TLI – Asia Pacific White Papers Series

A Risk Management Framework for Supply Chain Networks

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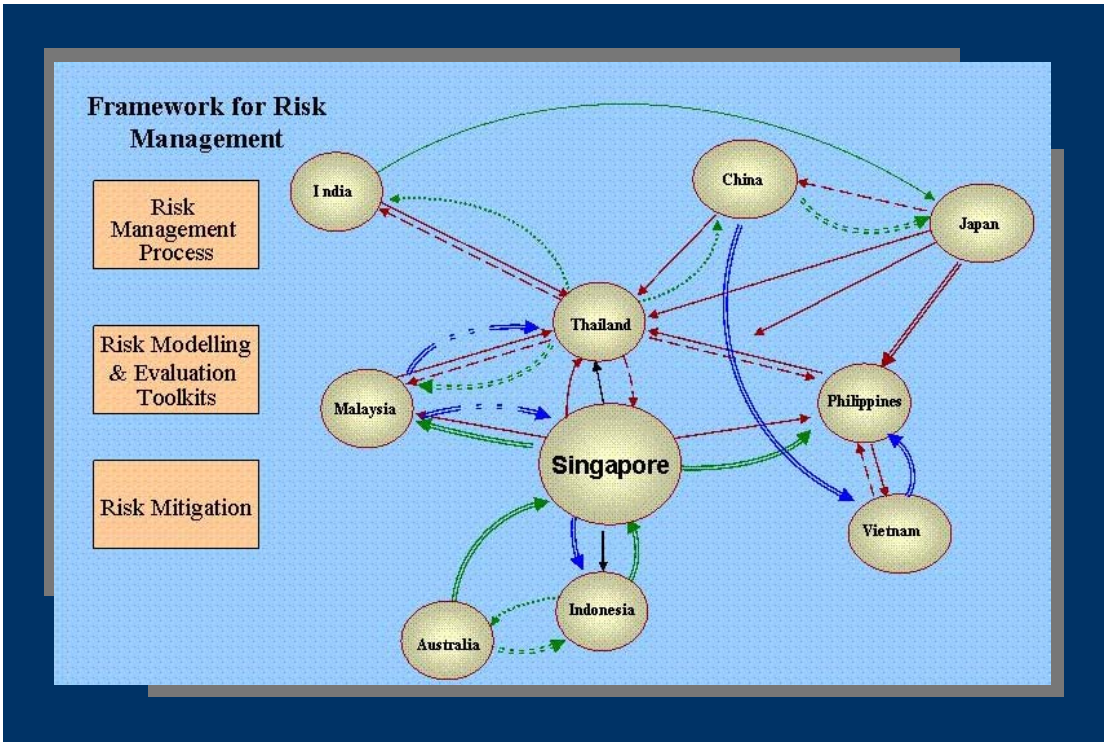

A Collaboration Between

The Logistics Institute Asia Pacific

NUS National University of Singapore

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The Logistics Institute – Asia Pacific (TLI – Asia Pacific) is a collaboration between the National University of Singapore and the Georgia Institute of Technology. Modelled after The Supply Chain and Logistics Institute (formerly TLI) at Georgia Tech, the Institute's vision is to be the premier institute in Asia Pacific nurturing logistics excellence through research and education. TLI – Asia Pacific was awarded the prestigious Asian Freight & Supply Chain Award (AFSCA) for Best Educational Course Provider for four consecutive years, from 2003 to 2006.

The Institute provides postgraduate education in logistics and SCM at the MSc and PhD level, notably the Dual Masters Degree in Logistics and SCM. It also undertakes leading-edge research and development in supply chain engineering, technology and management in collaboration with industry; and hosts a regular series of Think Tables that brings thought leaders in research and industry to discuss contemporary issues, challenges and solutions in supply chain management in a dynamic environment.
The key research themes for Phase 2 include:

Supply Chain Intelligence: This area seeks to focus on providing an overarching analysis of the logistics market, the trade flows, and economic barometers of the various countries in Asia as far as it pertains to effective supply chain management for various industries. Interest in this area is heavily driven by data, empirics and company cases. The Institute conducts annual on-going surveys to test the pulse of the respective markets and industries such as cold chain, 3PL, etc.

Supply Chain Optimisation: This, being the traditional and existing strength of the Institute, seeks to deepen expertise in supply chain global network design and optimisation, involving the respective modes of transportation. Intensive supply network simulation on a regional/international basis e.g. port and maritime logistics, consolidation of logistics hubs, flexibility of regional distribution centres are a primary feature of this group. Other areas of interest include system productivity at the port, the integration of manufacturing and services within the value network, dynamic pricing and revenue management for high end perishables, and the study of mergers and acquisition and its impact on the respective industries.

Supply Chain Technology: This is an emerging area for the Institute, which intends to look at the test bedding of RFID and data capture related technologies, within the context of an independent environment. Work done in this area involves both investigative led research and joint development of supply chain technology based innovation with other agencies and companies. Policy and implementation issues pertaining to new supply chain technology and the end-to-end supply chain network are undertaken on a contract research basis.

A Risk Management Framework for Supply Chain Networks

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Glossary

3PLs	Third Party Logistics Providers
GUI	Graphical User Interface
LLP	Lead Logistics Provider
SAA	Sample Average Approximation
SCRMF	Supply Chain Risk Management Framework
VaR	Value at Risk

Risk Averse Rate	A value between 0 and 1 given by the decision maker in advance
Investment Loss Rate	The investment loss rate which is a number between 0 and 1
Initial Capital	The initial investment capital set by the decision maker
Material Loss Rate	The rate of the material loss which lies between 0 and 1
Expected Total Profit	The expected total profit of the decision maker before the realization of the risks occurred in the supply chain network

Introduction

Success in today's business depends on superior supply chain planning and execution. Supply chain speed and flexibility have become two key levers for competitive differentiation and increased profitability. Within a global trade environment, one of the biggest challenges is the ability to manage seamless forward and backward flows of material and information. Faced with increasing global competition in the past two decades, a popular strategy adopted by many successful companies to address these challenges involves outsourcing logistics and supply chain activities/processes to reliable third-party logistics providers (3PLs), and focusing on core competency. Indeed, logistics outsourcing continues to expand in the Asia-Pacific. With more than 84% of companies operating in the Asia-Pacific relying on 3PLs, the logistics outsourcing industry in this region increasingly attracts global 3PLs.

In general, supply chain management deals with the management of material, information, and financial flows in a network consisting of vendors, manufacturers, distributors and customers. As such, supply chain management can involve a variety of issues ranging from product/process design, production, third party logistics and outsourcing, supplier contracting, incentives and performance measures, multi-location inventory coordination, and so forth. Today, many different disciplines such as marketing, economics, operations research, management science, and operations management, have brought to bear concepts that are commonplace throughout the supply chain management literature. Managing flows in this network is a major challenge due to the network complexity, the proliferation of products and the presence of multiple decision makers who each owns and operates a piece of this network and optimizes a private objective function. Work on supply chain management research, as found in the taxonomic review by Ganeshan et al. (1999), can be classified under three aspects: competitive strategies, firm focused tactics, and operational efficiencies.

For supply chain networks that comprise hundreds of companies with several tiers, there are numerous risks to tackle (we will elaborate on some of these in a later discussion). Generally, these risks can be classified into two types: risks arising from within the supply chain network and risks external to the network. The attributes of operational risks are due to the interactions between firms across the supply chain network, such as supply risk, demand risk, and trade credit. Disruption risks arise from interactions between the supply chain network and its environment, such as terrorism, or natural disasters like SARS. Therefore, supply chain risk management can be defined as the identification and management of operational risks and disruption risks through a coordinated approach amongst supply chain members to reduce the supply chain vulnerability as a whole.

It should be noted that risk cannot be eliminated. Because of the complex nature, various tools may be used to allow business stakeholders and government bodies to build up an overall picture of the risk situation and plan a migration strategy to address critical areas.

At present, with growing emphases on globalization, business process outsourcing and the need to control terrorism, there is a stronger need to understand and handle supply chain vulnerabilities. Paulsson (2003) has presented an article, reviewing current research on supply chain risk management. However, neither detailed strategic approach nor quantitative model was discussed. This project aims at filling this gap.

A risk management framework has been developed to allow various risk assessment methodologies to be categorized in terms of their roles in building this risk picture. This framework is built around various stages of risk identification, evaluation and reaction, positioning appropriate tools to each stage. This framework will accommodate new tools and methodologies. The established toolkit can be applied to supply chain network models with multi-tier suppliers and leading logistics provider network models. A user-friendly interface to implement the toolkit has also been designed.

We have also carried out an impact analysis of risk factors in supply chain management. A survey on risk management in supply chains of firms in Singapore was carried out. We focussed on 3PLs services in Singapore as the findings could be viewed as future benchmarks for the whole Asian region, especially for the Southeast Asian region.

Singapore as a Global Distribution Hub

This work is set in the context of Singapore as a global distribution hub of the future, providing a supply chain ecosystem that is enabled by technology. This context is depicted in Figure 1.

Within this context, there are two major aspects: supply chain management, and supply chain risk management. First, according to the Council of Supply Chain Management Professionals (www.cscmp.org), supply chain management can be defined as: *the management of material, information and financial flows through a network of organizations (i.e.: suppliers, manufacturers, logistics providers, wholesalers/distributors, retailers, etc.) that aims to produce and deliver products or services for the consumers. It includes the coordination and collaboration of processes and activities across different functions such as marketing, sales, production, product design, procurement, logistics, finance, and information technology within the network of organizations*. Following Deloitte and Touche (www.deloitte.com), supply chain risk management is defined as: *the management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity*.

In general, supply chains risks can be categorized into two types: *operational risks* and *disruption risks*. Based on the above definitions on supply chain management and supply chain risk management, to mitigate supply chain risks, we can adopt the following basic approaches simultaneously: supply management, product management, demand management, and information

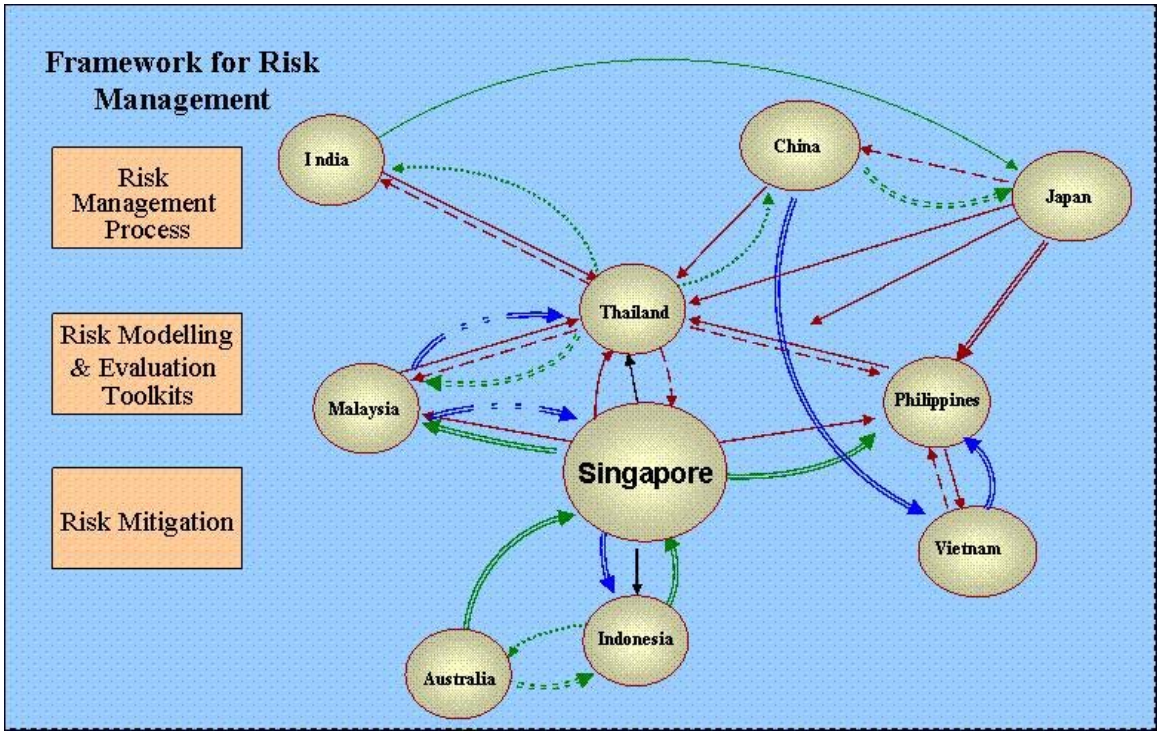

Figure 1: Singapore as a Global Supply Chain Hub

management, where operational risks and disruption risks are involved. Table 1 provides some plans for managing supply chain risks tactically and strategically.

It is known that operational risks are referred to the inherent uncertainties involved in supply chains,

	Supply Management	**Demand Management**	**Product Management**	**Information Management**
Strategic Plan	supply network design	product rollovers, product pricing	product variety	supply chain visibility
Tactical Plan	supplier selection, supplier order allocation, and supply contracts	shift demand across time, markets, and products	postponement and process sequencing	information sharing, vendor managed inventory, and collaborative planning, forecasting and replenishment

Table 1: Plans for Managing Supply Chain Risks

such as: uncertain customer demand, uncertain supply, and uncertain cost. These random factors can be found in dynamic supply chains. Disruption risks represent major disruptions caused by natural and/or man-made disasters, such as: earthquakes, floods, hurricanes, terrorist attacks, electricity blackouts, diseases, etc., or economic crises, such as: currency evaluation or strikes. In most cases, the business impacts associated with disruption risks are much bigger than those associated with

operational risks. However, the former occur with very low possibility while the latter occur with high possibility. Thus, people from both the academy and the industry have paid more efforts in dealing with operational risks in the past. However, with increasing terrorism risks, natural disasters, and diseases which have occurred recently, such as: the South Asian tsunami on 26 December 2004, the London bombings on 7 July 2005, and the H5N1 bird flu in Asia in 2005, both governments and people from the industry and the academy began to realize the importance of managing disruption risks as well as mitigating the following impacts.

Figure 2 describes four basic approaches to mitigate the impact of supply chain risks: supply management, demand management, product management, and information management. Each of these four basic approaches is intended to improve supply chain operations via coordination or collaboration as follows: (i) a firm can coordinate or collaborate with upstream partners to ensure

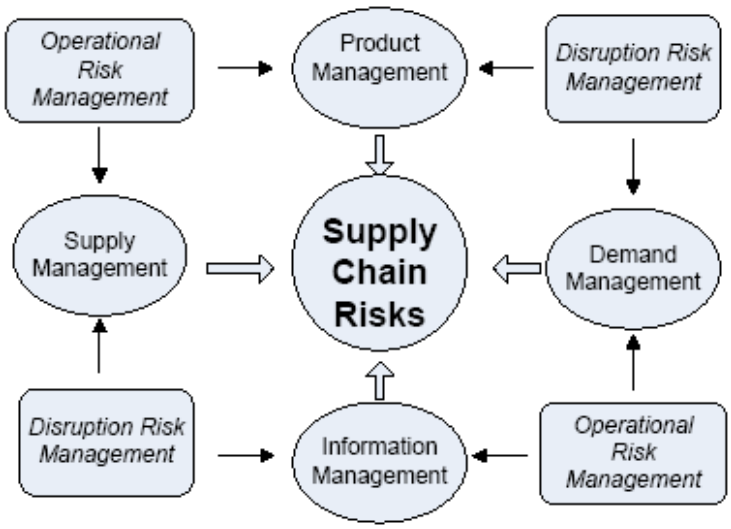

Figure 2: Approaches for Managing Supply Chain Risks

efficient supply of materials; (ii) a firm can coordinate or collaborate with downstream partners to influence demand in a beneficial manner; (iii) a firm can modify product or process designs to balance supply and demand; and (iv) supply chain partners can improve their collaborative performance if they can share necessary information through the supply chain. While implementing the above four steps, a firm needs to consider both operational risks, disruption risks and risks involved with its upstream and downstream partners as well.

An Integrated Supply Chain Risk Management Framework

There are commonly used risk management processes that are widely applied in the industry. This work is set in the context of a familiar risk management process which is generally adopted for risk management in the industry. This avoids having to re-invent common risk management processes,

facilitates understanding of our new work and promotes acceptance. However, we have extended this framework in order to focus on the specific needs of managing risks in supply chains.

In general, most risk management processes consist of four main components, namely: ***risk identification***, ***risk assessment***, ***responding to risk***, and ***monitoring and evaluation***. This process is iterative and is shown in Figure 3. It should be noted that Figure 4 presents a supply chain risk management framework which includes the extensions that have been added to Figure 3 and is particular to this project.

As shown in Figure 4, the extensions to the common processes are Risk Measure, Disruption Risk Management, Toolkits/Stochastic Models, Solution Method and Operational Risk Management. These extensions are to provide new measures for the study of supply chain risks.

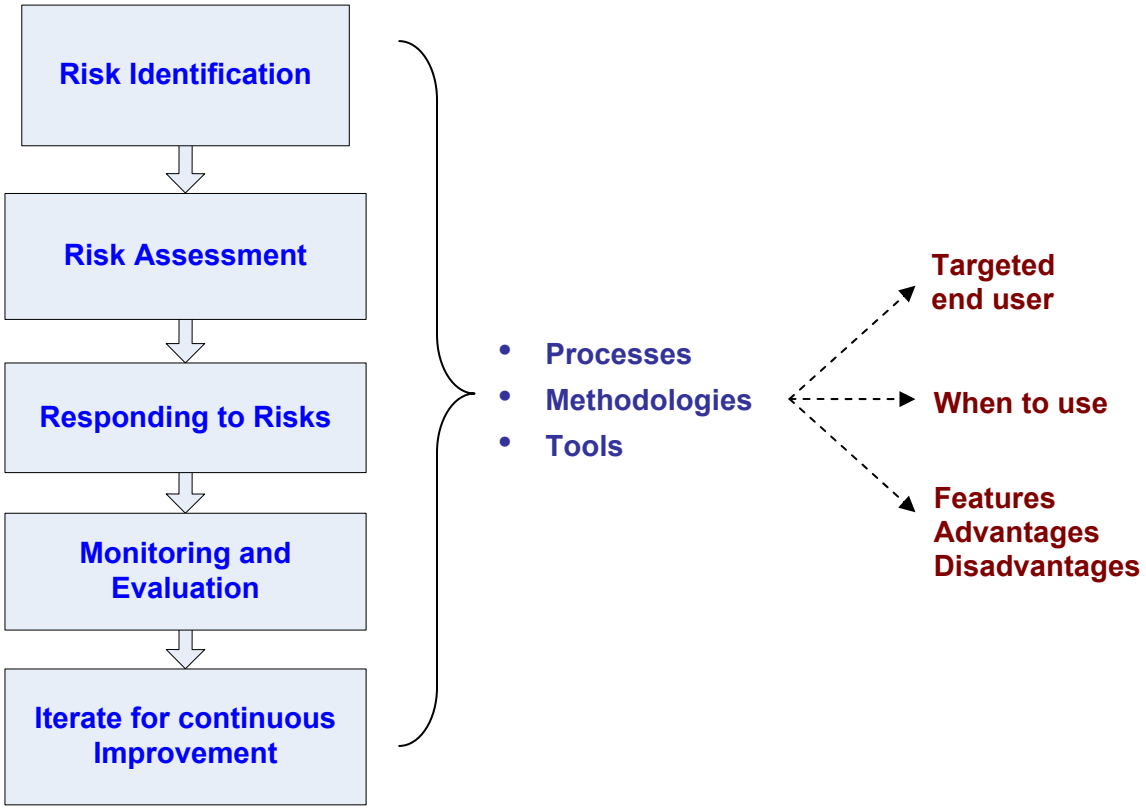

Figure 3: Risk Management Framework

The supply chain risk management framework (SCRMF) covers both disruption risk management and operational risk management. In the framework, we adopt two recent-developed techniques in measuring risks and in simulation, respectively:

- A measure of risk: Conditional Value at Risk (CVaR);
- A numerical approach: Sample Average Approximation (SAA).

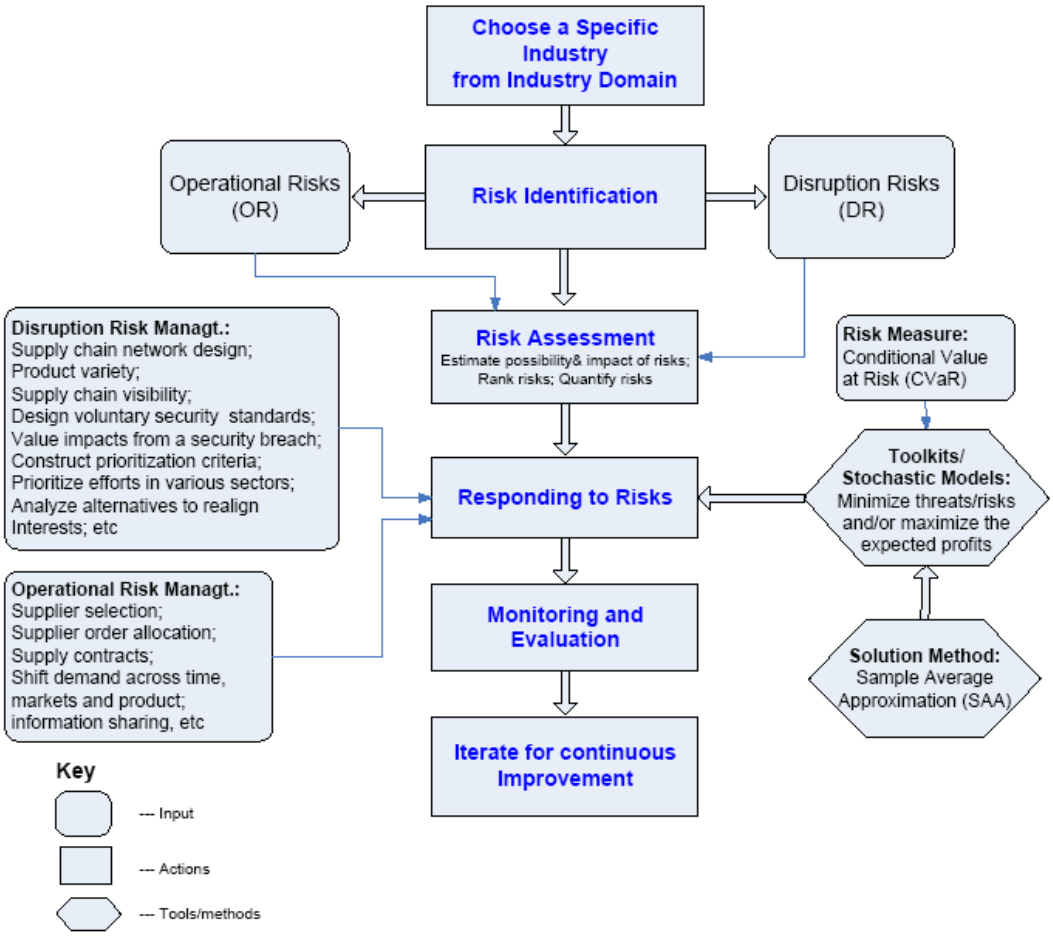

Figure 4: Supply Chain Risk Management Framework

Risk Identification

In general, the firms need to consider the following items in risk identification:

- Defining the problems or opportunities, scope, context and associated risk issues;
- Deciding on necessary people, expertise, tools and techniques, such as: scenarios and brainstorming;
- Performing a stakeholder analysis, determining risk tolerances, stakeholder position, attitudes, etc; and
- Identifying critical supply chain system, process, and production activities.

Risk Assessment

After identifying risks, the firms need to make a risk assessment. One way to characterize risk can be defined as the multiplication of its impact of consequence and the likelihood of its occurrence. The firms should take into account the following factors in general:

- Analyzing results of environmental scan, determining categories of risks, significant organization wide issues, and vital local issues;
- Measuring the associated risks using likelihood and impact risk matrix tables based on the empirical/scientific evidence and public context; and
- Ranking risks, considering risk tolerance.

Using the likelihood and the impact of risk, we can characterize the value of risks by the following equation:

Risk = Impact x Likelihood

Responding to Risk

After deriving the risk product profile matrix, the firms should study how to respond to underlying risks. The following points are very important and can be used during this stage:

- Defining objectives and expected outcomes for risks in a certain period;
- Identifying and analyzing options by minimizing risks/threats and maximizing opportunities/profits;
- Choosing a strategy, applying decision criteria;
- Applying the precautionary approach or principle as a means of managing risks of serious or irreversible harm in situations of scientific uncertainty; and
- Developing and implementing a plan.

In the following, three toolkits for responding to risks (see Figure 5), called the *Basic Toolkit*, the *Intermediate Toolkit*, and the *Advanced Toolkit* will be introduced. These toolkits have their own interests and features in managing risks in supply chains and somehow complement each other. As we shall see, the Basic Toolkit serves as a tactical scenario whereas the Advanced Toolkit serves as a strategic containment or remedy while the functions of the Intermediate Toolkit appear between these two toolkits.

Basic Toolkit

Table 2 shows the *Basic Toolkit*, where Category A and B represent Operation Risk and Disruption Risk, respectively. H, M, and L stand for High, Medium, and Low, and represent the different weights

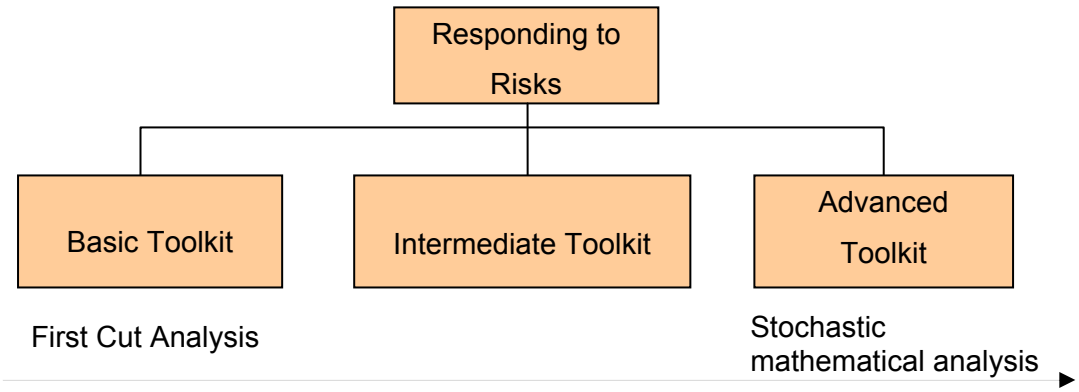

Figure 5: Classification into Three Risk Response Toolkits

of risks. Note that the Basic Toolkit in Table 2 can be treated as a risk management pattern which should be adjusted based on a case by case basis. For example, in practice, there may be a couple of or even tens of categories regarding the risks for a certain industry or firm. In such a case, we need to recast the risk indices accordingly. Similarly, the weights of risks can also be further divided into more options, such as: High, Medium High, Medium, Medium Low, and Low.

Risk No.	Category	Weight	There is a risk that … Risk description	Because…(causes) Containment (what we'll do to stop it)	Therefore …(impacts) Fallback (what we'll do if it happens)
R001	A/B	H/M/L	……	……	……
R002	A/B	H/M/L	……	……	……
R003	A/B	H/M/L	……	……	……
……	……	……	……	……	……
Rxxx	A/B	H/M/L	……	……	……

Table 2: Basic Toolkit for Supply Chain Risk Management

Intermediate Toolkit

The next toolkit, called the *Intermediate Toolkit*, is described in Table 3, and is designed based on the risk product score matrix for a certain potential risk in the supply chain network for a specific firm. The bigger the value in the matrix, the more rigorous and extensive are control and management. The managers may also refer to the scenarios concerning disruption risk management and operational risk management suggested in the risk management framework in Figure 4. Moreover, due to the huge impacts of disruption risks, senior management executives should be informed timely when needed

and immediate and proactive scenarios or alternatives should be made to hedge and mitigate the expected consequence of risks.

Impact	Risk Management Action		
High	5 Considerable management required	**15** Must manage and monitor risks	**25** Extensive management essential
Medium	3 Risks maybe worth accepting with monitoring	9 Management effort worthwhile	**15** Management effort required
Low	1 Document risks	3 Document and monitor risks	5 Manage and monitor risks
	Low	*Medium*	*High*
	Likelihood		

Table 3: Intermediate Toolkit for Supply Chain Risk Management

Advanced Toolkit

We now propose a novel toolkit, the *Advanced Toolkit*, for risk management in supply chains, which is developed in this project. The supply chain network under consideration consists of one object player in the supply chain network; say a manufacturer company, or even a certain economic region such as Singapore, just depending on the nature of the objects in the network; and two tiers of finitely many players in the network which are closely connected to the object player. For example, the players of the downstream tier could be suppliers who ship raw materials to the object player for producing products, while the players from the upstream tier can be viewed as the distributors, which deal with the products manufactured by the underlying player. Clearly, there are many different kinds of risk that could occur in the chain. Our toolkit is aimed to help the object player to make an optimal decision for its production activity with the purpose of maximizing the profit and minimizing the risks.

The Advanced Toolkit, with a series of boxes and mechanisms, is presented in Table 4 and shows the interactions among them. The purpose of the Risk Engine is to maximize the profit as long as the risk impact, which is measured by the conditional value at risk, satisfies a prescribed allowance in advance. The mathematical model in the Risk Engine is the sample average approximation problem of a stochastic mathematical program, in which the decision-maker seeks to maximize the expectation

of his profits and at the same time to minimize the risks/loss due to the random supply chain risks, satisfying all constraints in the entire supply chain network. The motivation of the model, in particular the adoption of the risk measure, CVaR, follows from the well developed risk management model in finance.

Note that the risk engine hides the mathematical complexities and allows firms to analyze and mitigate risks easily. The inputs in the risk engine are basic elements for firms, such as: the confidence level or the likelihood of the occurrence of loss and return, prices of transactions, capacity, and the profit objective. For the sake of convenience and simplicity in understanding and implementing the toolkit, one can set some technical parameters like the sample size used in the simulation and the smoothing parameter used in numerical computations as defaults in the system. Also, the mathematical model used in the Risk Engine can be altered depending on the preference of the decision-maker.

Input:

the risk averse rate, the initial capital, the investment loss rate, the prescribed possibility, prices of transaction, capacity constraints, the profit objective, the number of underlying players, the types of random risks and their distributions, the sample size used in simulation, ·····

↕

Risk Engine:

$$
\begin{aligned}
\max_z \quad & (1-\lambda)\tfrac{1}{N}\textstyle\sum_{i=1}^{N}\varphi(x,y^i) - \\
& \lambda\left(u+\frac{1}{2N(1-\alpha)}\textstyle\sum_{i=1}^{N}\left(\sqrt{(u-f(x,y^i))^2+\mu^2}-u+f(x,y^i)\right)\right) \\
\text{s.t.} \quad & \tfrac{1}{N}\textstyle\sum_{i=1}^{N} h_l(x,y^i)=0, \quad l=1,2,\cdots,\iota, \\
& \tfrac{1}{N}\textstyle\sum_{i=1}^{N} h_l(x,y^i)\le 0, \quad l=\iota+1,\cdots,\kappa, \\
& u+\frac{1}{2N(1-\alpha)}\textstyle\sum_{i=1}^{N}\left(\sqrt{(u-f(x,y^i))^2+\mu^2}-u+f(x,y^i)\right)\le \gamma M_0, \\
& u+\frac{1}{2N(1-\alpha)}\textstyle\sum_{i=1}^{N}\left(\sqrt{(u-f(x,y^i))^2+\mu^2}-u+f(x,y^i)\right)\ge \beta, \\
& z=(x,u)\in X\times\mathbb{R}.
\end{aligned}
$$

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Output:

the optimal responses, the expected total profit with respect to the risk averse rate, the mean of loss with respect to the risk averse rate, the minimum value of risk or loss with the prescribed possibility

Table 4: Advanced Toolkit for Supply Chain Risk Management

Here, x denotes the vector of decision variables and y denotes the vector of risks occurred in the supply chain network. λ denotes the risk averse rate with $0 \leq \lambda \leq 1$, which is given by the decision maker in advance. φ denotes the profit function of the firm which equals to the difference between its revenue and cost. α denotes the likelihood of the occurrence of loss and return, M_0 represents the initial investment, γ denotes the investment loss rate. B denotes a lower bound of the minimal value at risk. h_l denotes the constraints which reflect the capacity, the product flow, etc. f denotes the loss function which equals to $-\varphi$. N denotes the sample size of the random vector. μ is a smoothing parameter which is a small positive number. u is an extra variable in the model. X denotes the feasible set of the decision variables, such as: the nonnegativeness or/both the boundedness.

Table 5 summarizes the different features of the three toolkits. Firms can use these three toolkits to monitor and mitigate risks in their supply chains.

Risk Toolkits	Basic Toolkit	Intermediate Toolkit	Advanced Toolkit
Main features	An intuitive method; easy to understand; convenient to implement; and no quantitative analysis.	An intuitive method; easy to understand; convenient to implement; and little quantitative analysis;	Hide complexity; a novel risk engine; new risk measure added; SAA simulation method; high quantitative analysis; and parameters can easily be adjusted.
When to use	Short-term planning	Short-term or mid-term planning	Mid-term or long-term planning
Who is likely to use	Mid/lower-level executives	Managers	Managers or senior executives
How to use	Manual	Manual	Computer-aided risk management toolkit

Table 5: Features of the Three Toolkits

Monitoring and Evaluation

At last, firms are required to monitor and evaluate the consequences of risks, actions taken in the last stage, based on the feedbacks. The followings are some main points to take into consideration:

- Learning, improving the decision-making and risk management processes not only locally but also at a company-wide level, using effectiveness criteria and reporting on performance and results; and
- Iterating for continuous improvement.

Visual Interfaces to Risk Management Tool

To implement the Advanced Toolkit as discussed previously, a graphical user interface (GUI) was developed. Specifically, three different kinds of supply chain network models are considered:

(i) a supply chain network with suppliers and distributors; (ii) a supply chain network with multi-tier suppliers and distributors; (iii) a LLP (lead logistics provider) supply chain network with 3PLs and manufacturers. The users only need to input the initial data of supply chain risk management problem.

Impact Analysis

An impact analysis of risk factors in supply chain management was made. A survey on risk management in supply chains of firms in Singapore was carried out. 83 firms took part in this survey. The risks factors were categorized into macro level risks, demand management risks, supply management risks, production/service management risks, and information management risks. In the survey, the impact and frequency of each type of risks were proposed to each firm. To quantify the risk, the risk score matrix in the intermediate toolkit was adopted. In this report, the values of impact were ranked from 1 to 4, where 1 denotes *very low*, 2 *minor*, 3 *serious*, and 4 *catastrophic* impact of risks. Similarly, the values of frequency were ranked as 1, 2, 3, and 4 to represent *rarely*, *sometimes*, *often*, and *very frequent* the frequency of the occurrence of risks. Based on the above equation, we have a risk score matrix together with risk management actions as shown in Table 6.

Three different kinds of risk management action zones were defined, i.e.: a *green zone*, a *yellow zone*, and a *red zone* according to the values of the risks. If the value of risk was less than or equal to 2, the risk then belonged to the green zone; if the value of the risk was greater than 2 and less than 7, then it belonged to the yellow zone; if otherwise, it belonged to the red zone. For the risk action zones, we can see that firms only need to document and monitor risks if the risk falls in the green zone, and that they must take preventive measures as well as writing proper documentation for risk management in the yellow zone. However, firms must take extensive management essential actions if the risk lies in the red zone. In the survey, respondents were required to choose the appropriate values of impact and the likelihood of the occurrence of every type of risks from the set of {1, 2, 3, and 4}.

Risk Management Action

	Very Low	Minor	Serious	Catastrophic
Rarely	1	2	3	4
Sometimes	2	4	6	8
Often	3	6	9	12
Very Frequent	4	8	12	16

Green	Document and monitor risks on a day-to-day basis
Yellow	Must take preventive measures as well as proper documentation for risk management
Red	Must take extensive management essential actions

Table 6: Risk Management Action

For each type of risks, its value was calculated using the responses of the firms according to the risk equation described in the Risk Assessment on page 7 (i.e.: Risk = Impact x Likelihood). The average value of the underlying risk of the total number of 83 respondent firms was then derived. The percentages of respondents belonging to the risk management action zone for each risk were also calculated. The results are reported in Table 7 to Table 11, respectively.

No.	Type of Risk	Risk Action Zone			Average Risk
		Green Zone	Yellow Zone	Red Zone	
a.	Natural Disaster (e.g., Earthquake, Tsunami)	50.6	48.2	1.2	2.33
b.	Diseases (e.g., SARS, bird flu)	28.92	67.47	3.61	3.14
c.	Political unrest (e.g., Civil unrest)	48.19	51.81	0.00	2.40
d.	Terrorism (e.g., 9/11)	36.14	57.83	6.02	3.30
e.	Currency fluctuations	28.92	51.81	19.28	4.71
f.	Government regulations (e.g., Environmental laws)	31.33	55.42	13.25	4.42
g.	IT breakdown (e.g., Virus, Internet disruption)	9.64	73.49	16.87	4.95
h.	Labor strikes	53.01	46.99	0.00	2.10
i.	Lack of skilled personnel	28.92	59.04	12.05	4.24
j.	Immigration related workforce shocks	67.47	30.12	2.41	2.05
Average Macro Risks		**38.31**	**54.22**	**7.47**	**3.36**

Table 7: Analysis of Macro Level Risks

No.	Type of Risk	Risk Action Zone			Average Risk
		Green Zone	Yellow Zone	Red Zone	
a.	Sudden loss of demand due to an economic downturn	16.87	71.08	12.05	4.58
b.	Volatile demand / decline in demand	13.25	67.47	19.28	5.31
c.	Receivable losses caused by delinquent customers	34.94	57.83	7.23	3.57
d.	Changes in customer tastes	37.35	53.01	9.64	3.99
e.	Failed communication with the customers	22.89	68.67	8.43	4.06
f.	Increase in customers' bargaining power	25.30	62.65	12.05	4.66
Average Demand Management Risks		**25.10**	**63.45**	**11.45**	**4.36**

Table 8: Analysis of Demand Management Risks

No.	Type of Risk	Risk Action Zone			Average Risk
		Green Zone	Yellow Zone	Red Zone	
a.	Delays in the availability of materials from suppliers, leading to shortage	28.92	59.04	12.05	4.00
b.	Suppliers' bankruptcy	57.83	42.17	0.00	2.22
c.	Failed communication with the suppliers	44.58	65.06	2.41	3.20
d.	Breach of partnership (e.g., violation of company information, integrity of cargo due to loss)	43.37	55.42	1.20	2.54
e.	Delays in material flow due to the inability of suppliers to respond to changes in demand (through high capacity utilization at the supply source)	32.53	57.83	9.64	3.93
f.	Delay in material flow due to the inability of suppliers to respond to changes in demand due to any other cause of inflexibility at the supply source	43.37	45.78	10.84	3.51
g.	Delay in material flow due to poor quality of yield at the supply source	38.55	54.22	7.23	3.37
h.	Delay in material flow due to excessive handling (such as at border crossings and change in transportation modes)	51.81	44.58	3.61	2.72
i.	Procurement risks stemming from exchange rate fluctuations (which may increase the cost of procurement)	39.76	53.01	7.23	3.22
j.	Procurement risks stemming from the percentage of a key component or raw material procured from a single source	49.40	46.99	3.61	2.80
k.	Procurement risks stemming from industry-wide capacity utilization	53.01	44.58	2.41	2.90
l.	Procurement risks stemming from price increases by suppliers	44.58	50.60	4.82	3.46
m.	Risks stemming from JIT program: Increased downtime	53.01	44.58	2.41	2.69
n.	Risks stemming from JIT program: Pull inventory at higher freight costs	45.78	54.22	0.00	2.78
o.	Risks stemming from JIT program: Pay higher prices to suppliers who can deliver faster	51.81	45.78	2.41	2.72
Average Supply Management Risks		**45.22**	**50.92**	**4.66**	**3.07**

Table 9: Analysis of Supply Management Risks

No.	Type of Risk	Risk Action Zone			Average Risk
		Green Zone	Yellow Zone	Red Zone	
a.	Risks stemming from an excessive inventory: Product Obsolescence	38.55	46.99	14.46	3.98
b.	Risks stemming from an excessive inventory: Inventory holding costs	32.53	51.81	15.66	4.33
c.	Risks stemming from an excessive inventory: Product Value (Holding excessive inventory for products with high value or short life cycles can get expensive)	42.17	44.58	13.25	3.82
d.	Risks stemming from an excessive inventory: Demand and Supply uncertainty leading to an inventory becoming expensive	39.76	48.19	12.05	3.75
e.	Risks stemming from underutilized capacity: Cost of capacity (investment in capacity)	44.58	53.01	2.41	3.14
f.	Risks stemming from underutilized capacity: Capacity flexibility (agility towards changes in demand)	43.37	50.60	6.02	3.52
g.	Risks stemming from underutilized capacity: Risks in recovering expenses	40.96	55.42	3.61	3.36
h.	Risks due to dependability and conformance to delivery schedule	37.35	53.01	9.64	3.98
Average Product/Service Management Risks		**39.91**	**50.45**	**9.64**	**3.73**

Table 10: Analysis of Product/Service Management Risks

No.	Type of Risk	Risk Action Zone			Average Risk
		Green Zone	Yellow Zone	Red Zone	
a.	Risks in forecasting: Inaccurate forecasts due to long lead times, seasonality, product variety, short life cycles, small customer base	28.92	59.04	12.05	4.34
b.	Risks in forecasting: Information distortion due to sales promotions, incentives, lack of supply-chain visibility and exaggeration of demand in times of product shortage	33.73	60.24	6.02	3.84
c.	Risks due to intellectual property: Reduced vertical integration of supply chains leading to more information collaboration	56.63	39.76	3.61	2.57
d.	Risks due to intellectual property: Globalization of supply chains leading to outsourcing to same manufacturers used by competitors	55.42	40.96	3.61	2.61
e.	Risks due to the failure of IT systems: Information infrastructure breakdown	19.28	78.31	2.41	3.80
f.	Risks due to the failure of IT systems: System integration of extensive systems networking	24.10	75.90	0.00	3.41
g.	Risks due to the failure of IT systems: E-commerce	42.17	56.63	1.20	2.78
Average Information Management Risks		**37.18**	**58.69**	**4.13**	**3.34**

Table 11: Analysis of Information Management Risks

From Table 7 to Table 11, it can be concluded that main risk factors in supply chain management for firms in Singapore are generally demand management risks and information management risks. In particular, the risks of sudden loss of: (i) demand due to an economic downturn; (ii) volatile demand/decline in demand; (iii) increase in customers' bargaining power; (iv) inventory holding costs; (v) product obsolescence; and (vi) risks due to dependability and conformance to delivery schedule are major risk factors in these two main risk categories. In addition, some of the macro level risks, such as: currency fluctuations, lack of skilled personnel, and government regulations are also very important risk factors in logistics. The impacts of supply management risks appear to be less serious than those of the other four types of risks in Singapore. However, risks arising from delays in availability of materials from suppliers seem to be a very important risk factor in this category.

Conclusions

The main contribution in this project is that we have developed an integrated supply chain risk management framework which contains four iterative and interactive components. These are: risk identification, risk assessment, responding to risk, and monitoring and evaluation. For risk assessment, we have provided methods to construct the risk score profile matrix which basically depends on three variables, namely: Risk, Impact, and Likelihood.

Responding to risks is the most significant stage in the entire supply chain risk management framework. We have investigated three different sorts of toolkits and have explained their features in detail. We have also used examples to show how to implement these three toolkits. Amongst them, a novel toolkit, i.e. the Advanced Toolkit, has been designed for risk management. In this novel toolkit, a new measure of risk, conditional value at risk, and an efficient Monte Carlo simulation method, as well as sample average approximations were adopted. The Advanced Toolkit hides the mathematical complexities. Furthermore, a graphical user interface (GUI) was developed to run the toolkit. As a result, users only need to input the basic initial data in the dialog window and then, at the click of a button within the interface, users get the results for maximizing profits and minimizing the risk.

In particular, the established stochastic risk toolkit can be applied to supply chain networks with multi-tier supplier models and LLP supply chain network models. The respective stochastic models are established as well. The user-friendly interface of the risk management toolkit is easy to implement for common users from the industry, especially after the users have undergone some basic training.

By using this toolkit, a user can easily discover how much risks/losses his/her company might incur and what the expected goals with the different choices of scenarios are. Hence, these quantitative analysis results enable the user to take appropriate actions on his/her supply chain risk management. In summary, the results/outputs generated by the Advanced Toolkit are scientific, objective, clear, and

accurate mathematically. This toolkit can be used by the executives of a firm as a strong and credible reference when making a mid-term or long-term plan for his/her company.

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Biography

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