential damages in supply chains. Nowadays, supply chains have become more and more complex in terms of manufacturing and trading globalization.

3.1 Supply Chain Risk'

As mentioned, today's supply chain is always complex and their risks are generally identified according to the origins and mitigation strategies are then developed targeting on those particular risks. However, further risks can be generated from the reactions of a supply chain entity. Thus a framework can help identify this type of risk should be proposed. In figure 2, supply chain risks are categorized at three levels according to their scopes: supply chain, cross supply chain/industry, and macro level.

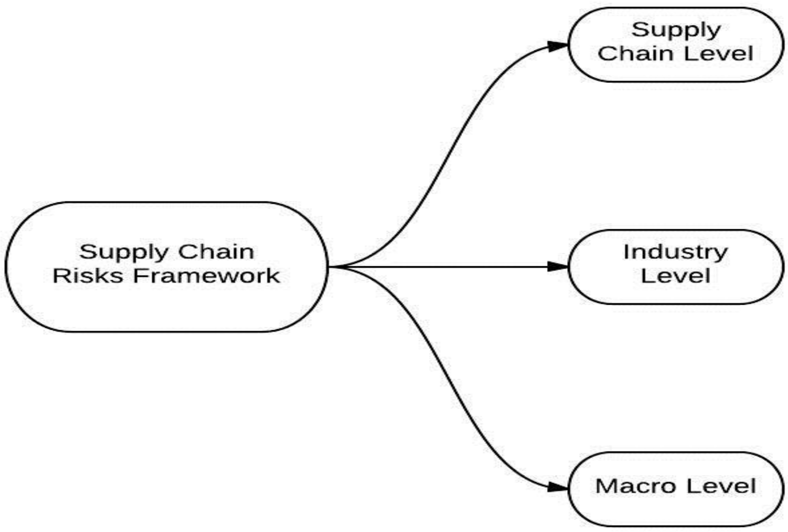

Figure 2 – Supply chain risks framework

3.2 Risks at Supply Chain Level

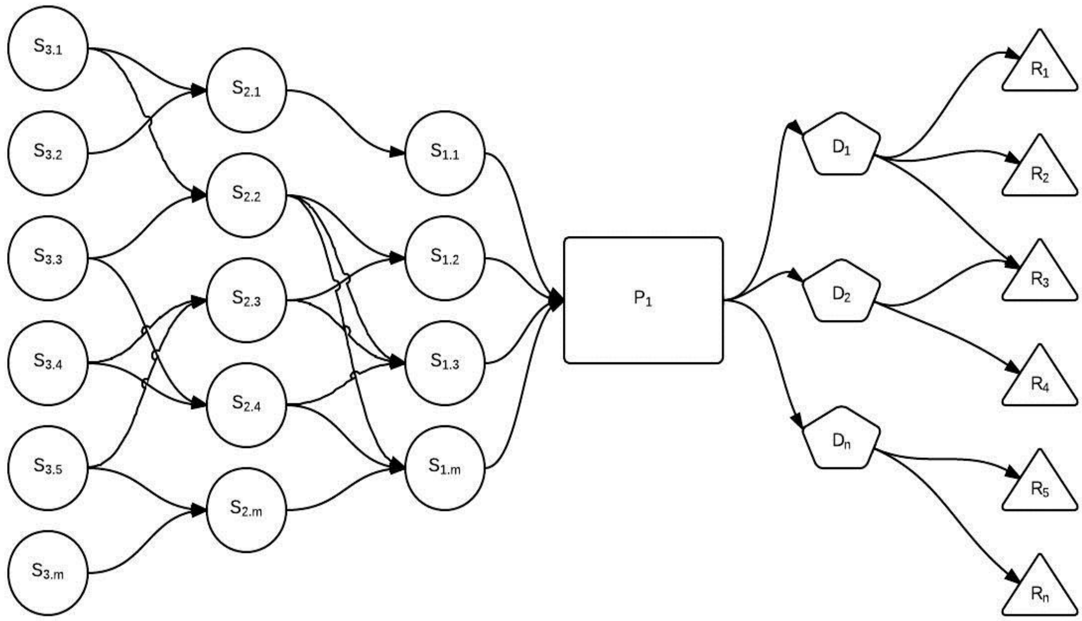

Figure 3 – Multiple echelons supply chain

The risks in a supply chain level refer to the risks occurring in the supply chain of a focal company. All risks are identified from this company's point of view. For example, figure 3 shows the generic supply chain networks with one focal company , which has three tiers of suppliers, one tier of distributors and one tier of suppliers. The possible risks of can be further decomposed into three categories: sourcing side, internal process and demand side risks in below figure 4.

Figure 4 – Supply chain level

On the sourcing side, the focal company can face risks such as delivery delays, proximity risk, tier risk, performance risks, interest rate fluctuations, exchange rate changes, and so on. We clarify some of these notes below.

- Delay in material flows is normally the result of the inability of a supplier to respond to changes in downstream demand. But it could also be caused by the unsatisfactory quality of supply of the delay in transportation.

- Proximity risk refers to the risk from geographic distance of a focal company's suppliers, which may be located within the same disaster zone. In the case of a disaster, those suppliers may fail to provide materials at the same time and thus causing supply shortage to the focal company.

- Tier risk refers to the risk brought out not by the focal company's first tier partners (e.g. S1.1, S1.2) but by its tier 2 or higher level partners (e.g. S2.1, S3.1) due to single sourcing or proximity risks. For example, the Japan Triple Disaster in 2011 put Apple at risk through its tier-4 supplier, Electrotechno (Mitsubishi Gas Chemical Sub), which provided BT resin to Apple's tier 3 suppliers but was hit by the disaster at Fukushima. At the time just before the disaster, Electrotechno in Fukushima produced about 50% of global BT resin supply.
- Relationship risk is explained in following section.
- Interest rate fluctuations and exchange rate changes refer to how changes in the global financial environment can affect business operation performance. This was particularly relevant during the recent intensive financial crisis.

In the internal process, risks can be in the form of forecast inaccuracy, inventory, capacity, information system, intellectual property, labor-employer relationship, etc.

- Forecast risk, such as the bullwhip effect, results from a mismatch between a company's projections and actual demand. Inaccurate forecasts may occur due to long lead times, seasonality, product variety, short life cycles, and small customer base. Bullwhip effect or information distortion due to sales promotions, incentives, lack of supply chain visibility and exaggeration of demand in times of product shortages also constitute forecast risks.
- Inventory risks can be driven by the rate of product obsolescence, inventory holding cost, product value, demand and supply uncertainty, etc.
- Information system risk can be driven by the information infrastructure breakdown or improper integration among the internal or external systems. The failure of an information system can have severe consequences like interrupted production and delayed order fulfillment. Information system is especially important for E-commerce companies.
- Intellectual property breach can be from the vertical integration of the supply chain or global outsourcing and market. (Chopra, S., & Sodhi, M. S. 2004)
- Labor relationship risk in the form of labor disputes or strikes can bring a company great losses such as low productivity and limited production capacity.

On the demand side, a focal company typically encounters risks of receivables and demand uncertainty.

- Receivable risk is related to number of customers and their financial strength.
- Demand uncertainty can be caused by life cycles of high-technology products, or higher levels of competitive activity, such as sales incentives and promotions. These sorts of risks can occur due to shortage of materials, loss of access to supplier, an inaccurate prediction of demand, and logistics or information technology failures.

3.3 Risks at Industry Level

Risks at an industry level refer to the risks occurring in the common resources shared by supply chains of different focal companies in the same industry. For example, figure 5 and 6 show that two competitive companies share some common resources in their supply chains, e.g. S1.2, S1.3, S1.m, D1 and D2. For each company, it not only has its own supply chain level risks described in the previous section, but also industry level risks categorized in figure 7, e.g. sourcing, demand pattern, trading pattern, technology change, and political/regulation changes.

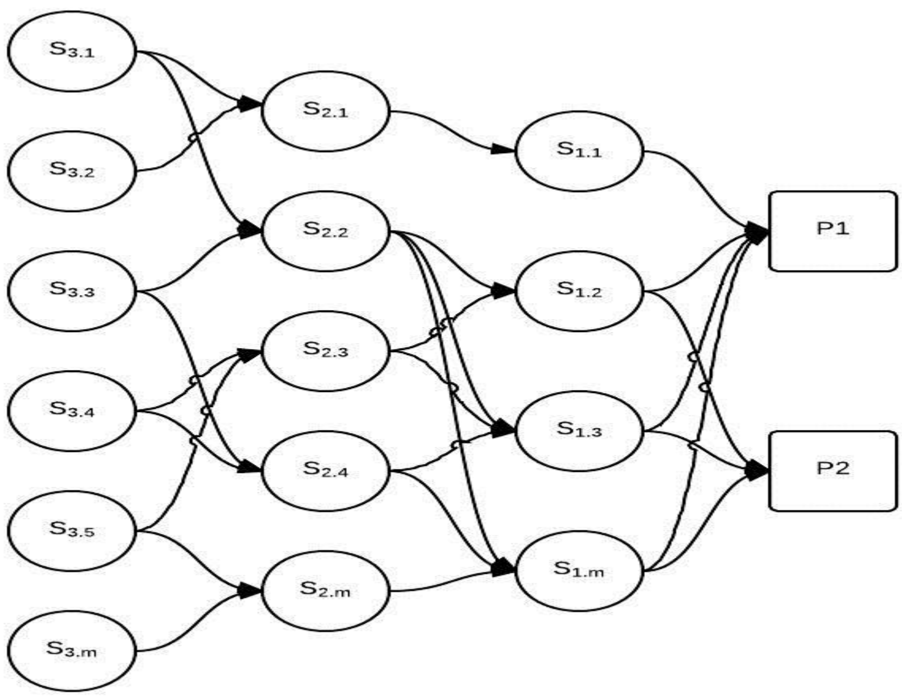

Figure 5 - Supply chains with two focal companies (upstream part)

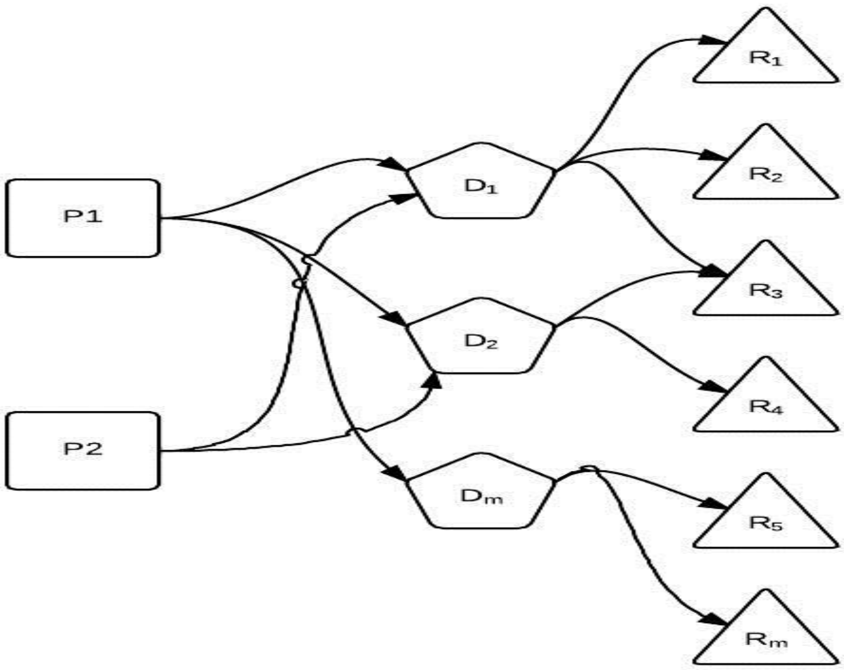

Figure 6 - Supply chains with two focal companies (downstream part)

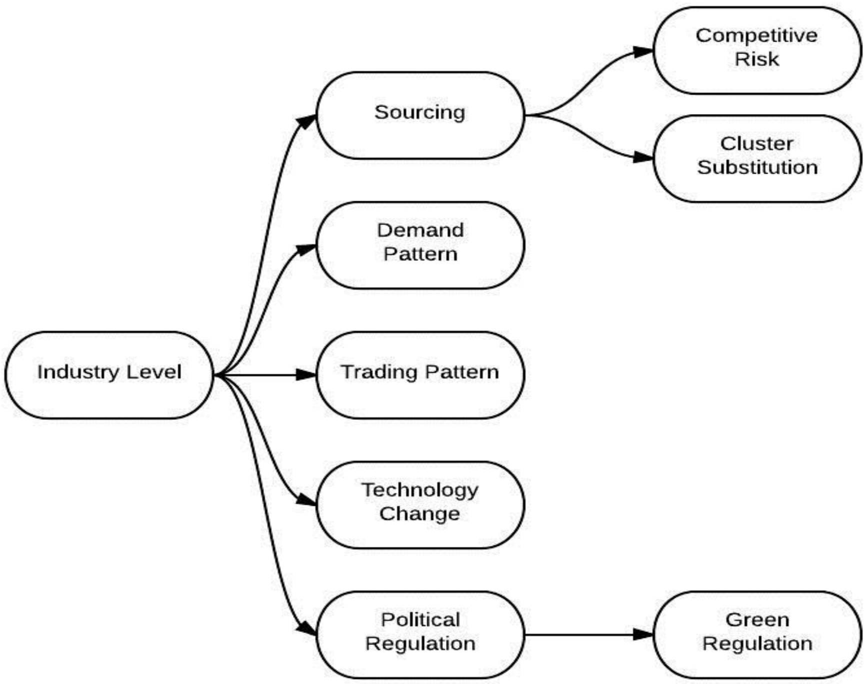

Figure 7 - Risks at the industry level

On the sourcing side, we identify two risks such that the impact of them on a focal company may be affected by the reaction of the focal company's computer. Those two risks are competitive risk and cluster substitution risk.

3.3.1 Competitive Risk

In figure 8, both plants P1 and P2 source materials from the same supplier S1.1. After a disruption, supplier S1.1 is no longer able to provide supply to P1 and P2at the same time. As the result, two plants have to turn to an alternative supplier, say, supplier S1.2.

(a) Before disruption (b) After disruption

Figure 8 - Competitive Risks

At this time, there will be no question if supplier S1.2 has enough capacity to meet both P1 and P2's demands. However, if S1.2 has only limited capacity, the following factors may influence supplier S1.2's decision of to whom it is going to provide supply. (Hopp, Iravani, & Liu, 2008)

- Plant size
- Willingness to pay
- Plant preparedness
- Business history
- Contractual agreements
- First-come-first-served
- Market share of P1 and P2

On the other hand, when a plant can secure supply from supplier S1.2, it still needs to decide the amount of supply according to its competitive strategy. An extreme example could be that the plant sweeps all the supply that supplier S1.2 can provide in order to starve its competitor. In doing so, the plant has to pay the holding cost incurred by unnecessary part of supply.

This is exactly what Nokia did when its supplier, a Philips semiconductor plant in Albuquerque New Mexico, was hit by a lightning bolt in March 2000. The lightning created a 10-minute blaze that contaminated millions of chips and subsequently delayed deliveries to its two largest customers – Finland's Nokia and Sweden's Ericsson. Nokia reacted promptly and swept all available supply from other suppliers. The net result was that Ericsson reported a $400 million loss because it did not receive chip deliveries from the Philips plant in a timely manner and couldn't find alternative suppliers, which had been snapped away by Nokia. (Sheffi & Rice, 2005)

Thus, one manufacturer's competitive advantage is its competitor's risk and competitive risk is triggered by the failure of supplier S1.1 to focal companies P1 and P2. The risk is industry-wised as involved entities like companies P1, P2 and suppler S1.2 may not be in the same supply chain. The impact of competitive risk to companies P1 and P2 is decided by

(1) The relative competiveness of P1 and P2 in the view of supplier S1.2

(2) The relative promptness of P1 and P2 reacting to the risk

The purchasing plan of P1 (or P2) to secure supply from S1.2 basing on its own capability and its understand of P2 (or P1)

3.3.2 Cluster Substitution Risk

A cluster is a geographical concentration of organizations in certain interconnected industrial groups tied by competitive pressures to form collaborative and competitive relationship. The California wine cluster, Italian leather goods cluster, French fashion design cluster, Silicon Valley in USA, software outsourcing in India, automotive cluster in Thailand and logistics cluster in Germany, Netherlands and Singapore are a few examples of clusters around the world. Although a cluster has its own advantages like inclusion, collaboration, cooperation for its participants, it is also subject to risks such as natural disasters or substitution by other clusters.

Figure 9 illustrates the risk of cluster substitution. Suppose suppliers S1.2 and S1.3 and S1.m are located in the same industrial cluster, which happens to be in a disaster zone. When a disaster occurs, it is most likely that all three suppliers will be affected, subsequently, bringing the competitive risk to plants P1 and P2. The unreliability of those suppliers will naturally urge plants P1 and P2 to explore alternative suppliers in other safer areas, e.g. area around supplier S1.1. The new suppliers may finally replace the existing ones and trigger the cluster substitution risk to suppliers like S1.2, S1.3 and S1.m.

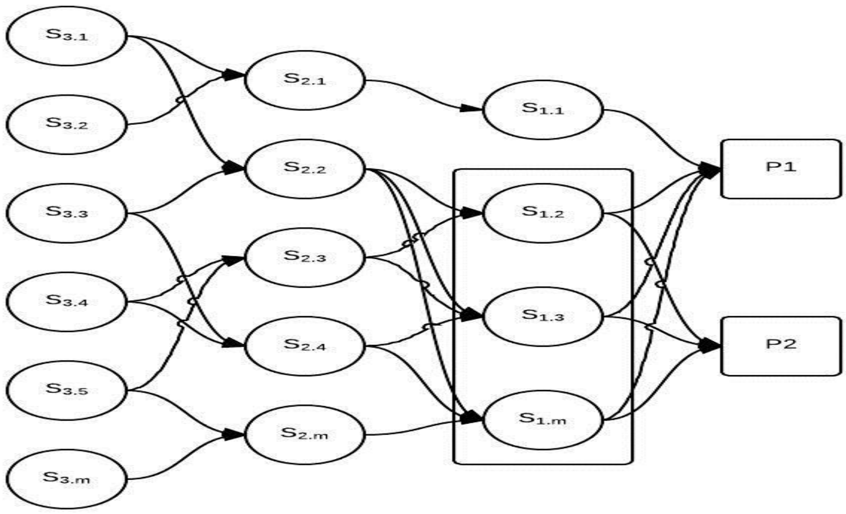

Figure 9 - Cluster Substitution

The severe Bangkok flood in October 2011 exposed the hard disc drive (HDD) cluster to the significant risk of substitution. The worst flooding in 50 years left production facilities of Western Difital, Hitachi Global Storage Technologies, Seagate, and suppliers of HDD manufacturers like Nidec submerged under water. The damaged production and inventory led to a global HDD shortage and consequently a hike in prices. Once manufacturers or suppliers in the disaster-pro cluster can find safer alternative locations with similar operational environments, the potential risk of cluster substitution may become a reality.

3.4 Risk at the Macro Level

Risks at the macro level refer to the risks which can impact across the supply chains of different industries. The impacts of a macro risk can be passed from the supply chain of one industry to the supply chain of another industry, and subsequently passed on to other supply chains. Even though the focal company may not be directly hit by the risk, it still can feel risks propagated from the source or from the risk reactions from other entities within or outside its own supply chain.

This type of risks includes natural disasters (e.g. earthquake, tsunami, flood, volcano, and fire), economic instability (e.g. GDP swings and economic crisis or recession), terrorist attacks, social condition, or contagious diseases (figure 10).

For example, the triple (9.0 magnitude earthquake, tsunami, and nuclear power plant leak) disaster of Japan in 2011 hit areas of Miyagi, Fukushima and Iwate, which are estimated to contain over 86,000 of the business that were affected, as well as US$ 209 billion in sales volume and 715 industries. (Dun, 2012)

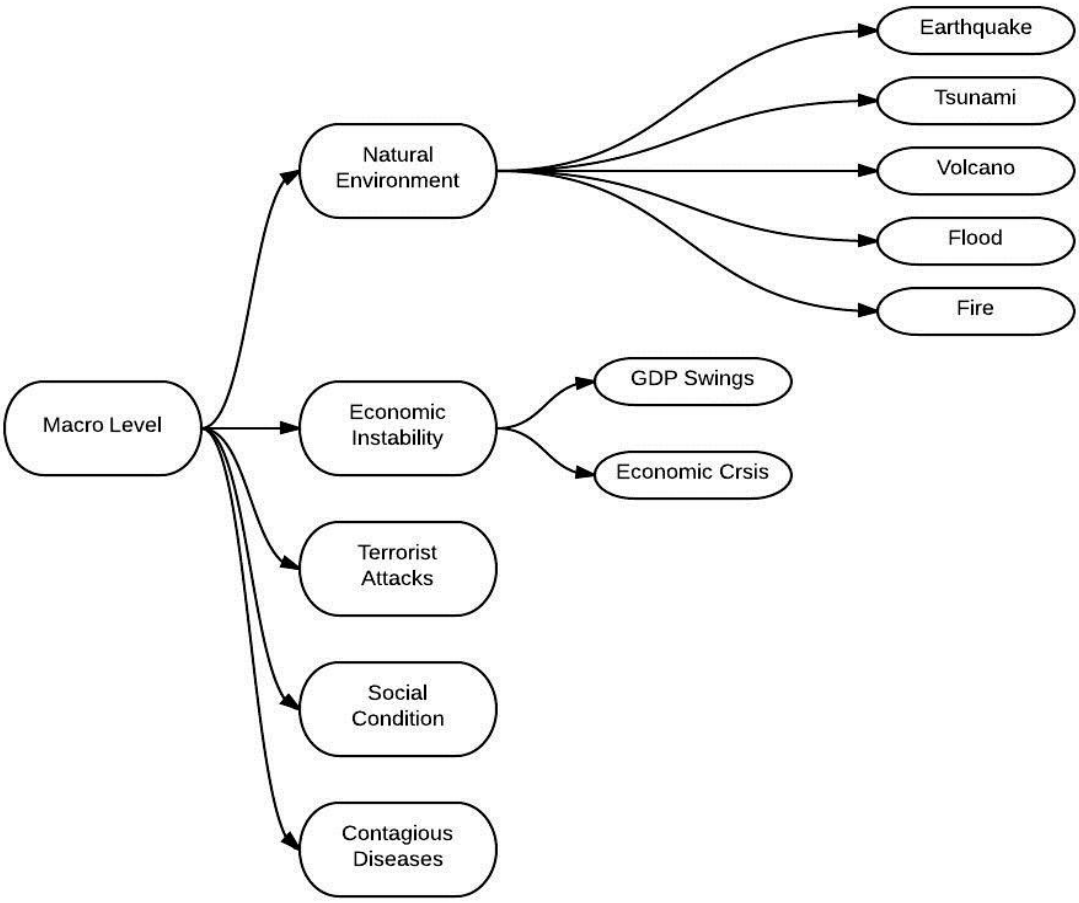

Figure 10 - Risks at the Macro Level

Japan is an important part of the chain in global supply networks, particularly the electronics, cars and airplanes, energy and fuel, as well as logistics. But the triple disaster had primary impacts on local operations damaged, personal lost, communications lost and secondary impacts on downstream customers suffered loss of supply from primary impacts causing shutdowns. (Rice, 2011)

By observation, macro level risks have some or all of the following characteristics.

- Across industries
- Across supply chains
- Risk propagation or cascading

Supply Chain Risk Framework

The framework of supply chain risks can be summarized in there different levels in terms of different scopes of risk impacts which are supply chain level, industry level and macro level. At the supply chain level, (Avijit Banerjee, 2003) the risks in one supply chain are the focus and the mitigation of them requires the reactions of the risk-hit entity only or interactions of entities from the same supply chain. From the focal company's point of view, risks are originated from sourcing, demands, and internal processes. In the industrial level, the occurrence of risks will impact entities in different supply chains. The mitigation of them may involve interactions between different entities in multiple supply chains. Two important risks are identified: competitive risk and cluster substitution risk. At the macro level, the happening of risk has a wider impact than the previous two types of risks. Risks in this level impact entities across supply chains and industries and they can also propagate from one location to others.

One important benefit of the frame work is to help identify risks, which are generally ignored in most supply chain risk frameworks. The mitigation of those risks, e.g. relationship risk, competitive risk, cluster substitution risk is not isolated but needs interactions from different entities.

CHAPTER IV COMPETITIVE RISK AND INFORMATION SHARING IMPACT ON SC

There are quite few literature related to supply chain risk analysis using system dynamics based on the review in previous section. There are two major works have been done in terms of analyzing disruption impacts by implementing system dynamics modeling technique. Product recovery operations in reverse supply chains face capacity planning and green image limitation. The simulation model of SD provides an experimental tool, which can be used to evaluate alternative long-term capacity planning policies using total supply chain profit as measure of policy effectiveness. (Vlachos, Georgiadis, & Iakovou, 2007) SD modeling has been developed in order to investigate the effect of a transportation disruption on supply chain performance, comparing a traditional supply chain and a vendor management inventory system (VMI) when a transportation disruption occurs between 2 echelons in a 5-echelon supply chain. (Wilson, 2007)

To analyze the impact of competitive risk between two manufacturers, causal loop diagram will be first presented to show the map of 3-echelon supply chain network including raw material suppliers, manufacturers and end-customers. This can help us better understand the structure and behavior of the system. Then, based on different assumption sets and historical data of one specific industry, we will simulate the system performance and make a comparison so as to gain insights about the overall network.

In order to monitor the competitive risk impact on supply chain performance, here we need firstly introduce a concept of competitive advantage of a company or organization. In reviewing the use of the term competitive advantage in the strategy literature, the common theme is value creation (Walters, Halliday, & Glaser, 2002). In this thesis, we have developed a normal case model and competitive risk case model which are both from a 2-echelon base model assumption. The supply chain modeled in this research contains three sectors: the end-customers, the manufacturers and the raw material suppliers. The following figure shows how goods and information flow between each partner in the chain for each scenario.

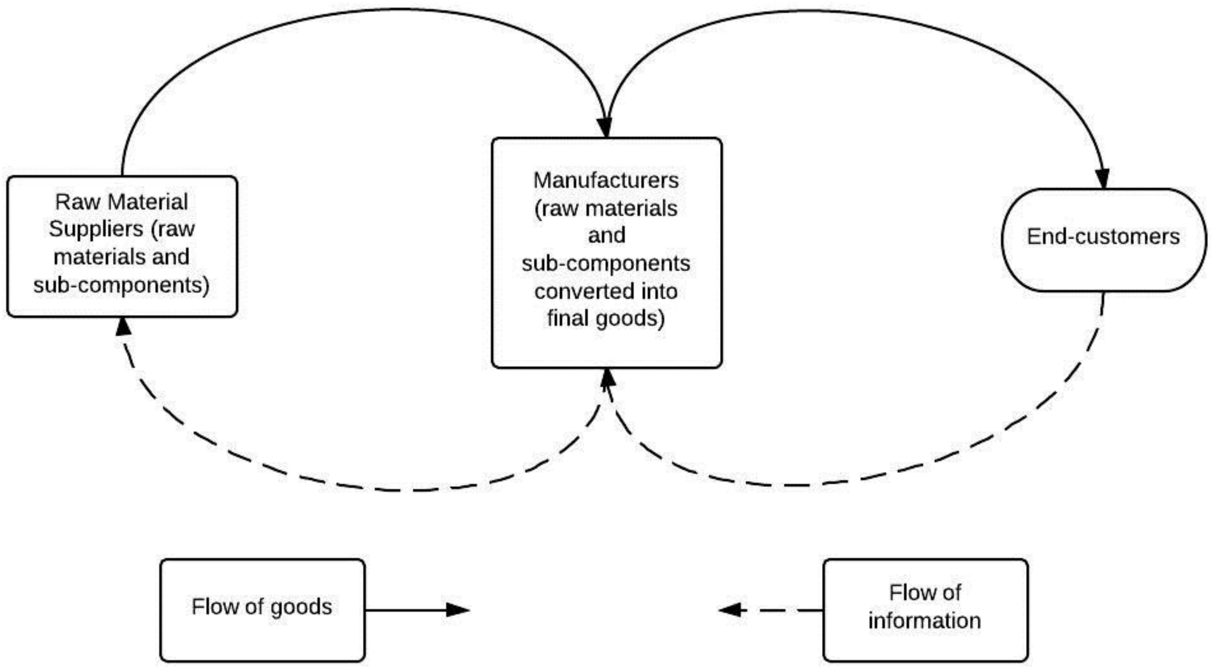

Figure 11 – 2-echelon supply chain

The competitive advantage of one manufacturer will be treated as competitive risk to another manufacturer in the same industry; especially when these two manufacturers share the similar raw material/sub-components suppliers in the supply chain network. One of the suppliers shut down for some uncertain disruptions, the manufacturer with strong and undeniable competitive advantage can fulfill more orders from another supplier and continue their manufacturing operations. At the same time, the competitive risk due to less competitive advantage for another manufacturer, its operation and manufacturing will be affected and its customer order fulfill rate will be negatively affected at the same time. In a conclusion, a company can mitigate its competitive risks by creating and sustaining competitive advantages in its industry. (Porter, 1985)

4.1 Competitive Advantage

To illustrate various approaches to competitive advantages, a summary below has been covered from a variety of thoughts on this subject by important researchers.

- Porter (Porter, 1985) (who is Porter and what is the reference) says "competitive advantages is at the heart of a firm's performance in competitive markets" and goes on to say that purpose of his book on the subject is to show "how a firm can actually create and sustain a competitive advantage in an industry ------ how it can implement the board generic strategies." Thus, competitive advantage means having low costs, differentiation advantage, or a successful focus strategy. In addition, Porter argues that "competitive advantage grows fundamentally out of value a firm is able to create for its buyers that exceeds the firm's cost of creating it."
- Peteraf (1993) defines competitive advantage as "sustained above normal returns." She defines imperfectly mobile resources as those that are specialized to the firm and notes that such resources "can be a source of competitive advantage" because "any Ricardian or monopoly rents generated by the assets will not be offset entirely by accounting for the asset's opportunity cost".
- Barney (2002: 9) says that "a firm experiences competitive advantages when its actions in an industry or market create economic value and when few competing firms are engaging in similar actions." Barney goes on to tie competitive advantage to performance, arguing that "a firm obtains above-normal performance when it generates greater-than-expected value from the resources it employs. In this final case, the owners of resources think they are worth $10, and the firm creates $12 in value using them. This positive difference between expected value and actual value is known as an economic profit or an economic rent."
- Ghemawat and Rivkin (1999:49) say that "a firm such as Nucor that earns superior financial returns within its industry (or its strategic group) over the long run is said to enjoy a competitive advantage over its rivals."
- Besanko, Dranove, and Shanley (2000: 389) say "when a firm earns a higher rate of economic profit than the average rate of economic profit of other firms competing within the same market, the firm has a competitive advantage in that market." They

also carefully define economic profit (1999: 627) as "the difference between the profits obtained by investing resources in a particular activity, and the profits that could have been obtained by investing the same resources in the most lucrative alternative activity."

Saloner, Shepard and Podolny say that "most forms of competitive advantage mean either that a firm can produce some service or product that its customers value than those produced by competitors or that it can produce its service or product at a lower cost than its competitors." They also say that "in order to prosper, the firm must also be able to capture the value it creates. In order to create and capture value the firm must have a sustainable competitive advantage."

4.2 Competitive Risk

In the previous section, we have summarized a list of factors that will affect company's competitive advantage when competitive risk is considered in complex supply chain network. Among them, they can be divided into qualitative and quantitative measurement. Competitive advantage occurs when an organization acquires or develops an attribute or combination of attributes that allows it to outperform its competitors. These attributes can include access to natrual resources, highly trained personnel workforce, market share dominance, reputation in shareholders, well established business processes etc. (Stutz & Walf, 2007) And competitive advantages seeks to address some of the criticism of comparative advantage. Michael Porter proposed a theory to emphasize productivity and revenue growths, sales order generations ability and shareholder benefits in his competitive advantage research. (Porter, 1985)

Thus, we take below four factors into our further survey based study to understand how they impact on supply chain performance. They are,

(1) Physical and target inventory level

(2) Outstanding backorders

(3) Customer satisfaction

(4) Shock length

(5) Recovery time

Customer demand variation

4.3 Problem Definition

In the context of this paper, a simple two-echelon supply chain is considered. Contrary to most literature this paper will consider two actors in the supplier echelon.

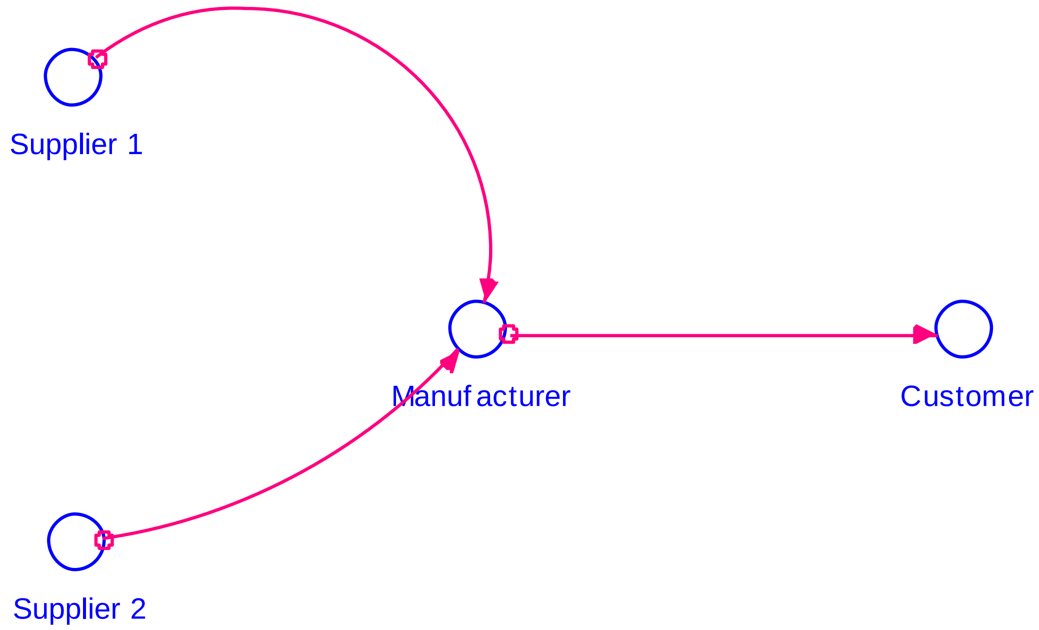

Figure 12 – iThink 2-echelon model

The model has been kept simple and focuses on a two-tiered supply chain system. Also, the information sharing that is considered in this experiment will be one-way, i.e. the manufacturer will have information about the supplier. The following simplifying assumptions are also made:

(1) The products are being supplied are identical

In the context of this model, it is assumed that there are two suppliers supplying the same product to manufacturer for final assembly. This is a simplifying assumption of real world practice of dual resource procurement strategy.

(2) Cost of suppliers' products are the same

The performance of each model will be measured by customer satisfaction at the end of each simulation.

(3) Customer demand follows a normal distribution

The demand follows a normal distribution with mean 150 and standard deviation 50. A normal distribution should be sufficient for the study because the main aim of this study is to understand and simulate the supply side fluctuation.

(4) Backorders from customer and suppliers are allowed

In the context of this paper, it is assumed that customers can backorder goods that they need at a later time. Similarly, for the manufacturer, orders made to its suppliers are also backordered when they cannot be fulfilled at a certain point in time.

(5) Lead time is the same for both of the suppliers

The lead time considered here is only the transport lead time from suppliers to the manufacturer. In this case, this lead time is the same for both suppliers. There is no production lead time in both cases of the suppliers.

The complexity of the supply chain and its reliance on the relationships between many factors makes Systems Dynamics a suitable candidate method to study this. It is of course, important to point out that Systems Dynamics runs on a continuous-time basis, which may be relatively ideal for a real-world application. Nevertheless, it serves as a good base for comparison between different ordering strategies, whether they include information sharing or not, and also between different models of information sharing.

4.4 Manufacturer Side Modeling

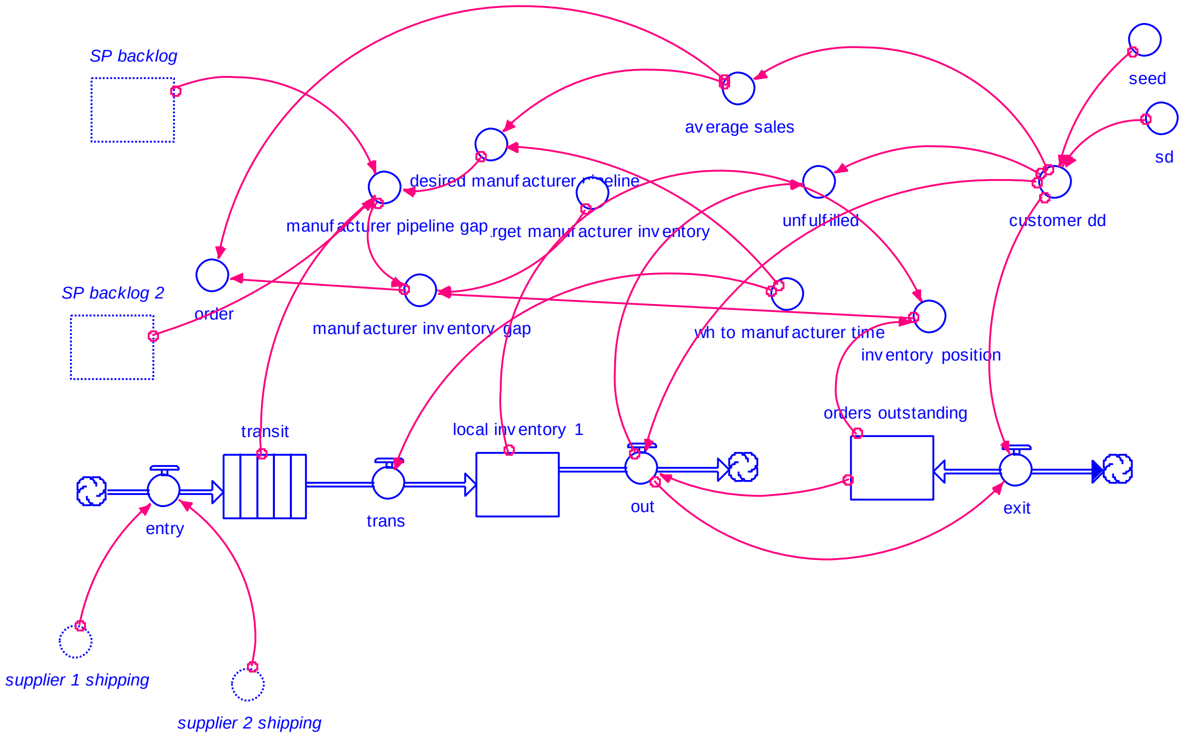

Figure 13 – iThink model on supplier side

The manufacturer maintains an inventory. The goods that they order from the downstream suppliers take a period of time to arrive, which is modeled by the conveyor stock "transit" as shown in above figure. It is assumed that manufacturer do not have information about the demand distribution, and have forecast demand pattern. To simulate it, a smoothing method is done such that $\widehat{D}_{M,t}$ becomes the expected demand that is derived from historical values of demand for up to three periods,

$\widehat{D}_{M,t} = \sum_{i=1}^{3} D_{M,t-i}$………………..(1)

When customer orders cannot be fulfilled, a stock to keep account of the accumulated backorders and "orders outstanding" keeps track of the outstanding backorders. Thus, goods shipped to the customer by the manufacturer at time t, $S_{M,t}$ fulfills the demand and these backorders. AT is defined as the adjustment time which gives an indication of how long the manufacturer will take to fulfill the backorders at time t, which is denoted by $BL_{M,t}$. For this model, it is assumed that all actors in the supply chain fulfill their orders within one time period, i.e. $AT = 1$.

$S_{M,t} = D_{M,t} + BL_{M,t}/AT$………………..(2)

The backorders to the customer, BL_M is a stock which is dependent on $S_{M,t}$ and $D_{M,t}$.

Demand that is not fulfilled is backlogged, which gives

$BL_{M,t} = BL_{M,t-1} + D_{M,t} - S_{M,t}$………………..(3)

The net inventory, $NI_{M,t}$ of the manufacturer is monitored and defined as the following:

$NI_{M,t} = I_{M,t} - BL_{M,t}$………………..(4)

Anchor-and-adjust policy is commonly used in Systems Dynamics literature, and thus it will apply for this model as well. The anchor and adjust policy aims to maintain inventory at a constant level, as dictated by the target inventory level. In order to do so, the manufacturer monitors both its physical inventory and its pipeline inventory.

$I^*_{M,t} = k$………………..(5)

$SL^*_{M,t} = \widehat{D}_{M,t} * LT$………………..(6)

The manufacturer sets a target inventory level, $I^*_{M,t}$ which is the level of inventory that he will keep to. In the context of this model, the calculations of an optimal target inventory level is beyond scope, and will just be set as a constant k which is the simplest model of an anchor and adjust policy. $SL^*_{M,t}$ refers to the desired supply chain level that the manufacturer will keep in its supply chain pipeline, which will be the expected demand over the lead time LT.

$\delta I_{M,t} = I^*_{M,t} - NI_{M,t}$………………..(7)

$\delta SL_{M,t} = SL^*_{M,t} - TI_{M,t} - BL_{1,t} - BL_{2,t}$………………..(8)

$\delta I_{M,t}$ and $\delta SL_{M,t}$ are the 'gaps' in the inventory level and the supply chain pipeline that will be ordered in order to maintain the desired level of inventory. For the supply chain pipeline, the transit inventory $TI_{M,t}$ and the backorders accumulated at the suppliers BL_1 and BL_2. It is assumed that the supplier will know the amount of backlog that is accumulated at the suppliers. While it may be idealistic to assume that the supplier can constantly monitor its transit inventory and the backlog accumulated at the upstream suppliers, the quantity can be derived quickly by the supplier by monitoring their orders that were made and those that have arrived and taking the difference. As such, the ordering quantity at time t, O_t follows this equation:

$$O_t = \frac{\delta I_{M,t}}{AT} + \frac{\delta SL_{M,t}}{AT} + \widehat{D}_{M,t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

4.5 Supplier Side Modeling

Similarly, the supplier follows an anchor-and-adjust policy, except that instead of ordering from another echelon, the supplier produces the said amount.

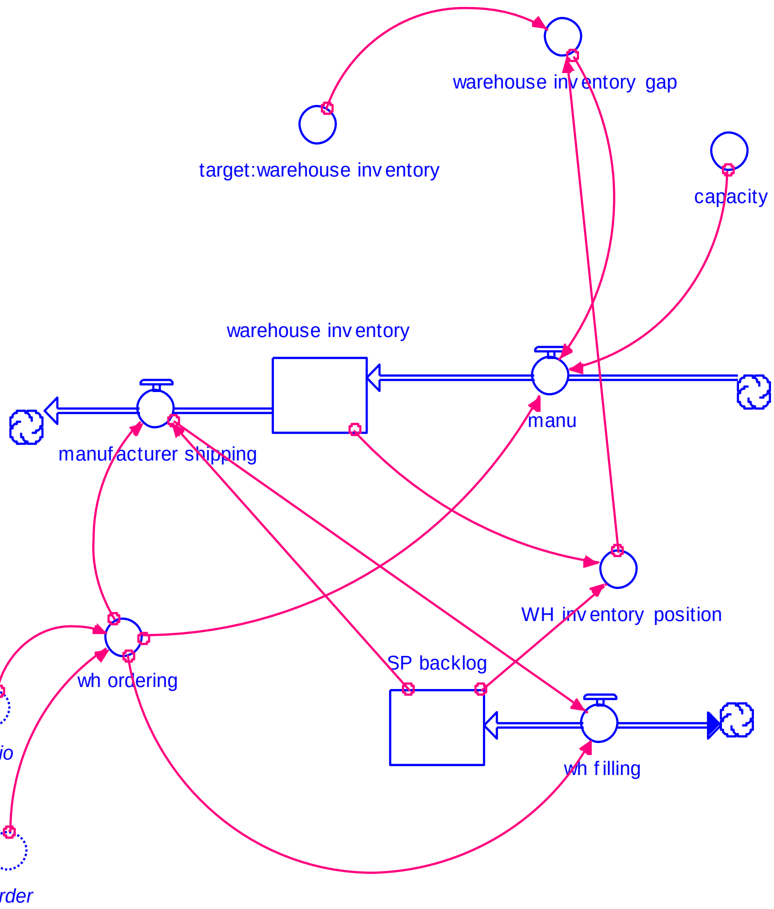

Figure 14 – iThink model on supplier side

In this case, most of the calculations are largely similar with the manufacturer other than customer demand, the ordering that is done by the manufacturer to the specific supplier becomes the "customer demand" in this system. For each supplier i, a net inventory $NI_{i,t}$ is calculated as follows.

$$NI_{i,t} = I_{i,t} - BL_{i,t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

$S_{i,t}$ is the amount of goods being shipped to the manufacturer at time t. It fulfills the orders and accumulated backorders that the supplier owes to the manufacturer.

$S_{i,t} = O_{i,t} + BL_{i,t}/AT$………………..(11)

$I_{i,t}^{*} = c$………………..(12)

$\delta I_{i,t} = I_{i,t}^{*} - NI_{i,t}$………………..(13)

In order to satisfy the manufacturer, the supplier will constantly monitor $NI_{i,t}$ with respect to the target inventory level $I_{i,t}^{*}$. A 'gap' $\delta I_{i,t}$ which is the difference between these two quantities is constantly monitored.

A converter "capacity" is included. This converter is a measure to simulate the limit on the ability of the supplier to produce required products, and will be reflected in our equations as C_i. It is a constant to limit production to a certain amount. It affects the manufacturing quantity which simulates a production line. Each supplier i will manufacture $P_{i,t}$ according to these rules:

$P_{i,t} = C_i,\ \delta I_{i,t} > 0$………………..(14)

$P_{i,t} = min(C_i, O_{i,t}),\ \delta I_{i,t} = 0$………………..(15)

$P_{i,t} = 0,\ \delta I_{i,t} < 0$………………..(16)

In this case, the supplier will produce at full capacity to get rid of backorders as quickly as possible, and also to bring his own inventory back up to the target level. When at the target inventory level, the supplier will just produce at demand rate, in this case, is the orders $O_{i,t}$ in order to maintain the inventory level.

Table of Constants	
Target supplier inventory, $\boldsymbol{I^{*}_{R,t}}$	150
Target supplier inventory, $\boldsymbol{I^{*}_{i,t}, i = 1,2}$	150
Lead time $\boldsymbol{LT_R}$	4
Adjustment time, $\boldsymbol{AT}$	1
Capacity for unaffected supplier	100
Demand, $\boldsymbol{D_{R,t}}$	Normal(150, 50^2)

Table 5 – Constants

4.6 Manufacturer Ordering Policy

It is established that the manufacturer will order according to the needs of demand and to fulfil its own policy of maintaining inventory. However, these orders have to be allocated to the two suppliers. The decision sector of the model thus models different ways of decision making, which may or may not encompass information sharing among the different echelons.

4.6.1 Ordering Policy 1 – No Information Sharing Between Manufacturer and Supplier

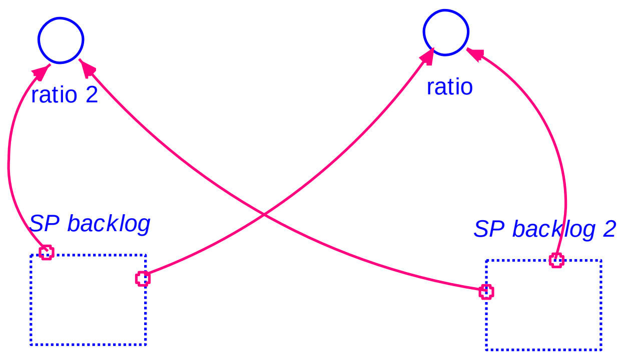

Figure 15 – Supplier backorder

It is assumed that the manufacturer has knowledge of the backorders accumulated at each supplier at time t. The manufacturer allocates the orders to each supplier based on this backorder accumulation. A ratio, r_i measures the ratio of backorders which will determine its ordering quantity from each supplier. For example, in the case of supplier 1, the ratio

$r_{1,t} = \frac{BL_{2,t}}{BL_{1,t}+BL_{2,t}}$, when $BL_{1,t} + BL_{2,t} > 0$. ………………..(17)

For the instance that there are no backorders at either one of the supplier, the manufacturer simply orders half from each supplier, i.e. $r_{1,t} = 0.5, BL_{1,t} + BL_{2,t} = 0.$ ………………..(18)

The order to supplier 1 will then be calculated as $O_{1,t} = O_t * r_{1,t}$. ………………..(19)

In the event of no information sharing, this ordering policy is chosen because it makes use of the available information, which in this case is the backlog, in order to make a decision. Intuitively, when orders to a particular supplier are unfulfilled for some time, manufacturer may postulate that these suppliers are not capable of fulfilling the orders and will change their ordering quantity to disfavor the weaker supplier, and divert more orders to the more reliable one.

4.6.2 Ordering Policy 2 – Level of Physical Inventory of Supplier will be Shared with Manufacturer

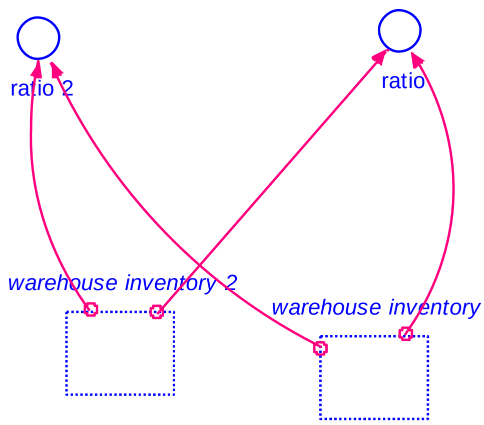

Figure 16 – Supplier physical inventory level

Under the assumption that there is only one kind of information that is available to the supplier, the manufacturer does a simple ratio calculation based on these quantities. In this case, a meaningful value for our calculation will be the physical inventory level of the suppliers. The ratio of orders to supplier 1, will be calculated as $r_{1,t} =$

$\frac{I_{1,t}}{I_{1,t}+I_{2,t}}$………………..(20)

when the sum of physical inventories on both suppliers is a positive number,

i.e. $I_{1,t} + I_{2,t} > 0$………………..(21)

When both supplier inventories are empty, i.e. $I_{1,t} + I_{2,t} = 0$………………..(22)

the manufacturer simply orders half from each supplier, i.e. $r_{1,t} = 0.5$………………..(23)

Correspondingly, the order to supplier 1 is as such: $O_{1,t} = r_{1,t} * O_t$………………..(24)

With limited information sharing, this is a rather intuitive decision to make on the manufacturer's part. Essentially, the manufacturer orders less from the supplier with lower inventory levels, and more from the supplier with higher inventory levels. As such, the ratio of inventory levels reflects this intuitive way of decision, and is used in this case and will be used in the study.

4.6.3 Ordering Policy 3 – Multiple Information of Supplier will be Shared with Manufacturer

In a more ideal scenario, it is considered that the manufacturer will have access to multiple sources of information in order to support its ordering decision. The principle behind this decision looks at the speed of clearing of backorders with each supplier, or the speed of diminishing of inventory of either one of the supplier. In our case, an entity/stakeholder is either in a state where it holds inventory or it holds backorders that it owes the manufacturer. There are eight possible combined scenarios that will affect manufacturer's ordering decision when it takes customer demand, supplier capacity, supplier backlog orders and inventory level into consideration.

Case	Conditions	Order 1	Order 2
1a	Suppliers 1 and 2 have physical inventory Demand > Capacity	$\frac{(O_t - C_{2,t})I_{1,t}}{I_{1,t} + I_{2,t}} + \frac{I_{2,t} * C_{1,t}}{I_{1,t} + I_{2,t}}$	$\frac{(O_t - C_{1,t})I_{2,t}}{I_{1,t} + I_{2,t}} + \frac{I_{1,t} * C_{2,t}}{I_{1,t} + I_{2,t}}$
1b	Suppliers 1 and 2 have physical inventory Demand < Capacity	$\frac{C_{1,t} * O_t}{C_{1,t} + C_{2,t}}$	$\frac{C_{2,t} * O_t}{C_{1,t} + C_{2,t}}$
2a	Suppliers 1 and 2 have outstanding backlog Demand > Capacity	$\frac{C_{1,t} * O_t}{C_{1,t} + C_{2,t}}$	$\frac{C_{2,t} * O_t}{C_{1,t} + C_{2,t}}$

2b	Suppliers 1 and 2 have outstanding backlog Demand < Capacity	$\frac{(O_t - C_{2,t})BL_{1,t}}{BL_{1,t} + BL_{2,t}} + \frac{B_{2,t} * C_{1,t}}{B_{1,t} + B_{2,t}}$	$\frac{(O_t - C_{1,t})B_{2,t}}{B_{1,t} + B_{2,t}} + \frac{B_{1,t} * C_{2,t}}{B_{1,t} + B_{2,t}}$
3a	Supplier 1: Backlog Supplier 2: Inventory Demand < Capacity	O_t	0
3b	Supplier 1: Backlog Supplier 2: Inventory Demand > Capacity	O_t	0
4a	Supplier 1: Inventory Supplier 2: Backlog Demand < Capacity	0	O_t
4b	Supplier 1: Inventory Supplier 2: Backlog Demand < Capacity	0	O_t

Table 6 – Multiple conditions of supplier

Using case 1 as an example, when the total capacity is higher than the total demand, it is a normal case, and a simple ratio of capacity is used to allocate the demand to the two suppliers. This is shown in case 1-1. In case 1a, demand is higher than capacity, thus, the supplier inventory will diminish at a rate

$C_{i,t} - O_{i,t}, i = 1,2$ ………………..(25)

Thus the objective is to change O_i based on the inventory of the suppliers. As such we have the following simultaneous equations

$\frac{I_{1,t}}{O_{1,t} - C_{1,t}} = \frac{I_{2,t}}{O_{2,t} - C_{2,t}}$………………..(26)

$O_{1,t} + O_{2,t} = O_t$………………..(27)

Where the respective order quantities O_i can be found and shown in the table.

Similarly, in the case 2a, when both suppliers are in a backlog situation, and demand exceeds capacity, the backorder quantity increases. In this case, the allocation of orders to each supplier will be based on the ratio of their capacities. In case 2b, when demand is less than capacity, the backlog diminishes at a rate of

$O_{i,t} - C_{i,t}\ , i\ =\ 1,2$……………….(28)

The objective will be to allocate O_i such as to allocate the orders such that the backorders can be fulfilled quicker. From this we have the following simultaneous equations

$\frac{BL_{1,t}}{C_{1,t}-O_{1,t}} = \frac{BL_{2,t}}{C_{2,t}-O_{2,t}}$……………….(29)

$O_{1,t} + O_{2,t} = O_t$……………….(30)

solving this equation which we get the output as stated in above table.

In this manner, the ordering policy also takes into account the state in which the respective suppliers are currently in. In the model, the process of deciding involves calculating the values for each case (from 1-4), which is done by the sector as seen in below figure, and also monitoring parameters to decide which case and which value to use, as done by the sector seen in below figure.

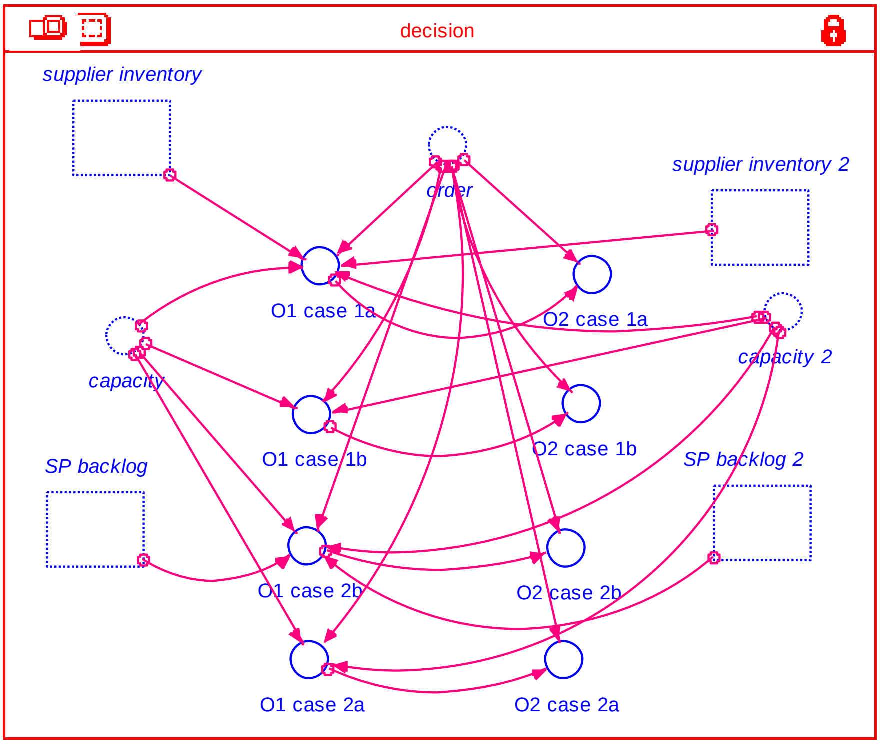

Figure 17 – Order policy 3 decision model

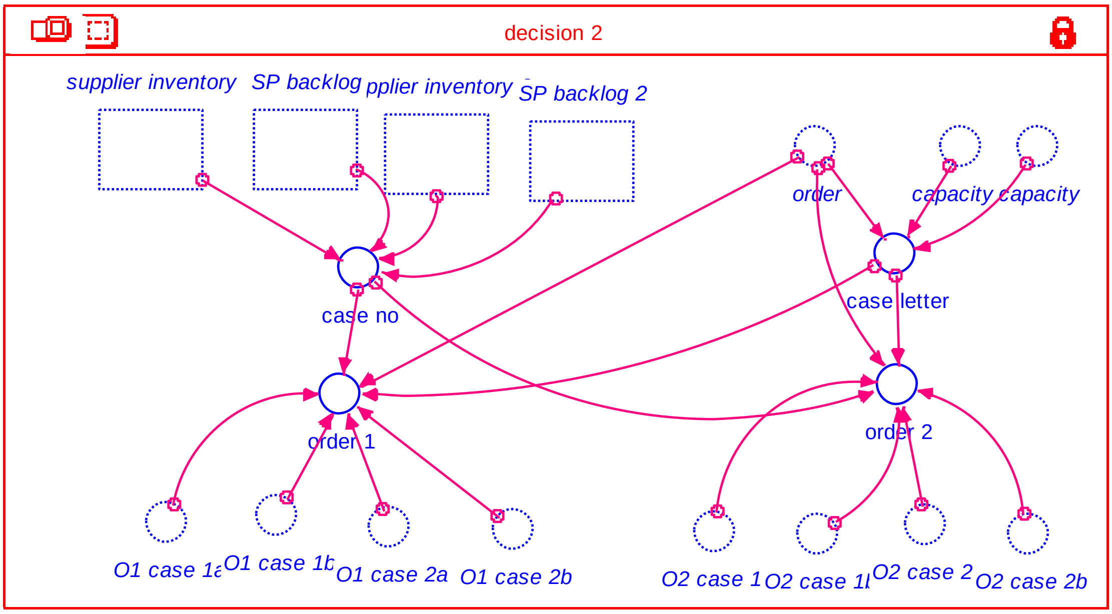

Figure 18 – Order policy 3 decision model 2

4.7 Simulation

As highlighted in previous chapter, part of the purpose of this paper is to explore the effectiveness of the different decision models in terms of reducing impact on customer dissatisfaction. Therefore, in this chapter under our simulation, the metrics that will be monitored will be the outstanding orders that will be accumulated throughout the simulation period of time. An example of how we measure the changes of customer backorders shown in figure 19 under ordering policy (OP1)

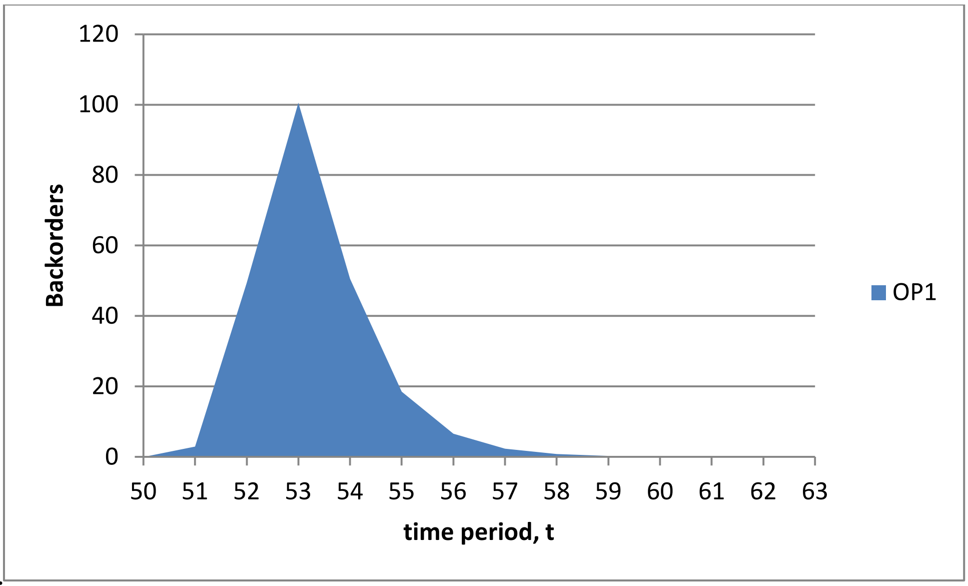

Figure 19 – Changes of cutomer backorders

The main metric that is used in this simulation is the area under the outstanding orders curve over time. It is calculated as such

$\int BL_{R,t} dt$, over entire simulation − warm up time………………..(31)

This gives a good indication of the customer service level. For this simulation, because of the random nature of the results, the distribution of the results will be considered. Box plots of the varying values of total backorders over the 100 periods will be studied for each ordering policy for each scenario.

Furthermore, in this case one of the suppliers shut down its plant for an unforeseen reason and it will recover immediately afterwards (mainly because machine shut down, unpredictable disasters etc.). Again, demand variation and length of shut down time will be two major sensitivity analyses.

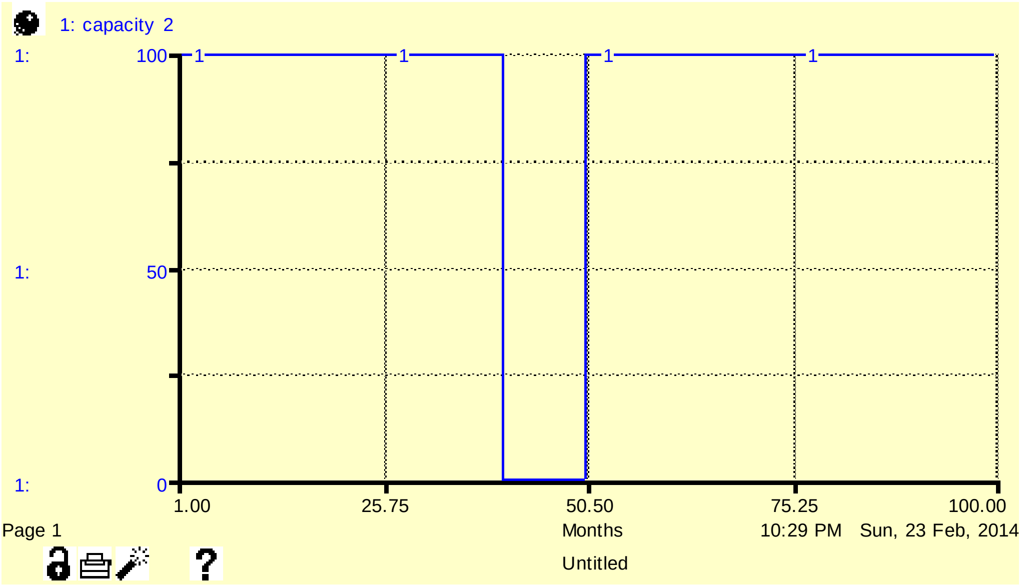

Figure 20 – Demand variation and length of shut down

4.7.1 Scenario 1

The first scenario is a sustained shock that cripples one supplier completely but recovers immediately. The shock lasts for 10 periods, and brings down one supplier to 0. During this period of shock, the total capacity is lower than the demand rate, thus backorders are definitely expected.

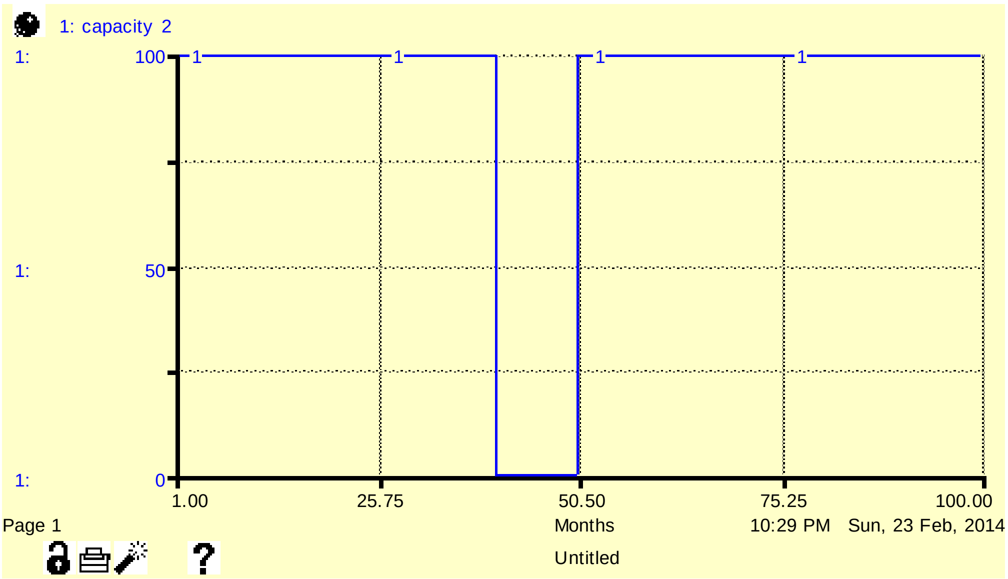

Figure 21 – Scenario 1

Following this shock, the simulation is run and the results of the outstanding backorders to the customers are recorded and collated. These results are discussed, and discussions of subsequent scenarios will also follow the same structure and flow.

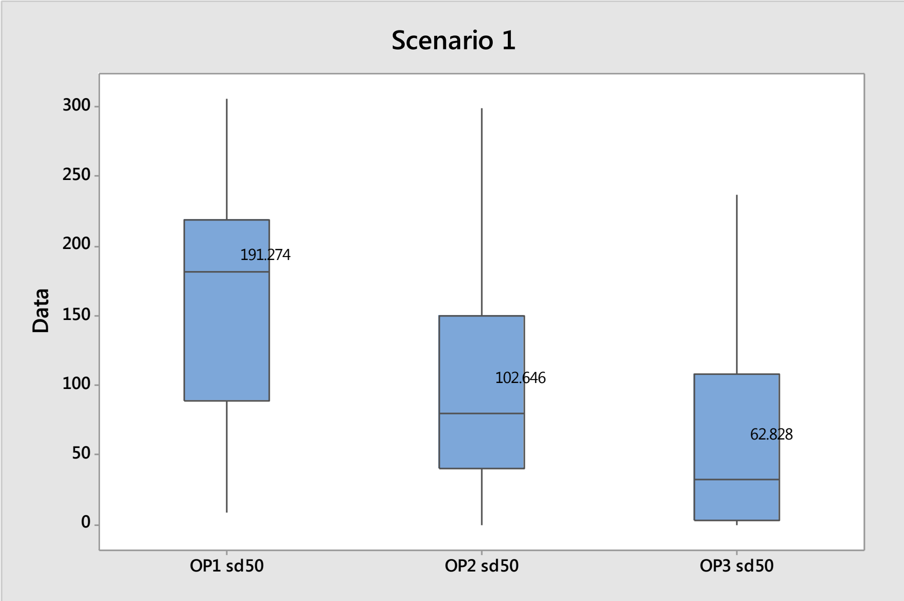

Figure 22 – Scenario 1 Impact of variability

Under scenario 1, it is obvious that the use of information is beneficial in terms of the reduction of outstanding orders. With policy 3, there is a 67% decrease in the number of backorders accumulated over time. Further studies on the impact of different parameters will be discussed in the next subsection.

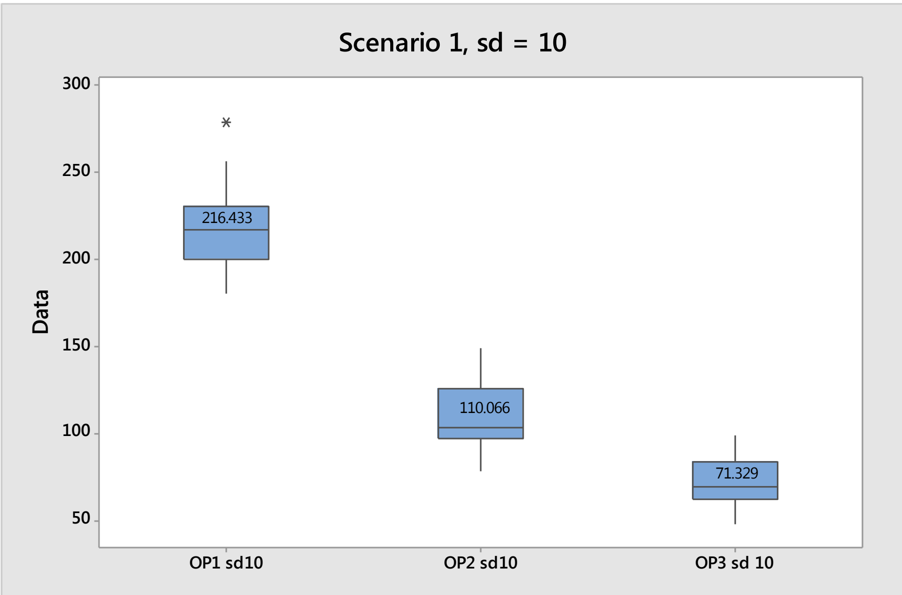

Figure 23 – Scenario 1 low variability (sd=10)

When orders are less variable, a similar pattern is derived from the graph, that some policies outperform the other policies with more avenues of information being more effective in terms of improving the performance of the system. There is a slight increase in terms of the percentage reduction in the backorders accumulated in the system. However, this is also accompanied by an overall increase in the performance of the system in terms of the number of backorders accumulated. As seen from figure 23, the spread of the resulting measure of accumulated backorders over time are also less variable.

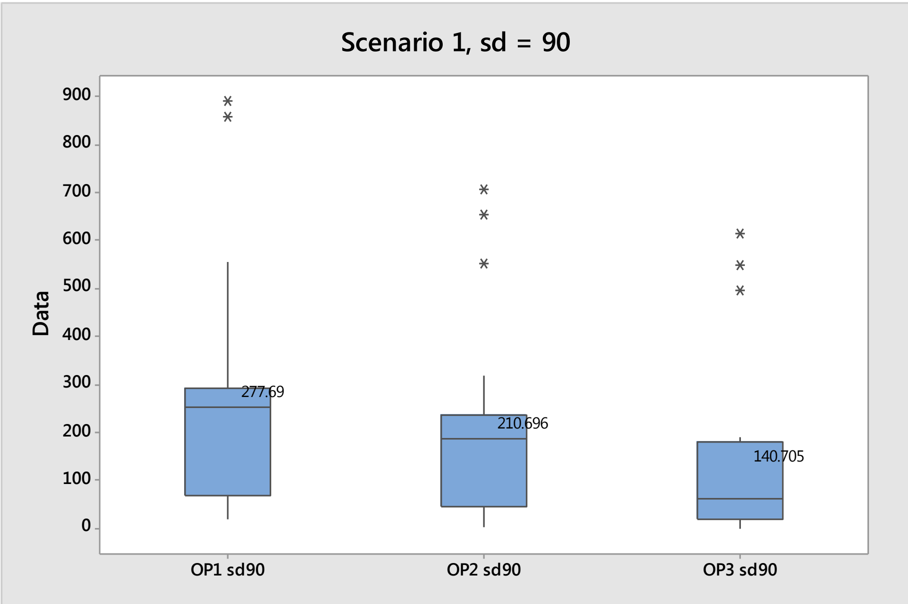

Figure 24 - Scenario 1 – high variability (sd=90)

With an increase in the standard deviation of the demand to a more extreme value, set at 90 for this case, the same result applies such that information sharing cases still trump the case in terms of the reduction of backorders to the customers.

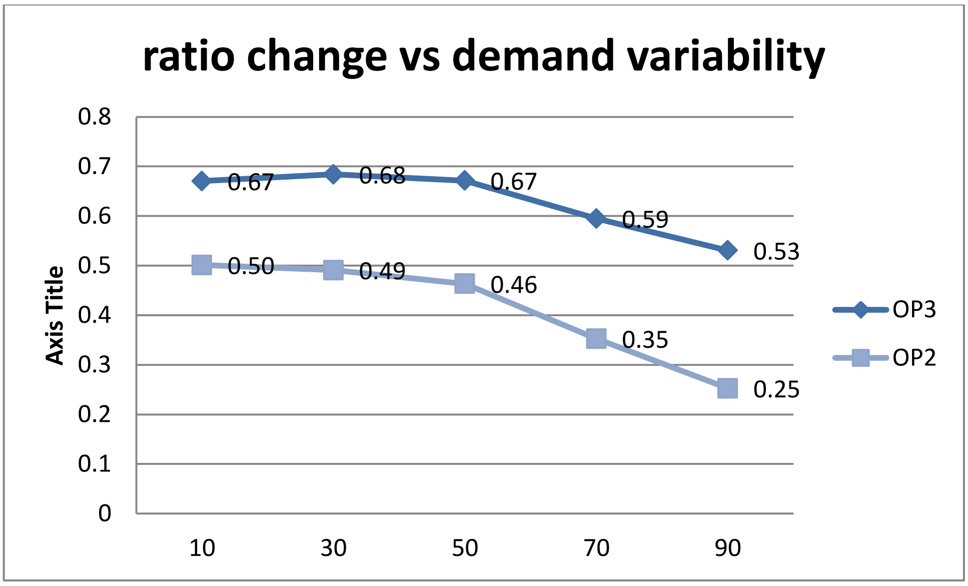

Figure 25 - Average effectiveness of information sharing with demand variability

Figure 25, which shows the ratio of the improvement of information sharing decisions with respect to no information sharing for different demand variability, shows us an interesting result: For Ordering Policy 3, there is a slight increase in the relative performance for different information sharing models with the increase of variability to a certain extend. It seems to suggest that the availability of more information becomes useful in this case. This may be true that for the case where there is higher demand uncertainty, a better grasp of the situation at the suppliers will be more important and more information may lead to a more robust and responsive inventory to hedge against rise and falls of customer demand, especially during times of crisis, i.e. the time when the shock is in play.

In summary, variability in demand up to a certain has a relatively small effect on the average performance of the systems and the respective ordering policies.

Scenario 1 – impact of shock length

In this scenario, the shock lasts for 10 periods. A sensitivity analysis is performed to observe the effect of different shock periods on the performance of each policy in terms of the backorders that are owed to the customer. As such the same simulation is run, but for shocks lasting 20 and 30 periods respectively.

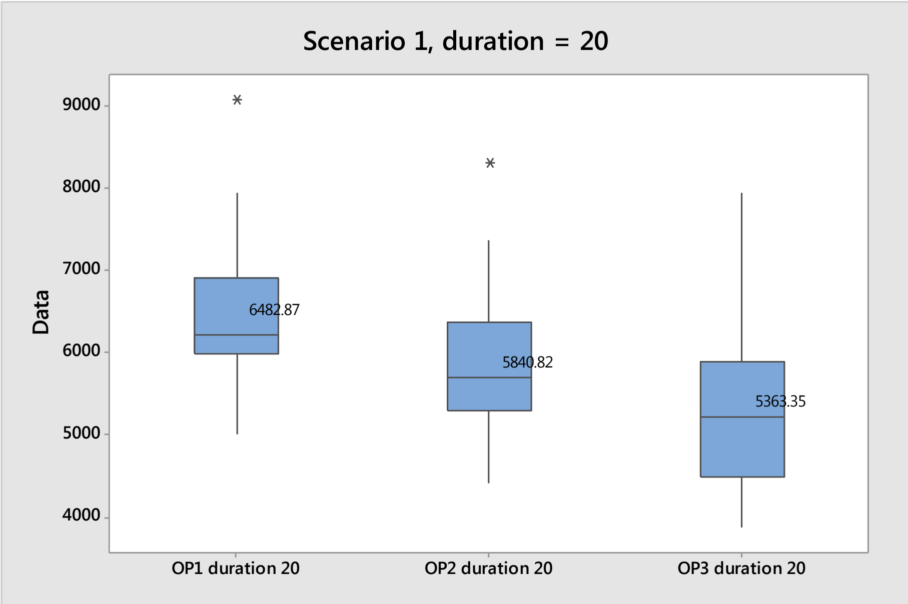

Figure 26 - Scenario 1 – shock length = 20

From these cases, it can be seen that the increase of shut down periods make the effect of information sharing apparently less significant with respect to the non-information sharing models. This can be seen from the graphs below. Nevertheless, this is intuitive, because the increase of shock periods mean that the entire system – with or without information sharing – is increasingly unable to support the demand required by the customers.

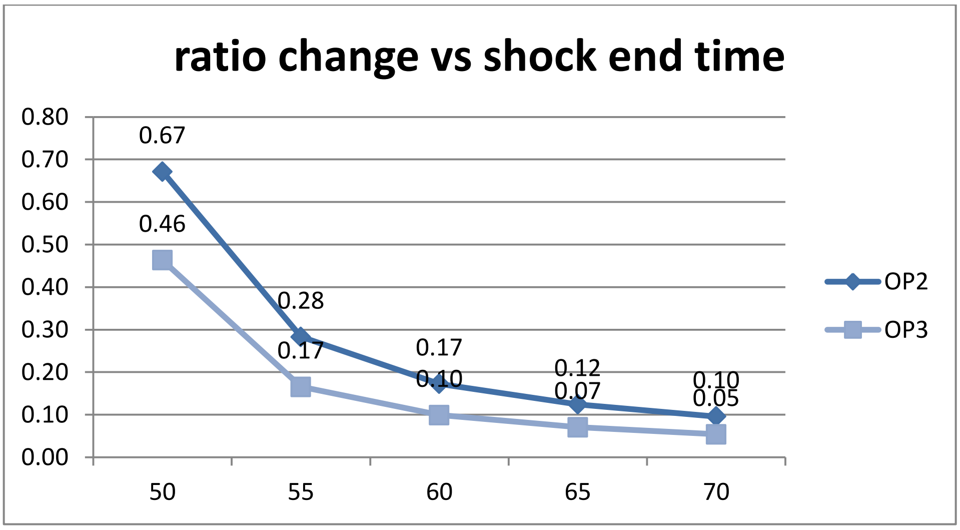

Figure 27 - Average effectiveness of information sharing with increasing shock length

It is noteworthy that the models with information sharing still result in the reduction of backorders to the customers. In the model with 20 periods of shock, 1119 backorders are reduced, and with 30 periods of shock more than 2000 of these backorders are reduced, which is still a rather substantial number.

4.7.2 Scenario 2

The shock is immediate, but thereafter recovers gradually. This simulates a situation as if the production lines are set up incrementally.

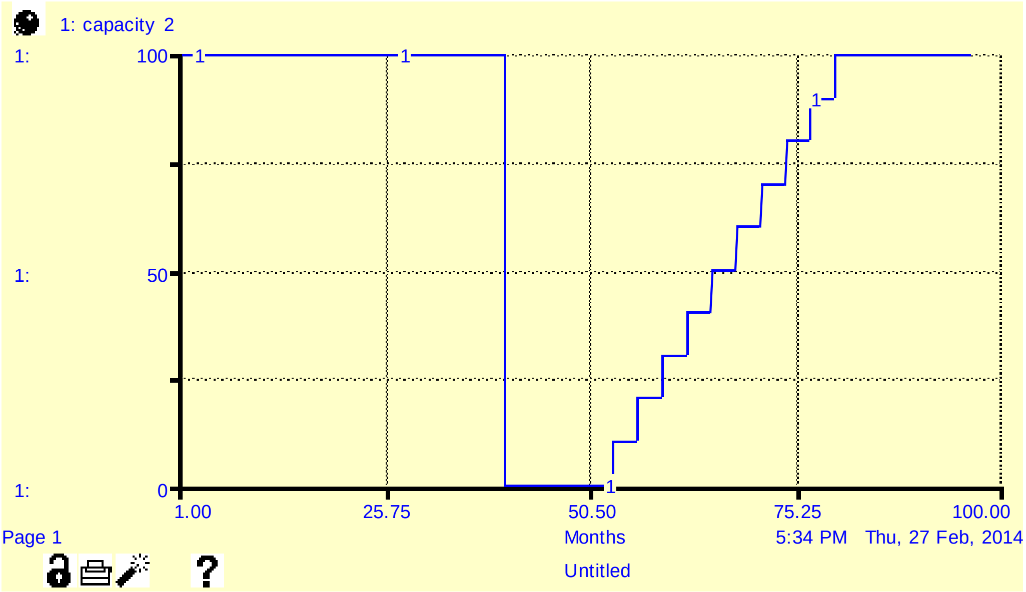

Figure 28 - Immediate shock with gradual recovery

The base case will see a recovery period of 10 periods – recovering at a rate of 10 units per period back to a capacity of 100 units. A further study to test the effect of different recovery periods will also be conducted during the progress of this paper.

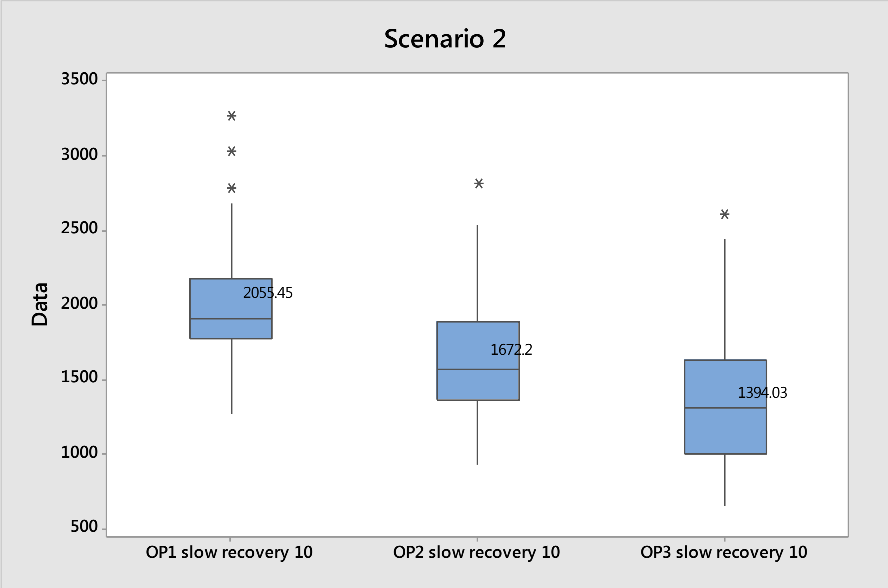

Figure 29 - Scenario 2 – gradual recovery with 10 units/period

Similarly, we can see the same varying performance in this scenario. While the distribution and the patterns of accumulation of backlog is different, inherently, the effect of information sharing on the performance of the system is still felt. At the same time, the policy with more sources of information also outperforms that with less information.

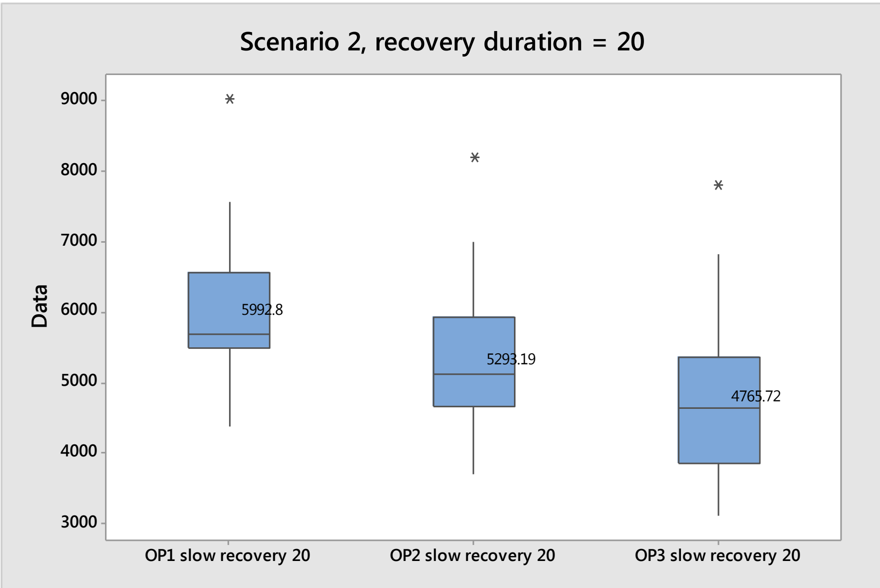

Figure 30 - Scenario 2 – gradual recovery with 20 units/period

In a similar argument, because of the fact that increasing recovery times will stress the entire system further, it is intuitive that in these more adverse conditions, the response and performance of all policies are affected. However, there is still value that justifies information sharing, because there is still a reduction in backorders accumulated, and this reduction is present in all conditions.

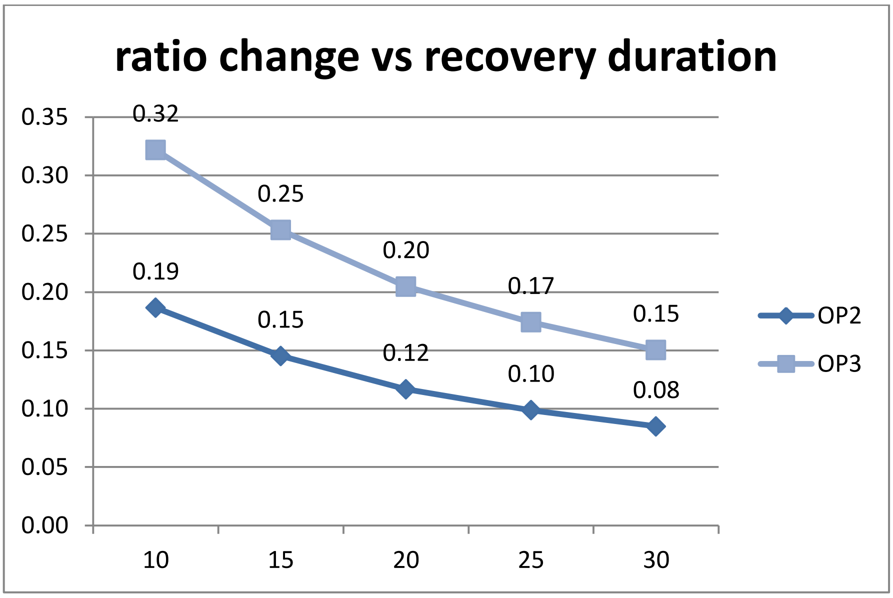

Figure 31 - Average effectiveness of information sharing with increasing recovery duration

4.7.3 Scenario 3

The previous scenarios described only deal with disruptions to one supplier. In this scenario, we will examine the possibility of a disruption to both suppliers. For the purpose of this paper, it is not meaningful to consider when both suppliers are completely down. A probable case is that they suffer a partial downtime and at different timings, which follows the distribution shown below.

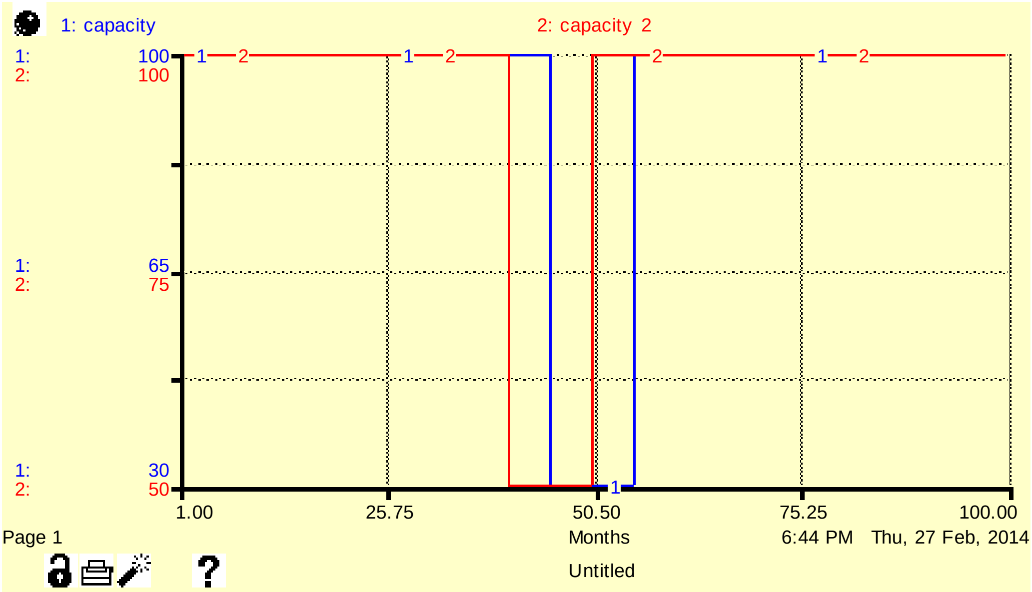

Figure 32 - Partial disruptions on both suppliers

For the discussion of these results, it is assumed that supplier 1 suffers a drop in capacity from 100 to 50 from time periods 40 to 50. Supplier 2 suffers a drop in capacity from 100 to 30 from time periods 45 to 55.

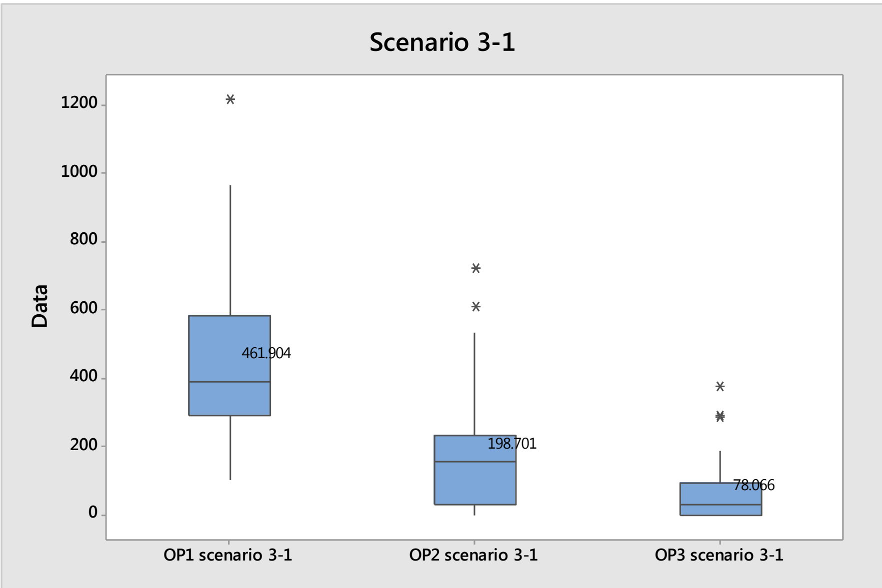

Figure 33 - Scenario 3 – supplier 1 drop in capacity from 100 to 50 during period 40 – 50 & supplier 2 drop in capacity from 100 to 30 during period 45 – 55

In another scenario, a slight variation of the shock is introduced. This time, one supplier is disrupted in a way that his capacity reduces from 100 to 30 from time 40 to 50, and the other supplier is disrupted in a way that his capacity reduces from 100 to 50 from time 45 to 55.

This scenario is tested to verify any difference in a larger shock introduced prior to a smaller shock.

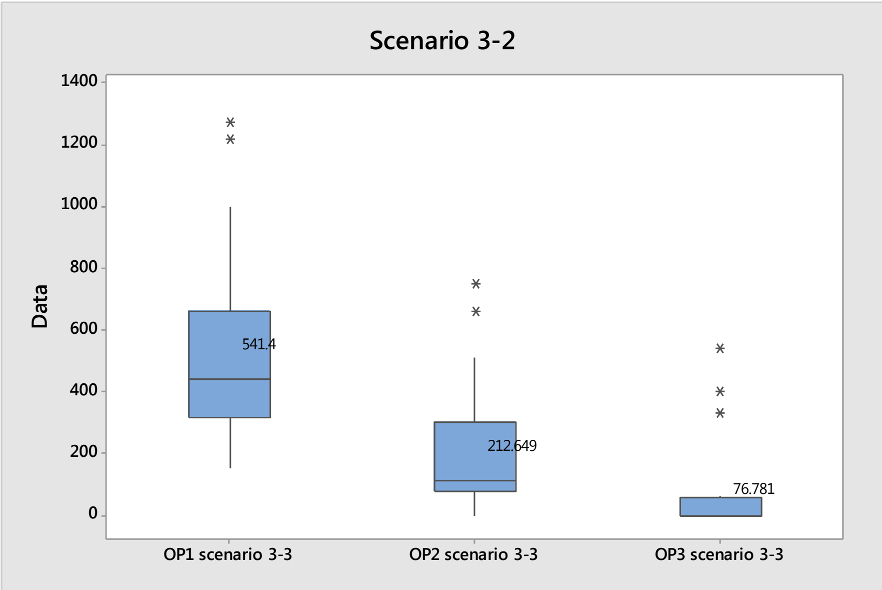

Figure 34 - Scenario 3 – supplier 1 drop in capacity from 100 to 30 during period 40 – 50 & supplier 2 drop in capacity from 100 to 50 during period 45 – 55

There are an infinite number of possibilities of combinations of partial shocks that can be tested, but this paper will look at the two just discussed.

These results are peculiar. Firstly, it shows a very pronounced difference between all the ordering policies. Next, attention should be drawn to the fact that in this particular scenario, the ordering policies that did not incorporate information sharing or incorporated partial information sharing performed worse than the base case as shown in scenario 1. This is intuitive because the shock is such that there should be a higher total number of shortages where both suppliers are concerned. Non-intuitively however, it is observed that the model with full information sharing actually fares better than its counterpart in scenario 1 as described previously.

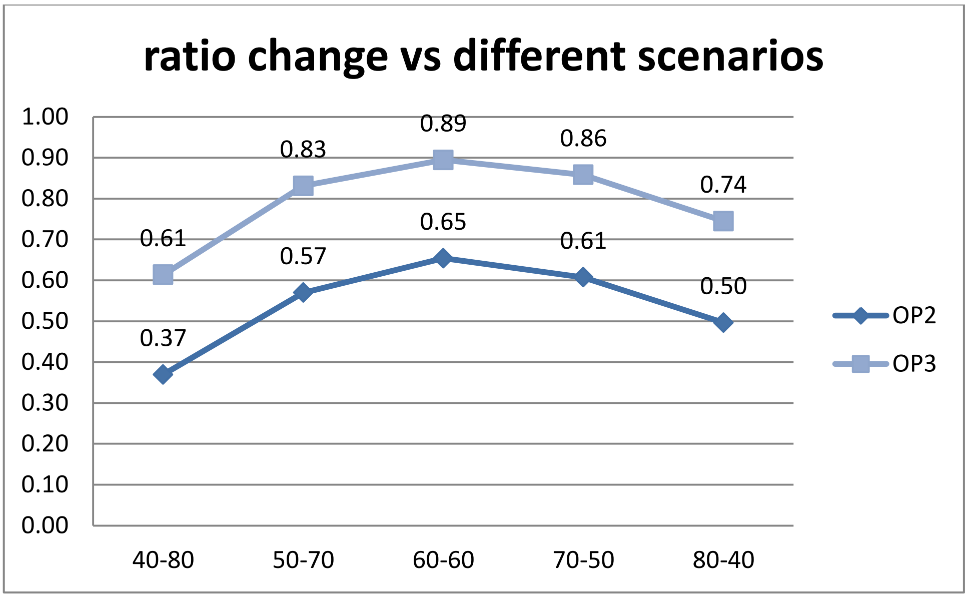

Figure 35 - Average effectiveness of information sharing with different scenarios

Figure 35 is to be read as follows. The x-axis shows us the type of shock that is introduced at which time period. For example, for '40-80', a supplier suffers a decrease in capacity from 100 to 60 from time period 40 to 50, and another supplier suffers a decrease in capacity from 100 to 20 from time period 45 to 55. Ordering policy 3 works best when the multiple shocks to both suppliers are almost equal. This increase in performance of the information sharing models may imply a better use of the available resources (i.e. the physical inventory in both suppliers) during these cases. This is much implication on the result of the study and the usefulness of the different ordering options. In the context of an environment where there may be multiple failures, it is advisable to consider all the information available. The significant change in performance for different ordering policies is also observed in other combinations that have been explored but not included in this paper.

CHAPTER V CONCLUSION AND FUTURE STUDY

5.1 Conclusion

In the context of this study, we started from a very broad topic, supply chain and supply chain risk management, to further investigate into supply chain risk identification, categorization, impacts evaluation. Derived from various literatures, we get to the point of how current supply chain tackle competitive risks by evaluate its competitive advantage in an appropriate way. From here, valued information could potentially be shared within a 2-echelon supplier (simplified model) has been summarized and further information sharing scheme is simulated in a System Dynamics model. In chapter IV, various ways of information sharing have been introduced and experimented. The focus has been kept to supply-side shocks and their respective results with regard to the backorders that are owed to the customers. Thus far, a few different scenarios have been explored:

i. The complete disruption of one out of two suppliers with an immediate recovery

ii. The complete disruption of one out of two suppliers with a slow recover

iii. Different levels of disruption to occur at both suppliers

The following have also been taken into account when dealing with these cases, namely, the variability of demand, the length of shock and the length of recovery of shock. A few different cases of partial disruption to both suppliers have also been explored.

It is concluded that the information sharing policies, in particular the ordering policy which takes into account multiple sources of information, works best in the 3rd scenario, there is value in introducing information sharing, with a customer service perspective in mind in all cases. Information about the state of the suppliers give suppliers a lower occurrence of not fulfilling a customer’s order and hence a higher service level.

5.2 Limitation and Future Study

In the context of this paper, there are many assumptions and simplifications in play which can be reviewed in further studies into this topic. Firstly, target inventory levels are constants and are based on simplifying assumptions. Further studies may look into the impact of different target levels as imposed by the different members within the supply chain.

Also, in this study of information sharing scheme, in order to keep things simple, a simple two-tiered supply chain is considered. This is not the case with many real-life supply chains which are much more complex and connects many more echelons and stakeholders. Further studies can deal with a supply chain with more layers and study the effect of the increase in complexity of the supply chain.

Furthermore, a big assumption is that suppliers are willing to share information with the manufacturer in order to attain a better service level. This may not be practical given the competitive nature of the suppliers. Suppliers may withhold information in order to retain its competitive edge over other members. This paper, while it forms the basis on which information sharing will benefit the supply chain, does not take into account the cost of information sharing. Further research can be done to incorporate this to perhaps justify the cost of sharing information, or determine a certain degree of information sharing that yields the best benefits.

Last but not least, system dynamics modeling is a fantastic tool to simulate complex model result by generating random number in order to better understand the real world with multiple scenarios. However, it is still a measurement system to measure pre-defined metrics which is backlogged orders in manufacturer in our case to analyze model. In future study, a repeatability and reproducibility study could be conducted to validate and demonstrate that model is reliable to deliver trusted result for further analysis and researching.

Due to lack of time and research experience, there might be some assumption to be to optimal and there might be some ambiguous explanations in this paper. Author would like to take any feedback for further discussion in order to improve the quality of this research. Again, some raw data, programming code are provided in Appendix.

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APPENDICES

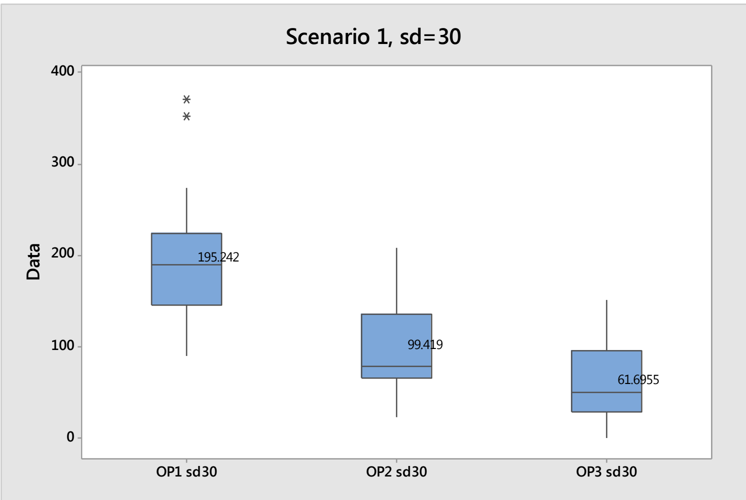
Appendix 1

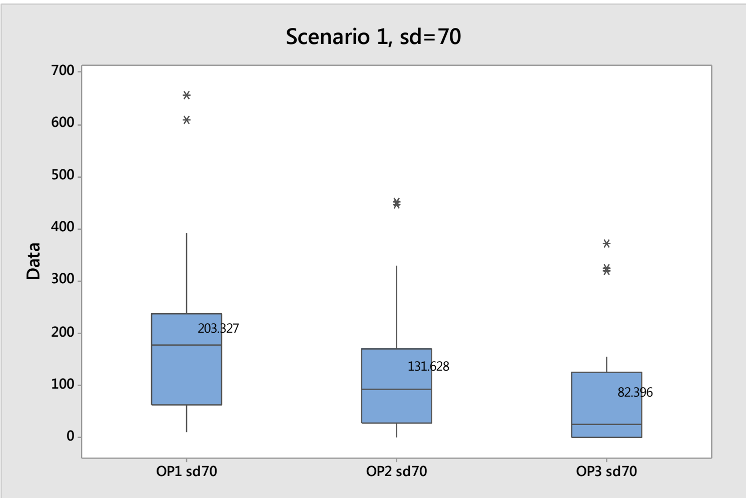
The following seed generators have been used in the course of the simulation. These seed generators were generated randomly.

22815	4520	31159	14117
2414	7913	12621	20170
2411	16520	21587	5951
26888	25756	24335	17884
29060	31556	3856	6761

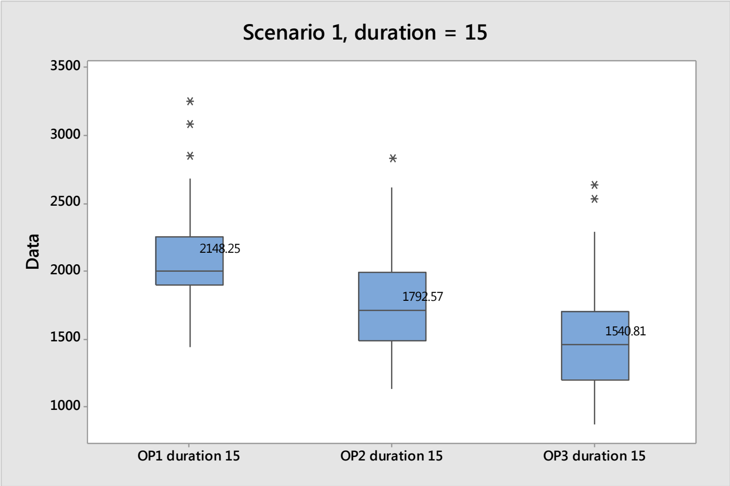
Appendix 2

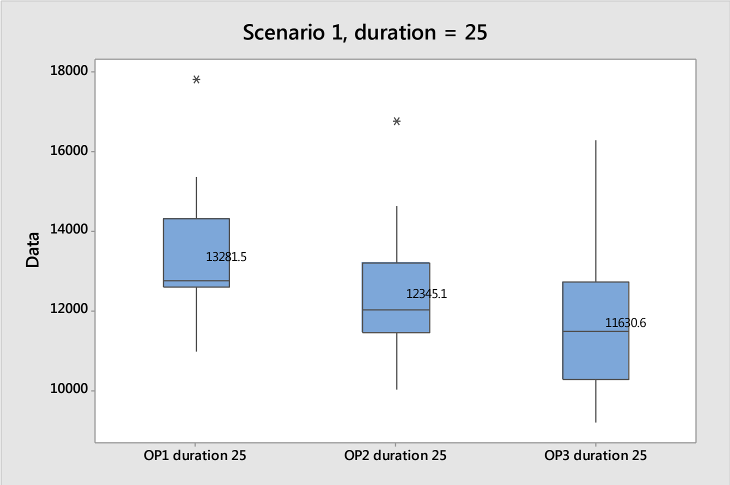
Ratio Changes vs. Demand Variation

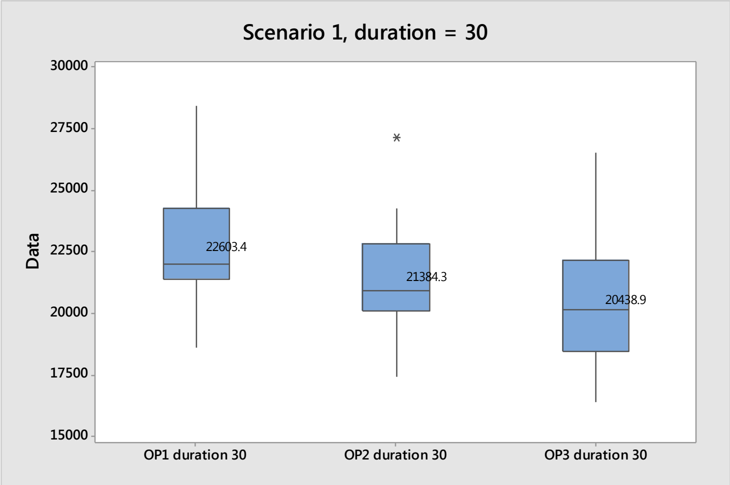




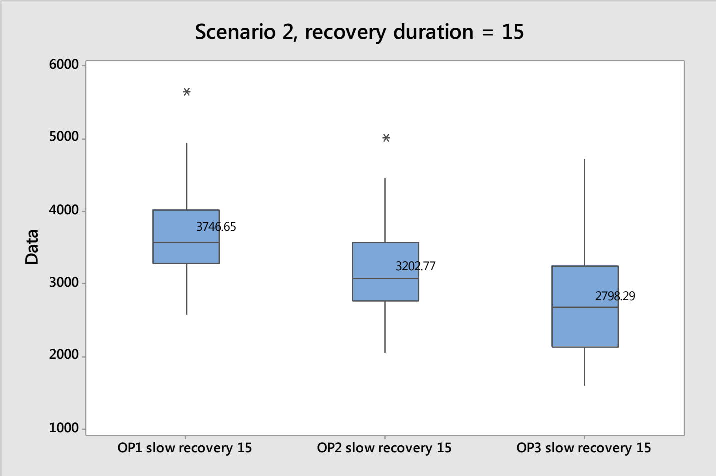
Ratio Changes vs. The Length of Shut Down

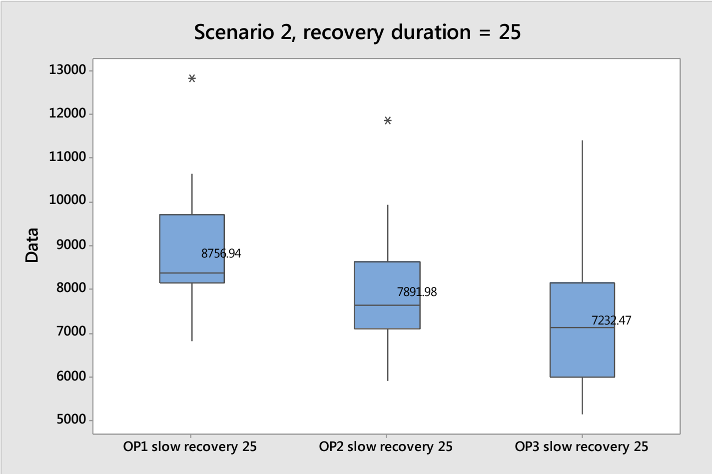


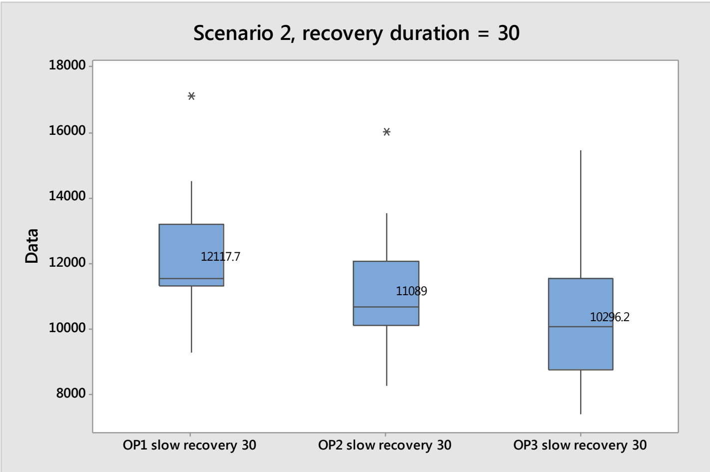




Ratio Changes vs. The Recovery Time







Appendix 3

Code used in iThink

The code here refers to that used in the base case, which has been defined to be scenario 1, with demand following a normal distribution with mean 150 and standard deviation 50.

Decision sectors for all three ordering policies have been added. Other scenarios follow largely the structure as follows except for changes with certain converters and stocks. For detailed codes for all scenarios, please contact the author.

Manuracturer inventory

local_inventory_1(t) = local_inventory_1(t - dt) + (trans - out) * dt

INIT local_inventory_1 = 0

INFLOWS:

trans = CONVEYOR OUTFLOW

    TRANSIT TIME = lead_time

OUTFLOWS:

out = orders_outstanding+customer_dd

Manufacturer backorder

orders_outstanding(t) = orders_outstanding(t - dt) + (BL_filling) * dt

INIT orders_outstanding = 0

INFLOWS:

BL_filling = customer_dd-out

Manufacturer transit

transit(t) = transit(t - dt) + (entry - trans) * dt

INIT transit = 0

    TRANSIT TIME = varies

    INFLOW LIMIT = INF

    CAPACITY = INF

INFLOWS:

entry = supplier_shipping_2+supplier_shipping

OUTFLOWS:

trans = CONVEYOR OUTFLOW

    TRANSIT TIME = lead_time

Manufacturer converters

avg_sales = SMTH1(customer_dd, 3)

customer_dd = normal(150,sd, seed)

desired_supplier_pipeline = avg_sales*lead_time

lead_time = 4

net_inventory = local_inventory_1-orders_outstanding

order = supplier_inventory_gap+supplier_pipeline_gap+avg_sales

recovery = 65

supplier_inventory_gap = target:supplier_inventory-net_inventory

supplier_pipeline_gap = desired_supplier_pipeline-transit-SP_backlog-SP_backlog_2

sd = 50

seed = 2

target:supplier_inventory = 150

supplier

SP_backlog(t) = SP_backlog(t - dt) + (wh_filling) * dt

INIT SP_backlog = 0

INFLOWS:

wh_filling = wh_ordering-supplier_shipping

SP_backlog_2(t) = SP_backlog_2(t - dt) + (SP_filling_2) * dt

INIT SP_backlog_2 = 0

INFLOWS:

SP_filling_2 = SP_ordering_2-supplier_shipping_2

supplier_inventory(t) = supplier_inventory(t - dt) + (manu - supplier_shipping) * dt

INIT supplier_inventory = 0

INFLOWS:

manu = if(warehouse_inventory_gap>=1) then capacity else if(warehouse_inventory_gap>-1)

then min(wh_ordering,capacity) else 0

OUTFLOWS:

supplier_shipping = if(SP_backlog=0) then wh_ordering else 1000

supplier_inventory_2(t) = supplier_inventory_2(t - dt) + (manu_2 - supplier_shipping_2) * dt

INIT supplier_inventory_2 = 0

INFLOWS:

manu_2 = if(supplier_inventory_gap_2>1) then capacity_2 else

if(supplier_inventory_gap_2>-1) then min(SP_ordering_2,capacity_2) else 0

OUTFLOWS:

supplier_shipping_2 = if(SP_backlog_2=0) then SP_ordering_2 else 1000

Supplier converters

capacity = 100

capacity_2 = 100 - step(100, 40) + step(100,recovery)

SP_inventory_position_2 = supplier_inventory_2-SP_backlog_2

SP_ordering_2 = order_2

target:supplier_inventory_2 = 150

supplier_inventory_gap_2 = target:supplier_inventory_2-SP_inventory_position_2

SP_inventory_position = supplier_inventory-SP_backlog

SP_ordering = order_1

target:supplier_inventory = 150

supplier_inventory_gap = target:supplier_inventory-SP_inventory_position

Decisions

Ordering Policy 1

ratio = (if(SP_backlog+SP_backlog_2 = 0) then 0.5 else

SP_backlog_2/(SP_backlog_2+SP_backlog))

ratio_2 = (if(SP_backlog+SP_backlog_2 = 0) then 0.5 else

SP_backlog/(SP_backlog_2+SP_backlog))

SP_ordering = order*ratio

SP_ordering_2 = order*ratio_2

Ordering Policy 2

ratio = if(warehouse_inventory_2+warehouse_inventory=0) then 0.5 else warehouse_inventory/(warehouse_inventory_2+warehouse_inventory)

ratio_2 = if(warehouse_inventory_2+warehouse_inventory=0) then 0.5 else warehouse_inventory_2/(warehouse_inventory_2+warehouse_inventory)

SP_ordering = order*ratio

SP_ordering_2 = order*ratio_2

Ordering Policy 3

case_letter = if(order-capacity_2-capacity<0) then 1 else 2

case_no = if(supplier_inventory-SP_backlog >0 and supplier_inventory_2-SP_backlog_2>0) then 1 else if(supplier_inventory-SP_backlog <0 and supplier_inventory_2-SP_backlog_2<0) then 2 else if(supplier_inventory-SP_backlog >0 and supplier_inventory_2-SP_backlog_2<0) then 4 else if (supplier_inventory-SP_backlog <0 and supplier_inventory_2-SP_backlog_2>0) then 3 else 0

O1_case_1a = if(supplier_inventory+supplier_inventory_2 = 0) then order/2 else supplier_inventory_2*capacity/(supplier_inventory+supplier_inventory_2) + supplier_inventory*(order-capacity_2)/(supplier_inventory+supplier_inventory_2)

O1_case_1b = capacity*order/(capacity+capacity_2)

O1_case_2a = capacity*order/(capacity+capacity_2)

O1_case_2b = if(SP_backlog+SP_backlog_2 = 0) then 0.5*order else SP_backlog*(order-capacity_2)/(SP_backlog+SP_backlog_2)+SP_backlog_2*capacity/(SP_backlog+SP_backlog_2)

O2_case_1a = order-O1_case_1a

O2_case_1b = order-O1_case_1b

O2_case_2a = order-O1_case_2a

O2_case_2b = order-O1_case_2b

order_1 = if(case_no = 1 and case_letter=1) then O1_case_1a else if(case_no = 1 and case_letter=2) then O1_case_1b else if(case_no = 2 and case_letter=1) then O1_case_2a else if(case_no = 2 and case_letter=2) then O1_case_2b else if(case_no = 3) then 0 else if(case_no=4) then order else 0

order_2 = if(case_no = 1 and case_letter=1) then O2_case_1a else if(case_no = 1 and case_letter=2) then O2_case_1b else if(case_no = 2 and case_letter=1) then O2_case_2a else if(case_no = 2 and case_letter=2) then O2_case_2b else if(case_no = 3) then order else if(case_no=4) then 0 else 0