INCLUDING COSTS OF SUPPLY CHAIN RISK IN STRATEGIC SOURCING DECISIONS

By

Avani Jain

Bachelor of Engineering in Electronics and Communication
Manipal Institute of Technology (2004)

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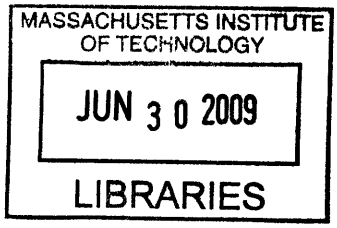

Signature of Author....
Master of Engineering in Logistics Program, Engineering Systems Division
May 8, 2009

Certified by.....
Dr. Amanda Schmitt
Postdoctoral Associate, Center for Transportation and Logistics
Thesis Supervisor

Accepted by.....
Prof. Yossi Sheffi
Professor, Engineering Systems Division
Professor, Civil and Environmental Engineering Department
Director, Center for Transportation and Logistics
Director, Engineering Systems Division

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Abstract

Cost evaluations do not always include the costs associated with risks when organizations make strategic sourcing decisions. This research was conducted to establish and quantify the impact of risks and risk-related costs on sourcing decisions for the automotive industry. The focus is on comparing distant, global suppliers entailing long supply chains with domestic, US-based suppliers.

The risk factors effecting supplier selection were classified into eight categories. A model was developed using Monte Carlo simulation for scenario generation and Value-at-Risk methodology from finance theory for developing the risk-cost relationship. The model was tested using multiple scenarios which were generated by varying the risk profiles of suppliers.

The results indicate that there is distinct and quantifiable relationship between supplier-related risk and total costs of sourcing. Furthermore, under high risk conditions, distant, global suppliers with relatively lower contract costs can exceed cost budgets as well as the cost of domestic sourcing. The model developed through this research can be used to compare two or more suppliers and map the total cost variation for suppliers under particular risk scenarios. Thus, the model can be used for strategically selecting low-cost and long-term suppliers.

Thesis Supervisor: Dr. Amanda Schmitt
Title: Postdoctoral Associate, Center for Transportation and Logistics

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1. Introduction

One aspect of global sourcing that has received a lot of attention lately is that the actual costs experienced are often significantly higher than planned costs, often wiping out projected savings. One hypothesis is that this difference between estimated and actual costs exists due to ignorance or underestimation of the costs of various risk factors associated with a global supply network. The purpose of this thesis to translate some of the inherent uncertainties involved in sourcing products from a distant global supplier to a measurable quantity and thereby the true cost of sourcing from a supplier.

This thesis investigates and analyzes the impact of risks on sourcing decisions in the automotive industry. A US-based automotive manufacturer, henceforth referred to as Acme Auto for purposes of confidentiality, is the sponsor and prime source of industry insights for this thesis. The research for this thesis has been tailored to meet Acme Auto's requirements and the tool developed will be used by Acme Auto for evaluating and selecting its suppliers in the future.

Risk factors and costs can vary in the spectrum from high cost and rare catastrophic incidents to frequent minor incidents with low costs. Risk factors that are considered include the risk of political uncertainty or an economic downturn in the country where the supplier is located. Other factors are the risk of financial insolvency of a supplier or costs of expedited delivery due to a disruption in the supply chain.

One risk that occurs frequently but is often ignored during upfront planning is the risk of expedited freight. Total landed costs for a part comprise of the part price as agreed upon in the contract, along with the logistics costs of sourcing using the mode specified in the contract. Thus, if the logistics costs are comparable, a buyer would always select the supplier with lower part

price. In many cases, international suppliers have lower part prices due to the lower cost of labor and raw material availability in international markets, and thus are the preferred choice. The supply chain as considered in a no-risk scenario is depicted in Figure 1.1. However, a sourcing decision based on part price does not take into account supplier related risk and associated costs. In case of a disruption such as a production or demand spike where expedited transport such as air freight is required, the logistics cost alters substantially. Thus the total landed costs from a source that is internationally located can become higher than that of a domestic source. This change in total cost influences the sourcing decision. In some cases the initial part price benefit offered by the international supplier can be dwarfed by the incremental costs of premier freight. The same supply chain as in Figure 1.1 is depicted under high risk conditions in Figure 1.2.

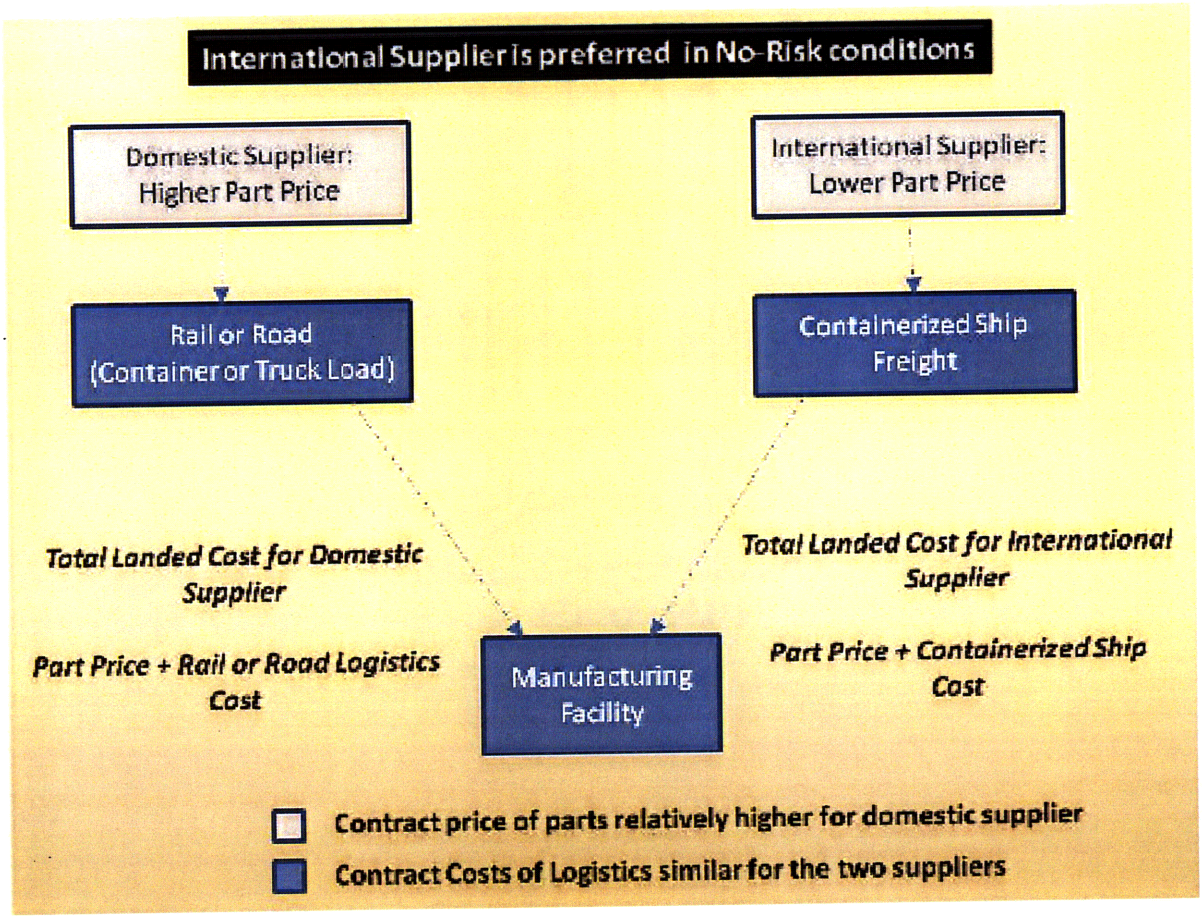

Figure 1.1 Supplier cost comparison under no-risk conditions

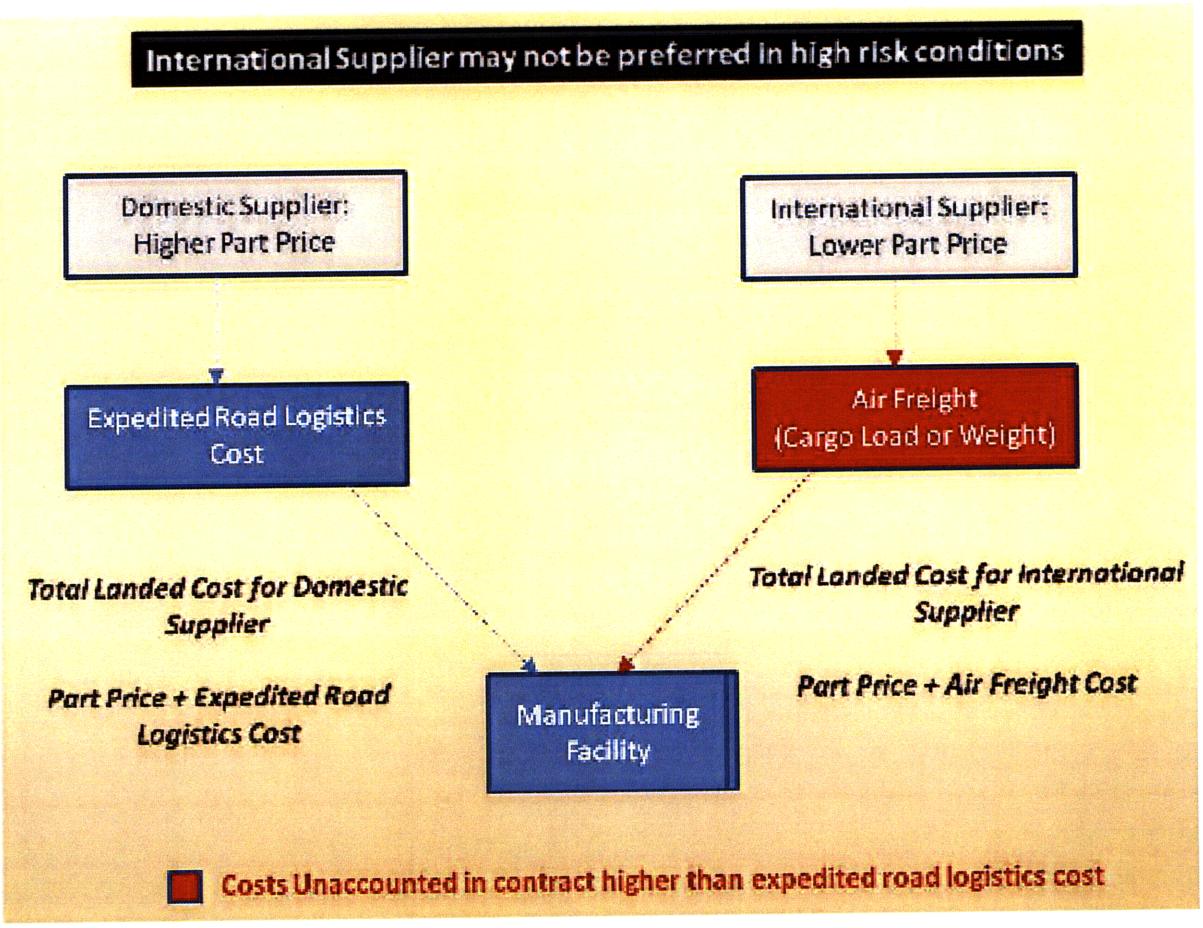

Figure 1.2 Supplier cost comparison under high risk conditions

1.1 Motivation

Most of the automotive industry original equipment manufacturers (OEMs) including Acme Auto operate in a Just in Time (JIT) environment. This implies that a disruption in their supply chain could potentially cause a plant or assembly line shutdown, which in turn has huge cost implications. As a result, Acme Auto generally has long term contracts and strong, long-standing relationships with its suppliers. Normal supply contracts last for the entire product lifetime, which is approximately four years or longer. Furthermore, due to relevance of economies of scale in the automotive industry as well as close relationships which are built while developing technological competence for parts production, Acme Auto usually has a small set of suppliers for each product line. Usually each supplier has sourcing contracts for multiple product lines at Acme Auto. For example, a supplier could be providing wheels for the one car model and ball bearings for another.

These closely-bound relationships between Acme Auto and its suppliers make supplier selection and sourcing an important strategic decision. However, with increasing global partnerships and use of intercontinental suppliers, the supply chains at Acme Auto have grown longer and as a result are more susceptible to risks and disruptions. The complexity in estimating the incremental costs over and above the contractual rate due to increased risk has prompted executives and decision makers at Acme Auto to seek a decision support mechanism which would allow them to quantify the cost differences between high risk and low risk suppliers.

1.2 Objectives

We propose to compare the relative difference in costs incurred due to a combination of risk factors associated with a supplier in a distant geographical location as opposed to a domestic

supplier. We do this by developing a model that will predict the cost associated with a supplier's risk profile with a specific accuracy or confidence level. The objective is to test various scenarios to identify whether there is a risk threshold at which it is economically viable to source from a domestic supplier instead of a supplier at a international location. The model developed has been incorporated in a tool in order to provide an interactive and simple method of utilizing the risk-cost relationship for decision making. This tool requires the user to enter an estimation of expected risk (probability of occurrence) of each risk factor for suppliers under consideration and the expected cost impact if the risk was to occur. The output is a graphical representation of the predicted costs for each supplier with an associated accuracy or confidence level. Depending on the estimated risk associated with a supplier, the tool then recommends which supplier should be selected based on lowest costs.

1.3 Research phases

The first step in the development of this decision analysis framework and tool was risk identification, which pertains to the listing of risks relevant to Acme Auto while sourcing in a global context. The risks involved while making a sourcing decision can be of a wide variety and this phase involved exploring the types of risks involved in the automotive industry and international supply chains and understanding their nature. This was followed by a review of the literature on risks specific to sourcing in a global environment and establishing focus areas for research through discussion with procurement managers as well as other strategic leaders in Acme Auto. This ensured that the risks factors and issues that are included in this research are based on relevance and value to Acme Auto.

The next step was to adopt a methodology to quantify or measure each type of risk and its impact. This process is called risk analysis. It involved the comparison of various risk analysis techniques currently used in finance and across various other industries. We identified those that were applicable or could be extrapolated to fit the need at Acme Auto.

Finally, based on the results of the risk analysis and input from the managers at Acme Auto, the decision tool was developed to compare the total landed costs of the two suppliers (including cost associated with risks) and recommend which supplier would be best suited. This phase stems from the selected risk analysis techniques and the tool deliverable to Acme Auto was developed using these techniques to evaluate suppliers. Multiple risk scenarios were then investigated using user inputs and data simulation and the model outputs were evaluated and tested for robustness. The results of the tests and simulated scenarios are analyzed and documented in this thesis and the learning will be summarized and communicated to executives at Acme Auto.

1.4 Challenges of the project

Risk analysis methodologies stem from financial risk management practices and often require substantial historical data and pattern of occurrences, which are well documented and traceable in the financial world. However, it is difficult to obtain accurate historical data in the field of operations or supply chain management due to the inherent random and infrequent nature of high risk events. The risks that Acme Auto wishes to explore, such as the risk of terrorism or natural disasters, are sometimes intangible and frequently difficult to measure or quantify.

The first challenge was therefore developing a supplier 'risk profile'. A risk profile in the context of this thesis is defined as the probability of occurrence of each risk factor for a supplier under a

given scenario. Each scenario captures a different set of comparison of suppliers with unique risk portfolios. It is important to note that since the objective is to compare the costs of sourcing from suppliers over a long time period, some error of estimation of the parameters is anticipated and acceptable. It is the *relative* risk and associated costs that will be used in the model. Therefore as long as the risk profile is representative of the best approximate risk and cost of sourcing from each supplier, the model should recommend the best choice of a supplier.

The next challenge was to map the impact of a risk occurrence through the supply chain and then to measure the monetary impact of such an occurrence. For example, in 1997 a fire in a brake-supplier's plant caused Toyota's production line and cost Toyota an estimated $ 40 million. If Toyota could have known the likelihood of such an event and the impact on its production line, they may have chosen to mitigate the effect by sourcing from more than one supplier. We seek to quantify the likelihood and impact of these types of risks in this thesis.

1.5 Document Map

This document has five remaining chapters. Chapter 2 is the review of relevant literature. Chapter 3 summarizes the background research conducted to understand the nature of risks to be investigated and used in decision analysis. The next chapter describes the phases in research and the methodology used in developing the model used for supplier selection, as well as the steps taken for creating the "Select Supplier" tool. Chapter 5 describes the analysis of output data and results of the tests conducted for various preselected scenarios. The final chapter summarizes the discoveries made during the course of research and possible extensions to this work.

2. Review of Literature

Supply chain management trends in the last two decades, including globalization, outsourcing, JIT manufacturing and reduction in supply base, have increased the relevance of supply chain risk management. Possible disruptive scenarios increased exponentially, and predicting and controlling these risks became a more complex process. Therefore studying risk and disruptions in supply chains is a growing field for research. This review of literature commences with the definition and review of general risk management terms and concepts. As the nature of business and supply chains has evolved, so has the nature of risk that effects supply chains. Thus in the first section of the literature review, we have documented the nature and types of some of the risks that are valid in the current global supply chain context. We then describe the different approaches used to quantify cost of supply chain risk and the applicability of the Value-at-Risk model and simulation approach to graph the risk portfolio for Acme Auto's suppliers. Finally we describe the sources used for quantifying risk estimation and some of the world-wide agencies that provide risk ratings.

The distinction between uncertainty and risk made by Knight (1921) who explains that uncertainty is characterized by its inability to be defined in probabilities and quantifiable outcomes, where as risk is measurable and quantifiable. Khan and Burnes (2007) discuss the definition of risk and risk management the application of these concepts in the field of supply chain in specific. They discuss the evolution of risk management practices and provide a detailed analysis and review of literature pertaining to key developments and debates.

2.1 The Nature of Risks in a Supply Chain

The nature of different types of risks related to supply chain management is a growing field of study, and most of the research has been conducted in the last two decades. Supply chains extend from supplier to end consumer and are thus vulnerable to a variety of risks, especially in the case of international supply chains. Levy (1995) simulates demand and production disruptions to explore the dynamics between two sets of decision making factors for sourcing in an international supply chain; location-specific factors and relational factors. He defines 'location-specific' factors as those dependent on the geographical location of the supplier such as wages, relative production costs, political and economic stability and attractiveness of the local market. 'Relational factors' as the name indicates, are the relationships and linkages between the various players in a supply chain. However, Levy focuses his research on the downstream or demand related variations and disruptions propagating up the supply chain. Acme Auto, on the other hand, believes that it faces greater risk from disruptions and inherent risk associated with location specific factors. The research for this thesis is focused on risks pertaining to supply, and in particular disruptive or low-frequency and high-impact risk factors such as natural disasters, terrorism, etc., rather than on risks related to demand variations.

de Mortanges and Allers (1996) study the political risk in the experience of Dutch firms and focus their research on ten factors, such as local ownership requirements, political and social unrest, and import restrictions etc., which are important when considering risk in international supply chains. The relevance of political risk to Acme Auto is due to its expanding base of suppliers in emerging markets, which are susceptible to political and social uncertainties. de Mortanges and Allers suggest three different methods for assessing these risk factors: qualitative unstructured methods, qualitative structured methods, and quantitative methods. The quantitative

methods include using political risk consultants and other secondary sources such as external rating agencies.

Since Acme Auto is concerned with disruptive risks, the study of mitigation and contingency planning discussed by Tomlin (2006) is important for determining the cost of risk mitigation and its contribution to total landed cost for one supplier versus another. Tomlin discusses categories for risk mitigation and the tactics for each along with industry examples. He also differentiates between mitigation and contingency tactics stating that:

> Mitigation tactics are those in which the firm takes some action in advance of a disruption (and so incurs the cost of the action regardless of whether a disruption occurs). Contingency tactics are those in which a firm takes an action only in the event a disruption occurs. Tomlin (2006).

The costs associated with each vary; thus the decision to select a risk mitigation strategy or a contingency plan can have significant impact on selecting a supplier.

The complexity of managing multiple risks in a supply chain becomes apparent as we study the nature of the risk of terrorism. Sheffi (2001) indicates that, the key mitigation strategy for this risk is dual sourcing. However, Choi and Krause (2006) discuss the cost, risk and responsiveness implications of increasing the size and complexity of the supply base. There is much discussion in academia regarding the dilemma of using redundant or dual sourcing options for mitigating risk and its optimal use needs to be evaluated on a case by case basis.

Another supply chain risk factor which has come to the forefront recently is supply chain security, which is discussed by Sheffi (2001) and Autry and Bobbitt (2008). Sheffi suggests that the trends that will dominate supply chain management as a result of security threats as

sustainable methods for security management evolve are increased supplier relationships and collaborations, and public-private partnerships. Autry and Bobbitt introduce the concept of the Supply Chain Security Orientation (SCSO) which they describe as a firm's concern and attentiveness to both supply chain security as well as supply chain risk management. They discuss various "emergent themes" which firms should consider developing SCSO capabilities. They also emphasize the importance of supplier relationships and security partnerships with suppliers. This thematic analysis discussed by Autry and Bobbitt is important to take into account while selecting suppliers.

2.2 Models and Methodologies for Profiling Supplier Risk

The concepts of risk and risk management emerged from the finance field and now influence business decisions ranging from supplier management to logistics and operations management. It is thus not surprising that models used for operational risk estimation and analyses were developed in finance theory. However, due to the subjective nature of risk determination, some qualitative techniques are incorporated in risk analysis methods.

An objective and quantitative methodology for mapping different types of uncertainties into risk is proposed by Quispez-Asin (2006) in his research thesis. He proposes a "Real Options" approach to risk assessment and management by using lattice and decision-analysis methodologies in conjunction. He proposes a six-step process which begins by mapping various risk scenarios into decision trees based on estimated risk at each node and risk management strategies. It concludes by constructing and comparing lattice VARG (Value-at-Risk and Gain) graphs for each scenario. This method has the advantage of avoiding expected value or complex utility functions which tend to lead managers to make risk-averse decisions and complicate the

problem. However, its major limitation is the effort, time and complexity involved in the accurate mapping of decision trees in a large organization such as Acme Auto with a vast supplier base.

Blackhurst, Scheibe and Johnson (2008) use a hybrid approach between the subjective and objective in order to develop a risk assessment methodology. They analyze of risks related to particular suppliers of an automotive manufacturer. They emphasize that the most important step during the process of risk assessment is the selection and definition of categories of risk which can be then weighed, compared and quantified depending on the industry or the special circumstances of the firm under consideration. They propose to classify risks in supply chains for the automotive industry broadly into 12 categories based on the feedback from their automotive partner. The risks within each of these categories are further subdivided into two sub-categories, internal and external risks, based on the ability to control the source of the risk. For example, hurricanes and other natural disasters are classified as external risks. Though this methodology, called multi-attribute risk assessment (MARA), is powerful for identifying critical parts and suppliers and assessing risks in the related supply chain, its accuracy depends on the highly subjective nature of the weights and estimates provided by management and staff of the firm under evaluation. In addition, it does not analyze the impact of risk on the total landed cost for a supplier, which is the leveling metric for a firm to compare suppliers.

In his research thesis, Feller (2008) proposes a methodology that uses questionnaires and interviews to classify risks in supplier selection, and then a quantitative method for realizing the impact of risks on total landed costs. Feller considers 20 factors across different risk categories as part of a risk portfolio. He models the outcome by using Failure Mode Effect Analysis

(FMEA) and a utility-weight algorithm to approximate the total landed cost due to a supplier risk profile.

Another financial risk analysis method that can be used to measure the cost impact of risk is the Value-at-Risk (VaR) metric. Value-at-Risk is the value or cost of an asset in the case of a particular risk scenario over a defined period with a given confidence interval. This thesis uses the VaR method in order to quantify the variation of total landed cost from the baseline contractual cost due to a supplier risk portfolio. Damodaran (2008) enumerates and explains the three main elements of the VaR approach which are: the estimate of loss in value or increase in cost of an asset, a fixed time period for considering the risk and a confidence interval.

Monte Carlo simulation is a statistical method for iteratively evaluating a non-dynamic model using sets of random variables as input. Kalos and Whitlock (1986) provide an introduction to the general Monte Carlo method as well as the mathematical proof of a mean derived from a Monte Carlo simulation representing the true mean of the data. This simulation method is widely used for simulation of stochastic natural phenomena for example stock prices and other financial analysis. The VaR assessment for this thesis is carried out by using the Monte Carlo simulation method.

2.3 Sources to Aid Risk Estimation

This thesis uses standard risk indices available from sources that are described and compared by Erb et al. (1996) to guide the users of the tool at Acme Auto to estimate a supplier's risk tolerance profile. These sources include the International Country Risk Guide (ICRG), which measures political, economic and financial risk, Institutional Investor's Country Credit Rating (CCR), Control Risks Information Services (CRIS), Business Environment Risk Intelligence

(BERI) and Economist Intelligence Unit (EIU). An earthquake risk index is explored in particular by Davidson (1997) in her report for the Blume Earthquake Engineering Center. A brief description of the use of these sources for risk estimation is described in Appendix B Section B.1. These various published sources are indicators of the risks common to suppliers located in certain geo-political locations. Risk factors that are unique to each supplier, such as the risk of the financial strength of the supplier need to be investigated and estimated on a case by case basis by drawing upon past experience and other research.

Though the review of literature yielded valuable insights on the nature of risk in supply chains, there are only a few documented approaches that we found for quantifying supplier related risk. Of these, a majority of the quantitative models are derived from financial theory and use convoluted utility functions to express the impact of risk. The risk-cost relationships in the form of these utility functions are difficult to comprehend or directly incorporate in the supplier comparison and selection process. This thesis proposes a model that allows Acme Auto and other industry users to explore the risk-cost relationship in an easily comprehensible and graphical manner. Thus, the model provides a means to compare globally dispersed suppliers in order to make the strategically optimal decisions.

3. Background Research on Risk Classification

Supply chain risks are diverse in nature and each risk source can be studied to great depth and granularity. However, for the purpose of developing a model a broad classification of risks was required. By grouping related risk causes and sources into meaningful categories, the model maps all relevant supplier-related risks for Acme Auto without adding significant complexity. The aim of risk classification is to ensure that the broad categories called 'risk factors' are easy to interpret in the output of the model and have business significance for decision-makers at Acme Auto.

This chapter begins with a review of some supplier risk classification methodologies. The selected risk classifications and sub-categories are then listed in Table 3.2. Finally, each risk factor used in the model is explained along with its relevance for Acme Auto.

Blackhurst et al. (2008) broadly classified supply chain risks into 12 categories based on feedback from their automotive supplier, as shown in Table 3.1 below.

Table 3.1 Categories of Supply Chain Risk (Blackhurst et al., 2008)

Category of Risk
Disruptions and Disasters
Logistics
Supplier Dependence
Quality
Information Systems
Forecast
Legal
Intellectual Property
Procurement
Receivables Inventory
Capacity
Management Security

Feller (2008) creates a portfolio of 5 major risk categories: organizational risk, inventory and quality related risks, finance risk, logistics risk, trade compliance risks and research and development related risks. Within these risk categories there are sub-categories of risks. Similarly, he defines categories and sub-categories of cost and then tries to relate the risks and cost using Failure Mode Effect Analysis (FMEA).

After reviewing the literature described above, we discussed the findings with Acme Auto managers and decision makers. With this input, the categories and sub-categories of risk listed in Table 3.2 were selected to be included in the decision analysis model and tool.

Table 3.2 Categories of Risk

Risk Category	Types of Risks
Political & Legal	Political and Social Unrest
	Profit Remittances and Exchange controls
	Contract Problems
	Risk of Expropriation
	Import Restrictions
	Labor disruptions
	Taxation
	Local Ownership Requirements
	Competition from Public Enterprise
Natural Disasters	Earthquakes
	Fire
	Flooding
Financial	Supplier Bankruptcy
Economic	Recession/ cyclical Downturn in Industry
	Fuel Price Hike (Similarly for other raw materials)
Security	Terrorism or War
	Information System Security
Logistics	Demand Related Disruptions - Expedited Shipping
	Production Related Disruptions
Supplier Relationships	Dependency of Supplier on Buyer
	Technological Collaboration and Advancement
Reliability & Quality	Defects Occurrence Frequency and Correction Timelines

3.1 Political and Legal Risk

Acme Auto has suppliers located across the globe. Political instability in the countries where the suppliers are located can create disruptions in the Acme Auto supply chain. If the political establishment in the country was to impose export/import restrictions, change laws for contractual obligations, or expropriate supplier assets and void contracts, then Acme Auto would need to redirect its supply from an alternate source. Since automotive plants require specialized machinery and R&D expertise, not many alternate suppliers would be able to meet Acme Auto's needs. Additionally, if the supplier under political threat was a high-volume supplier, alternate suppliers would not be able to ramp up capacity immediately to meet Acme Auto's demand volume.

It is therefore likely that the secondary supplier will charge a rate higher than the contractual cost agreed upon with the primary supplier. This cost differential, plus the potential cost of missing customer demand if capacity cannot be procured, can be expressed as the cost of political and legal risk mitigation.

3.2 Natural Disasters

Natural disasters, such as fire, flood, earthquake, hurricane etc., create high-impact disruptions in the supply chain. Such events are hard to predict. Moreover, if such an event occurs and leads to widespread damages for the supplier, its impact is extremely costly and has long term effects for downstream partners. Acme Auto, like most automotive manufacturers, primarily operates in a Just in Time (JIT) environment and engages in long-term contracts with its suppliers. Thus it is susceptible to bearing the high costs associated a key supplier being severely affected by a natural disaster. One such example is the acute parts shortage faced by sound card maker Kelly

Micro Systems due to the destruction of its suppliers' manufacturing units by the 1994 Kobe earthquake in Japan (Johns 1995).

3.3 Financial Risk: Supplier Bankruptcy

The risk of supplier bankruptcy becomes especially relevant when considering suppliers based in developing countries. Amongst other factors affecting the financial solvency of a supplier is the impact of economic recessions and downturns. A financially-fragile supplier could propose a low cost contract, which may seem appealing at face value. However, decision makers and strategic leaders at Acme Auto are interested in supplier relationships and investments which are sustainable and strategically advantageous in the long term.

There are major cost implications of investing in technological capabilities and IT infrastructure for a financially-fragile supplier if they suffer a bankruptcy. These costs can be in the form of investment write-offs, costs of sourcing from alternate supplier or providing financing options for a strategically important supplier. UK-based chassis supplier UPF-Thompson posed similar problems for Ford Motor Co. when the supplier faced bankruptcy in 2001 (Lester 2002).

3.4 Economic Risk

The cost of raw materials can fluctuate during economic cycles. Automotive parts require a wide variety of raw materials, including metals such as copper, aluminum, steel etc. During recessions or economic downturns prices for these items can fluctuate considerably, causing the supplier costs to increase rapidly to a point where operations costs may become unviable. Another manifestation of economic risk is in the form of fuel price fluctuations. These fluctuations, caused by external economic triggers, can create a domino effect across all industries. Logistics

costs for a domestic supplier can substantially increase while the costs of air shipping from a distant supplier can become formidable.

3.5 Security and Terrorism

In recent years the threat of terrorism has changed the ability of US-based manufacturers to source from international suppliers. Sheffi (2001) explains that a supply chain disruption may not be directly caused by a terrorist threat, but by the government reaction to such a threat. All inbound and outbound means of transport may be sealed in such an event, and shipments from an international supplier may not be able reach the manufacturing plant. Production lines, including that of Acme Auto, can potentially come to a complete halt due to lack of parts.

Supply chain security risks can also stem from sabotage and compromise of information and data. Another source of risk is port security and other physical security threats, such as damage to equipment during strikes or thefts. By understanding the extent of a supplier's vulnerability to such risks, Acme Auto can seek to adopt optimal risk mitigation strategies.

3.6 Logistics Risks

Identification of the need for Acme Auto to investigate supply-related risks stemmed from unforeseen cost expenditures on expedited air shipping from distant global suppliers. If the conventional channel of transport (ocean freight) was to break down due to channel overload or port and infrastructure issues, or if it was considered too slow if a spike in demand were to occur, expediting through air freight would become essential. Air freight charges are substantially higher than contractual ocean freight charges. Therefore the risk of a disruption in the normal logistics operations of a supply chain could lead to a substantial variation from the initial cost

estimate of sourcing from a supplier. In the long term, Acme Auto would like to take these expected variations into account so that actual costs don't substantially deviate from expected costs.

3.7 Supplier Relationships

Manufacturers often create technological and R&D partnerships with suppliers to ensure that the part constructed by a supplier meets their requirements and specifications. These partnerships benefit the suppliers, since they are ensured long term contracts with suppliers and are able to differentiate themselves from competitors. At the same time, buyers are ensured of a product that fits their requirements and is at the cutting edge of technology. However, such exclusive partnerships lead to supplier dependence, which in turn causes risks such as dependence on supplier's capacity flexibility. If the supplier is unable to ramp up capacity to meet the needs of a buyer such as Acme Auto, an alternate source with sufficient technical knowhow may not be readily available. Thus the production volumes and profitability for the downstream manufacturer could suffer.

3.8 Reliability and Quality

A supplier who delivers sub-standard quality parts creates production backlog at the manufacturing site. This is because part supply shortages can occur if large volumes of parts are rejected from the shipments received. The ability of the supplier to correct the defect in a timely manner could greatly impact the total costs experienced by the product recipient. A reliable and quality conscious supplier can prevent large volume backlogs from being created by using a few expedited deliveries. Thus the quality and reliability of supplier contributes to long term incremental costs, but these are not included in contracts. Having experienced such issues with

some of its suppliers, Acme Auto is interested in quantifying these costs as well during supplier selection.

4. Description of Methods

The problem evaluation and solution synthesis took place in three phases listed below:

1. Risk Identification and Classification
2. Risk Estimation and Analysis
3. Model and Tool Development

We outline these steps throughout this chapter.

4.1 Risk Identification and Classification

This phase involved research and review of literature on the automotive industry, procurement and supply chain related risks and review of documented case studies on specific supply related risk scenarios. In addition risk management practices across all industries were studied in order to identify all possible risk factors and risk categorization methodologies. The results of this research were then discussed with executives at Acme Auto to select categories of risk relevant for strategic sourcing at Acme Auto. The classification and description of these risks is summarized in Chapter 3.

4.2 Risk Estimation and Analysis

4.2.1 Estimating risk occurrence

In order to determine the approximate probability of occurrence of a risk the following methods and consideration were used.

1. External rating and ranking agencies (refer to Section 2.5) provide an overview of the risk of the country or region in which the supplier is located. Thus an approximate

probability of risk occurrence was arrived at by studying the ratings under various risk factors such as political stability of the region, economic conditions, etc.

2. Another method recommended is to draw on the experience of local managers and other Acme Auto staff who directly interact with suppliers. Surveys can be conducted amongst all employees that interface directly with the supplier to determine the probability of a supplier risk. This method is especially useful when analyzing risks such as supplier reliability, quality etc.

4.2.2 Estimating the impact of a risk

There are two ways to estimate the impact of a risk or disruption. One is by estimating the cost incurred if no steps are taken to avoid or compensate for the disruption. An example that illustrates this method of impact estimation is in the case of a hurricane at the location of a manufacturing plant. If the hurricane disrupts all transportation to and from the location and a critical part is unable to reach the manufacturing facility in time, the cost incurred would be the cost of shutting down the entire assembly line.

Another method of measuring the impact of a disruption is by using the cost of implementing a "Risk Mitigation" plan. Risk mitigation includes all efforts that are taken to reduce either the probability or the consequences of a threat. These may range from physical measures (protective fences) to financial measures (insurance) etc.

Using this information, decision analysis can be carried out to quantify the risk vulnerability of each of Acme Auto's suppliers. Decision analysis is a method by which decision makers use available information to evaluate possible outcomes from a decision by taking into the inherent uncertainties into account. Whereas, in more traditional economic evaluations only the most

'likely' outcome is studied. One suggested method of carrying out decision analysis is by drawing decision trees defined as:

> The *decision tree* is a conceptual device for enumerating each of the possible decisions that can be made, and each of the possible outcomes that may occur according to each of the events or states of nature that may arise. (Neufville 1990)

The decision tree comprises of two elements, the decision node and the chance node. The decision node represents the point in a scenario when a choice or selection is made and the chance node represents the outcome of a decision or selection. The managers at Acme Auto can choose from a host of software applications such as TreeAge, @Risk, etc. to map risk factors that a particular supplier is susceptible to. For example, if a US based supplier is selected, than one branch of the decision tree could map this supplier's susceptibility to reliability and quality related risks. The managers at Acme Auto could use their experience historical data to map the chance nodes or possible outcomes of the risk of defects and thus quantify the cost of risk mitigation or impact of risk for such a supplier. Due to the subjective nature of this process, it is recommended this activity is conducted in conjunction by senior strategic leaders along with managers who are in direct contact with the suppliers.

4.2.3 Generating test scenarios

The model was tested and validated by first establishing a base case scenario. The base case was set up to compare a supplier in a distant and relatively high risk location with a supplier in a stable, domestic location. Hence, the base case scenario would map the typical behavior of total costs with given supplier risk profiles.

The next sets of scenarios were developed for analyzing the sensitivity of the model to the inputs, i.e. risk tolerance thresholds and the costs of risks. The risk tolerance thresholds were varied to simulate a high risk and low risk scenario for each risk factor for the international supplier. The changes in total cost were then noted. The aim was to study the cross over percentiles, i.e. the confidence interval at which the decision to source from one supplier changed as the selected supplier's total cost exceeded that of the alternate supplier. The risk factors for which the thresholds were found to have greater impact on total cost variation and the cross over percentile would be the factors relevant for strategic supplier selection under a given risk scenario. Similarly, the costs of risks were assumed to have a normal distribution with the mean cost kept constant and the standard deviation varied from 10 to 200%. Thus the sensitivity of the risk-cost relationship to the cost of risk mitigation was studied.

During the evaluation of sensitivity of the model to risk tolerance thresholds, a special case was developed for the risk of terrorism and natural disasters. This scenario would assume a small, discrete distribution for the probability of occurrence of these risks. Thus, a more realistic mapping of these risks would allow the model to simulate a pragmatic risk-cost relationship under low-frequency, high-impact risks.

Finally, a scenario comparing 3 suppliers was developed to model a decision scenario often faced by sourcing managers. In this scenario, total costs of 3 suppliers with differing risk profiles and contract costs were compared for optimal decision making.

4.3 Model and Tool Development

In order to quantify the impact of risk probabilities and costs on the supplier selection decision we graphically represent the total cost of sourcing from two suppliers with unique risk portfolios. We build a model that helps Acme Auto identify the supplier which would have a lower total cost in the majority of future incidents. Since the objective is to compare the relative costs of the two suppliers rather to estimate risk or true cost, model requires risk and cost estimates as inputs. The model is incorporated in a tool called the "Select Supplier". The decision makers at Acme Auto input data regarding their supplier choices into the tool/model based on their experience and research. The tool then simulates probabilities of risk occurrence for each of the suppliers. The result is a graphical representation of the cost incurred by each supplier for the trials run on the model. Therefore, a supplier which is found to have a lower total cost at the outset due to its lower contractual cost may incur a comparatively higher total cost in a majority of the trials due to associated risk. Such a supplier would not be a long term preferred sourcing partner for Acme Auto. The model has been developed in Microsoft Excel and the Monte Carlo simulation is run using the Oracle Crystal Ball software add-in. We explain the simulation analysis below.

4.3.1 Data Simulation

Acme Auto is interested in studying low frequency, high impact disruptions and risks in particular. These risks and events are by nature hard to quantify as a frequency because little historical documentation or data is available for analysis. To compensate for this unavailability

of historical data or a clear relationship between various risk factors we use a static Discrete Event Simulation (DES) method: Monte Carlo sampling or simulation. The Monte Carlo simulation uses random numbers (ranging between 0 and 1) to indicate the probability of occurrence of a risk factor for a trial. Thus by running a simulation of a thousand trials and using random sampling, data can be generated to predict the future occurrence and costs associated with these risks.

4.3.2 Simulation Model

The model setup requires user estimated risk probability and cost (refer to Sections 4.2.1 and 4.2.2) for each supplier to be input. These risk probabilities are set as threshold values for the model such that if the simulated event probability of the risk exceeds the risk threshold, a risk mitigation/ management cost will be incurred. If the trial generates a probability of a risk being lower than the threshold set, there is no additional cost incurred. The simulation is run for 1000 trials. In this manner the cost contribution of each risk factor is estimated based on simulated probability of risk occurrence.

In addition the contractual cost or price of a part as stated in the supplier contract needs to be entered as input to setup the model. The contractual cost is defined as the price as decided in the contract and includes the cost of logistics. The total cost of a supplier for one scenario of risk profile is generated by the summation of the contractual cost and the cost contributions of individual risk factors. Thus for each trial run of the simulation one such total cost is determined for a supplier; i.e. the Value-at-Risk of the supplier is calculated. These values from a thousand such trials are then represented as the total cost for percentile of trial runs and are graphically drawn. By drawing these curves for each supplier, the total cost of the suppliers with individual

risk profiles can be compared. The supplier with the lower total cost at a higher percentile of the trials is the preferred low cost supplier as recommended by the model. The next step is to vary (probability of occurrence or cost of) individual risk factors and note the sensitivity of this recommendation or decision.

4.3.3 Assumptions

1. At any given time each supplier being evaluated has a risk profile which can be quantified in the form of probability of occurrence of selected risk factors. It is important to note that the model is intended to compare the costs associated with multiple suppliers. Thus an absolutely accurate risk measure is not necessary as long as the relative disparity in risk between the suppliers is captured.
2. Each of the risk factors is independent; i.e. the probability of occurrence of one type of risk does not influence the probability of occurrence of any other risk. In reality two or more risks can be correlated; if this correlation is high enough, then an additional risk factor (representing the combined occurrence of both risks) could be added with its own associated probability and cost.
3. The cost incurred due to exchange rate fluctuations is excluded from this analysis because Acme Auto hedges against this currency fluctuation.

5. Data Analysis and Results

This chapter discusses the results obtained by running the model through multiple scenarios and analyzing the results. The first section describes the base case scenario which proves the hypothesis that the total costs of sourcing from a supplier can vary considerably due to risk. The next section explains the sensitivity of the supplier selection decision to various risk factors, i.e. how the decision alters as the risk factor thresholds change. The risk tolerance threshold is expressed as the probability of risk occurrence and a cost of risk mitigation is bourn if probability of occurrence of risk for a particular scenario exceeds this tolerance level.

5.1 Base Case Description and Analysis

A base case was defined in order to test the model and analyze the results. Two suppliers were assumed; the first being a US domestic manufacturer and the other an international supplier based in Indonesia. The model is used for selecting one of these two suppliers for the procurement of a single part which is a 'Shaft ASM'. The data specifications for the base case are listed in Tables 5.1 and 5.2.

Table 5.1 Base Case: Suppliers' location and part cost specification

	Domestic Supplier	International Supplier
Location	USA (Domestic)	Indonesia (Asia)
Contractual Cost of Part	$10	$5

Table 5.2 Base Case: Suppliers' risk profile definition

Risk Factors	Domestic Supplier		International Supplier	
	Risk Tolerance Threshold	Cost of Risk (Thousand $)	Risk Tolerance Threshold	Cost of Risk (Thousand $)
Economic Risk	0.6	1	0.5	2
Political & Legal Risk	0.9	1	0.6	3
Financial Risk	0.5	2	0.3	2.5
Natural Disasters	0.7	3	0.4	3
Terrorism and Security	0.9	1	0.35	3.5
Logistics	0.6	2	0.4	3
Supplier Relationship	0.5	2	0.4	2
Reliability and Quality	0.4	3	0.3	3

The risk thresholds for each supplier were estimated using discretion and risk categorization sources (refer to Section 2.2). All costs are for one thousand parts in thousands of US Dollars and are indicative of the actual costs.

The supplier selection model was run using this base case and the results are graphically depicted in Figures 5.1 and 5.2.

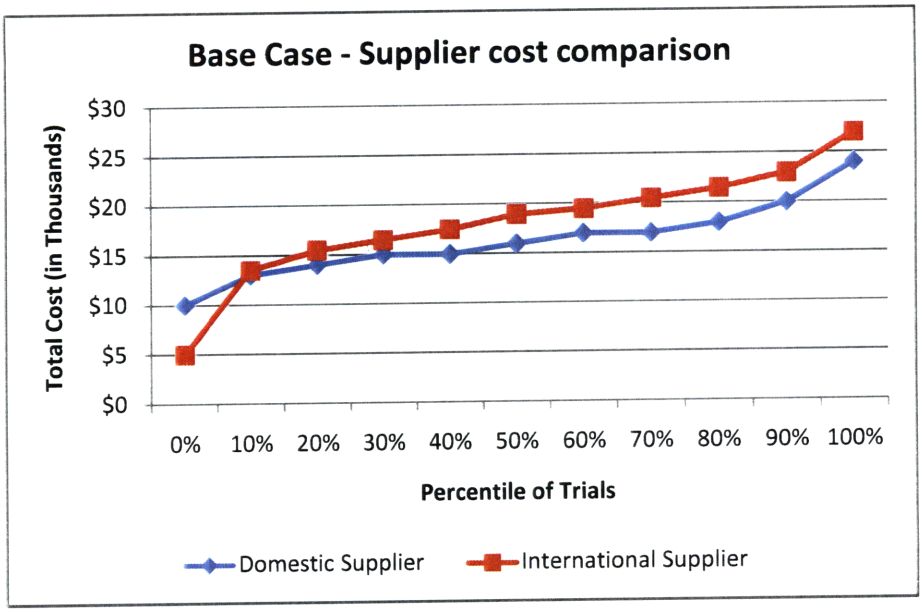

Figure 5.1 Results from base case supplier analysis illustrating change in supplier preference

The results from the base case evaluation indicate that risks and costs significantly alter the decision to source from a supplier. Figure 5.1 is a graphical representation of confidence level; i.e. the percentile of trials in which the total cost incurred by each supplier was less than the cost threshold indicated on the y axis. Therefore we can conclude that as shown in Figure 5.1, the costs of the international supplier are lower than that of a domestic supplier in only 10% (or less) of the cases. Note that a decision made without regard to risk, based on the expected costs, would generate a 0% percentile decision and would lead the decision-maker to choose the international supplier.

Figure 5.2 is a graphical representation of the variation of total cost from the original cost estimated in the supply contracts. It's clear from the graph that in 80% of the trials, the total cost of risk for an international supplier is double that of the domestic supplier. This variation depends on the estimated risk mitigation costs input in the model. Also noteworthy is that in a

few trials (extreme cases) the cost of the domestic supplier increases as well. This is due to finite yet small probability (0.1) of political and legal risks for the domestic supplier.

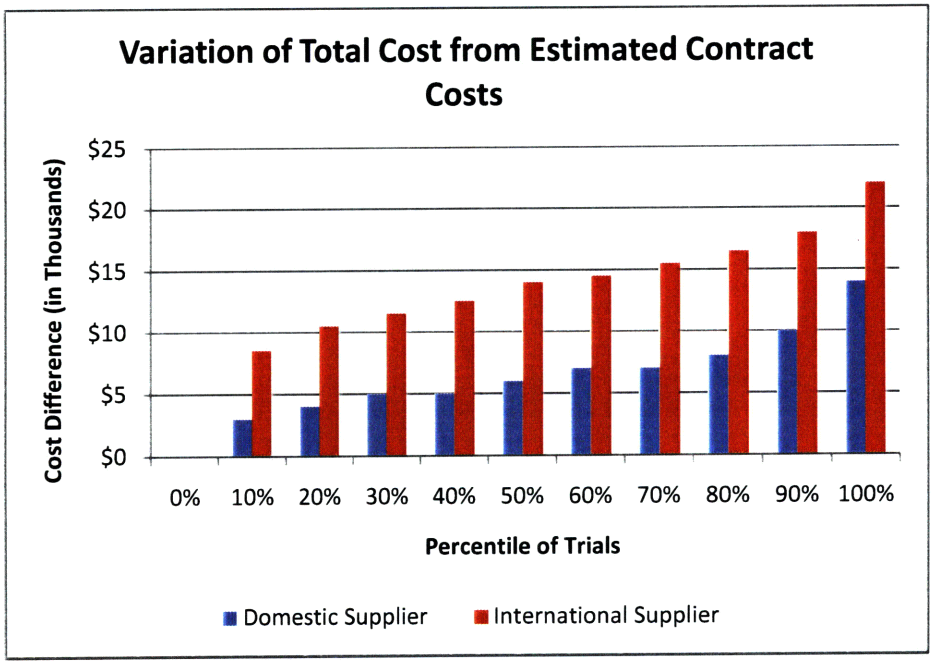

Figure 5.2 Variation of total costs of international supplier from estimated costs for the base case

From the results, it is clear that though the contractual cost per part is much lower for the international supplier, it would be preferable to source from a domestic supplier. This is due to the international supplier's risk profile and the associated mitigation and management costs.

5.2 Sensitivity of Supplier Selection to Risk Thresholds

In order to understand the variation in the total cost of a supplier, and as a result in the supplier selection due to the various risk factors, a sensitivity analysis was conducted. The costs due to a risk factor were held constant and the risk tolerance threshold was varied. Thus by increasing the

risk tolerance threshold, a 'low risk' scenario could be investigated and vice versa for investigating a 'high risk' scenario.

5.2.1 Sensitivity to Political Risk

The relevance of political risk and its sub-categories are discussed in Chapter 4, Section 4.1.1. To determine the sensitivity of the total cost to the risk of political and legal disruptions, we ran two scenarios on the model by changing the political risk threshold of the international supplier. By setting a high threshold of political risk tolerance of 0.9 we observe the change in total costs for the international supplier in a low risk scenario. All other risk thresholds are kept the same as specified in the base case. Similarly, we simulate a high risk scenario by setting a low risk tolerance threshold of 0.1.

Figures 5.3 and 5.4 illustrate the change in the confidence level of total cost from a supplier with the change in the political risk prediction. As shown in the figures, the international supplier has lower total costs than the domestic supplier in only 20% of the trials in a low political risk scenario (Risk tolerance threshold of 0.9, which is the same as that for a domestic supplier). Whereas in a high political risk scenario (Risk tolerance threshold of 0.5), the international supplier is preferred in only 5% of the trials.

Thus we observe that at the time of supplier selection, the international supplier had lower contractual costs than a domestic supplier. However, in the case of high political uncertainty in the supplier's base country the total costs will be lower for the international supplier only 5% of the time.

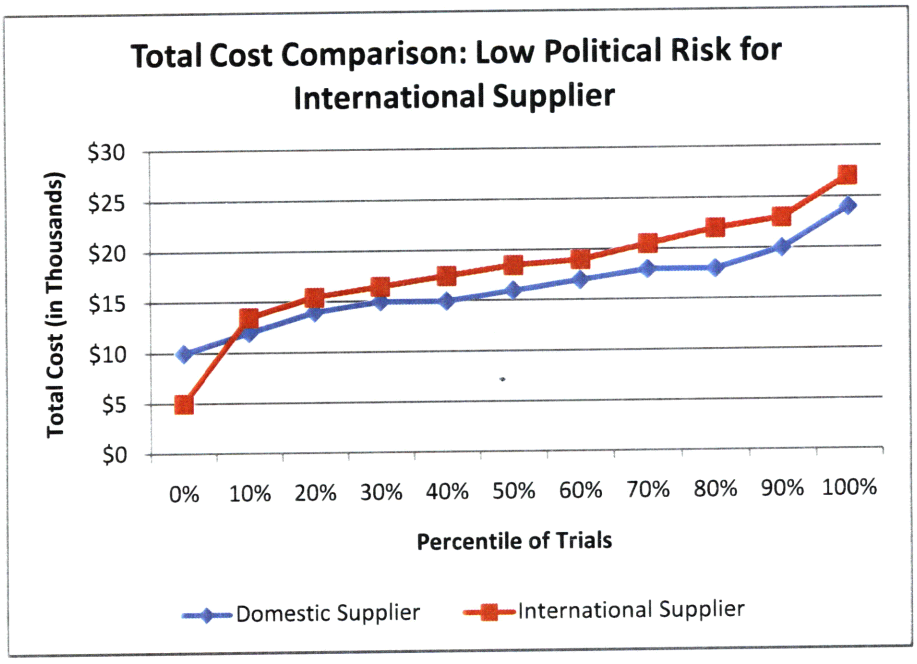

Figure 5.3 Comparison of total cost of supplier in conditions of low political risk

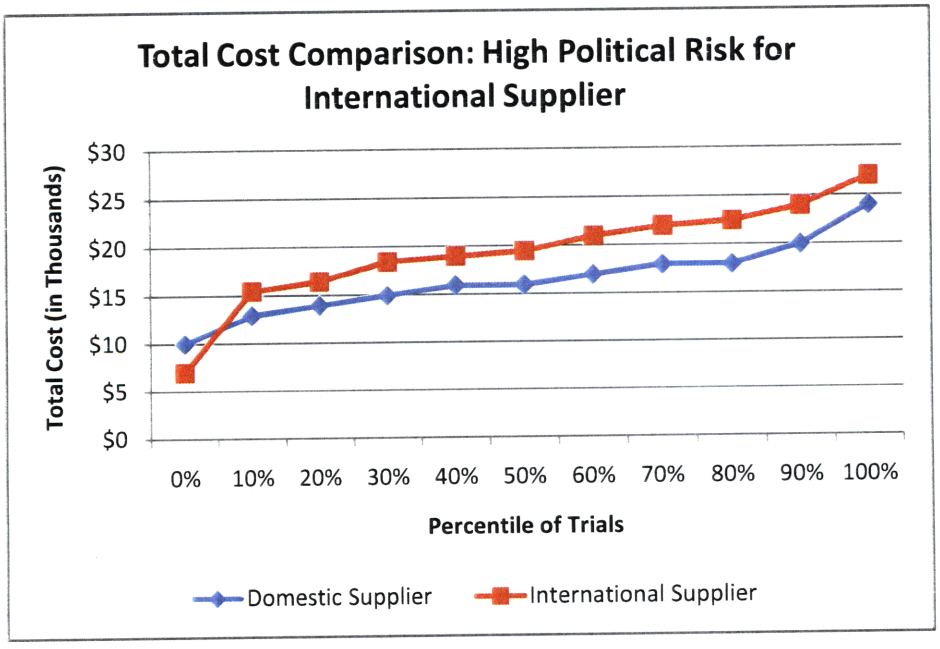

Figure 5.4 Comparison of total cost of suppliers in conditions of high political risk

5.2.2 Sensitivity to the Risk of Natural Disasters

The motivation for studying the risk of natural disasters and their impact on the cost of sourcing is described in Section 3.1.2. The sensitivity of the total cost to the tolerance threshold for the risk of natural disasters was conducted in a manner similar to that of political risk as described in Section 5.2.1. The risk threshold for natural disasters for an international supplier was changed in isolation to all other risk thresholds to simulate high and low risk scenarios. The results of these two scenarios are graphically represented in Figures 5.5 and 5.6.

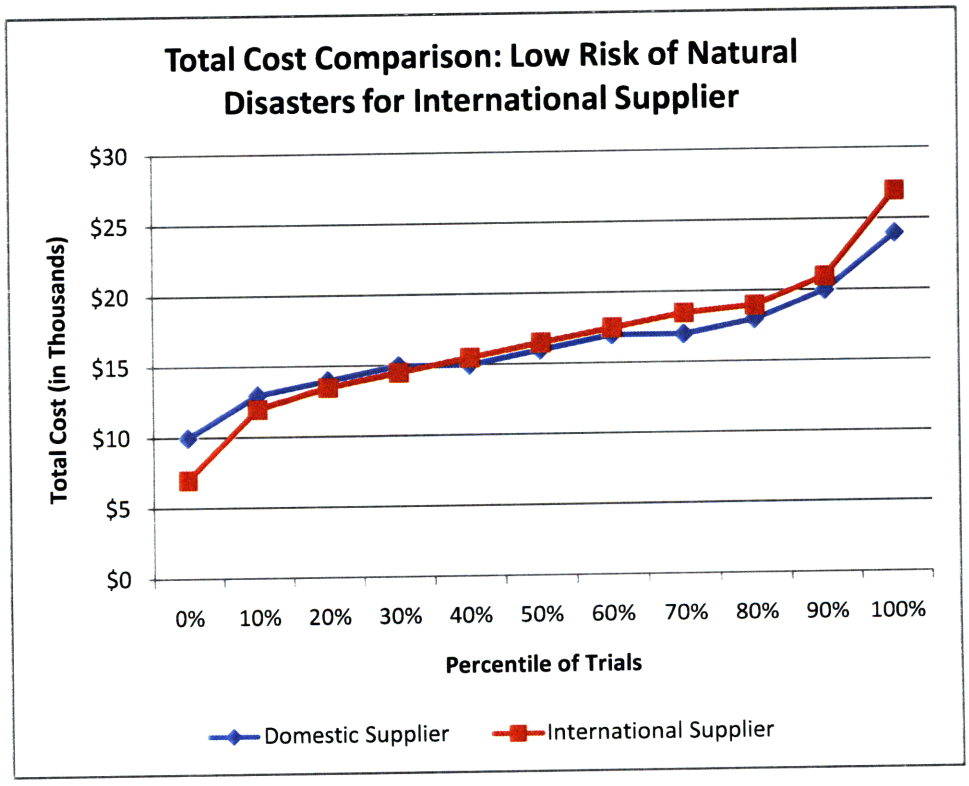

Figure 5.5 Comparison of total cost of supplier in conditions of low risk of natural disasters

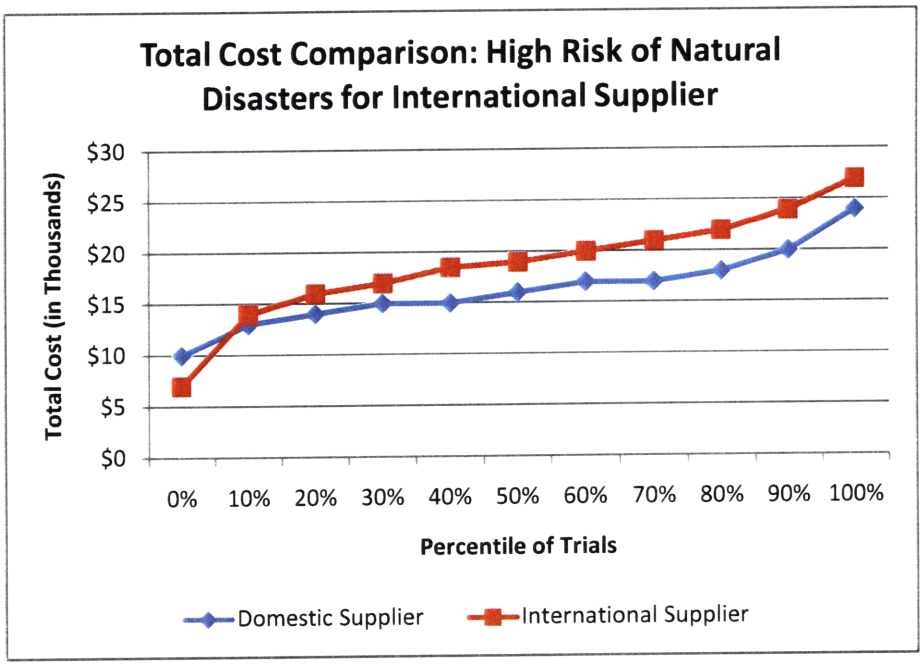

Figure 5.6 Comparison of total cost in conditions of high risk of natural disasters

The graphs depict that the international supplier is the least cost solution in only approximately 11% of the cases in a high risk scenario. But in a low risk scenario the international supplier would be preferred in almost 40% of the trials. The decision to source from an international supplier in this case therefore depends on how risk-averse the buyer is. If a 40% confidence in sourcing from an international supplier is sufficient to select a supplier, the additional cost increments can be built into the supply contract. Thus the decision to source from a supplier susceptible to the risk of a natural disaster alone would be considerably different from a supplier susceptible to political risk only.

5.2.1 Sensitivity Summaries for Individual Risk Factors

In a similar manner sensitivity analysis was carried out for the risk tolerance threshold of each risk factor for both the domestic and international supplier. By altering the risk tolerance threshold for a single factor at a time, high and low risk scenarios were developed. The results were compared to the base case and are summarized in Table 5.3. The cross-over percentile represents the percentile of trials where the international supplier has lower costs, i.e. was preferred. Therefore it indicates the threshold at which the supplier selection changes. The graphs for these simulations are included in Appendix A.

Table 5.3 Summary of results: Sensitivity of total cost of international supplier to risk factor tolerance thresholds

Risk Factors	Low Risk		High Risk		Base Case	
	Tolerance Threshold	Cross -over Percentile	Tolerance Threshold	Cross - over Percentile	Tolerance Threshold	Cross -over Percentile
Economic Risk	0.9	9%	0.1	6%	0.5	10%
Political & Legal Risk	0.9	10%	0.1	5%	0.6	10%
Financial Risk	0.9	30%	0.1	10%	0.3	10%
Natural Disasters	0.9	40%	0.1	11%	0.4	10%
Terrorism and Security	0.9	42%	0.1	11%	0.35	10%
Logistics	0.9	28%	0.1	6%	0.4	10%
Supplier Relationship	0.9	20%	0.1	7%	0.4	10%
Reliability and Quality	0.9	20%	0.1	10%	0.3	10%

Based on the analysis of this simulation we find that 4 risk factors experience a higher cross over percentile (the number of cases where the international, i.e. risky supplier is preferred) in high risk scenarios. These risk factors include financial risk, risk of natural disasters, terrorism and security risks and logistics risks. Whereas the other risk factors show little change with change in

risk tolerance thresholds. Risks related to logistics show the greatest variation between high and low risk scenarios making this risk most sensitive to change in risk thresholds.

After testing the sensitivity of the supplier selection to minimum and maximum risk threshold scenarios, we investigated the influence of varying the risk threshold using a normal distribution. All risk factors were varied by assuming a normal distribution of the risk tolerance thresholds and the variation in total costs are depicted in Figure 5.7. The risk tolerance thresholds vary using the values specified by the user, which are the same as the base case, and a standard deviation of 100% of the mean for the domestic supplier and 200% of the mean for the international supplier.

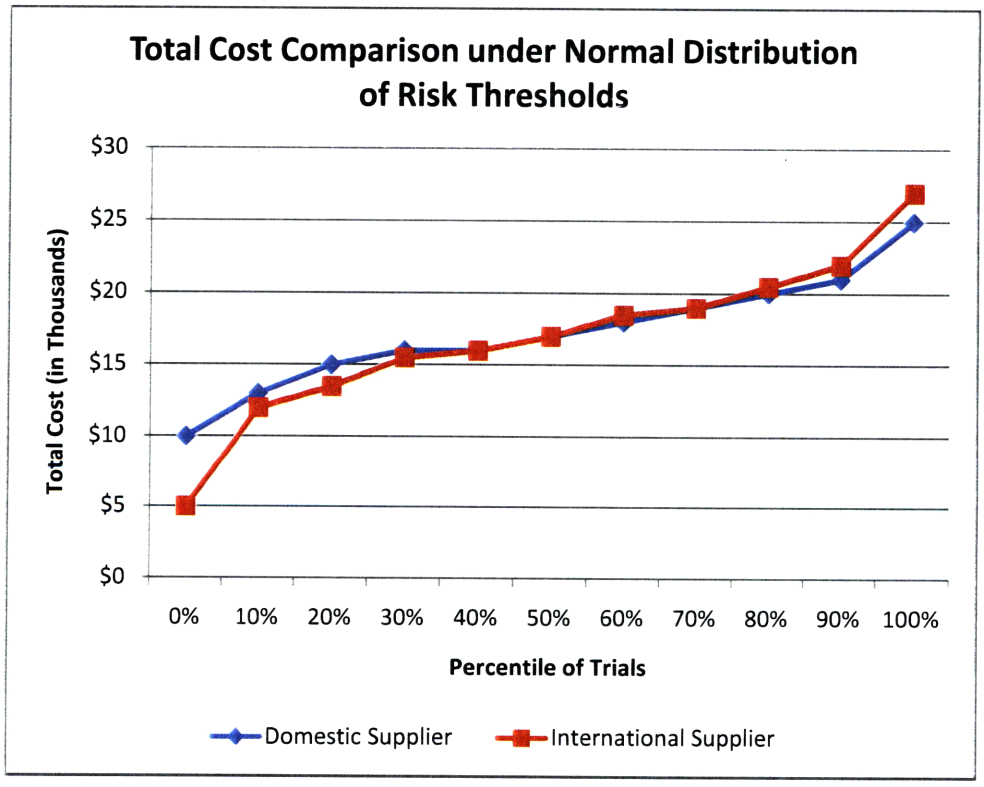

Figure 5.7 Comparison of suppliers under normal distribution of risk tolerance thresholds with standard deviation of 100% for domestic supplier and 200% for international supplier

5.2.2 Special treatment of risk tolerance for natural disasters and terrorism risks

Disruptive events caused by natural disasters and risks of terrorism and war are very infrequent events. Therefore it's necessary to treat the risk tolerance thresholds for these factors as extremely small discrete probabilities of occurrence with a high cost impact. In order to portray a more pragmatic probability distribution for these risk thresholds we assumed a risk tolerance threshold of 1 in 10,000. The results are depicted in Figure 5.8.

We observe that in the case of low risk of natural disasters and terrorism the international supplier is preferred in 50% of the trials. In practical situations faced by managers making sourcing decisions, the benefit of sourcing from an international supplier is evaluated without considering the small but finite possibility of experiencing risks such as that of natural disasters and terrorism. The results from this scenario analysis demonstrate that total costs change substantially in case of the occurrence of an infrequent disruptive event. In fact, the costs change significantly enough in 50% of the trials to change the decision to source from an international supplier to sourcing from a domestic supplier.

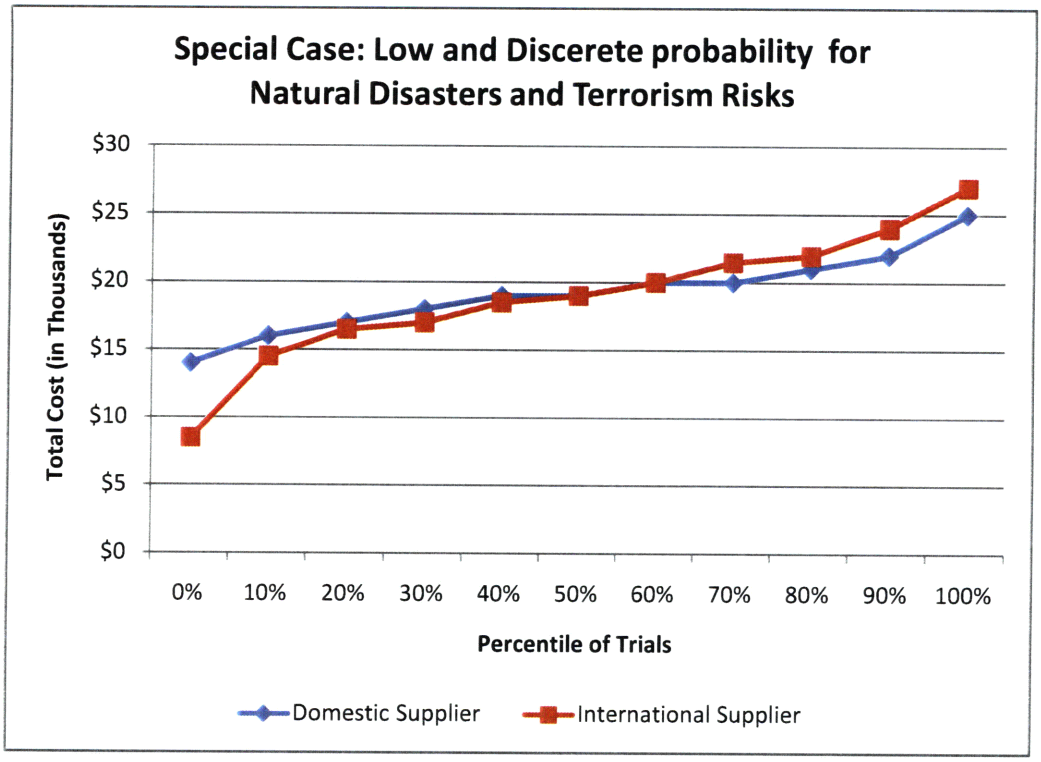

Figure 5.8 Comparison of suppliers with low and discrete probability for risks of Natural Disasters and Terrorism

5.3 Sensitivity of Total Costs to Cost of Risk

The cost of risk can be defined as the cost of risk mitigation or management or the cost that has to be borne if no risk management plan exists. Since these costs are hard to estimate and can greatly vary from initially estimated values when a disruptive event actually occurs, it is necessary to study the sensitivity of total costs predicted by the model to the cost of risks.

In order to study the sensitivity to cost of risk multiple scenarios were developed. In each scenario the costs of risk were assumed to have a normal distribution with varying standard deviations (from 10% to 200% of the mean). In the first scenario all risk factors for the international supplier were assumed to have costs normally distributed with a standard deviation

of 10%. The results of this scenario are depicted in Figure 5.9 where the international supplier was preferred in less than 10% of the trials.

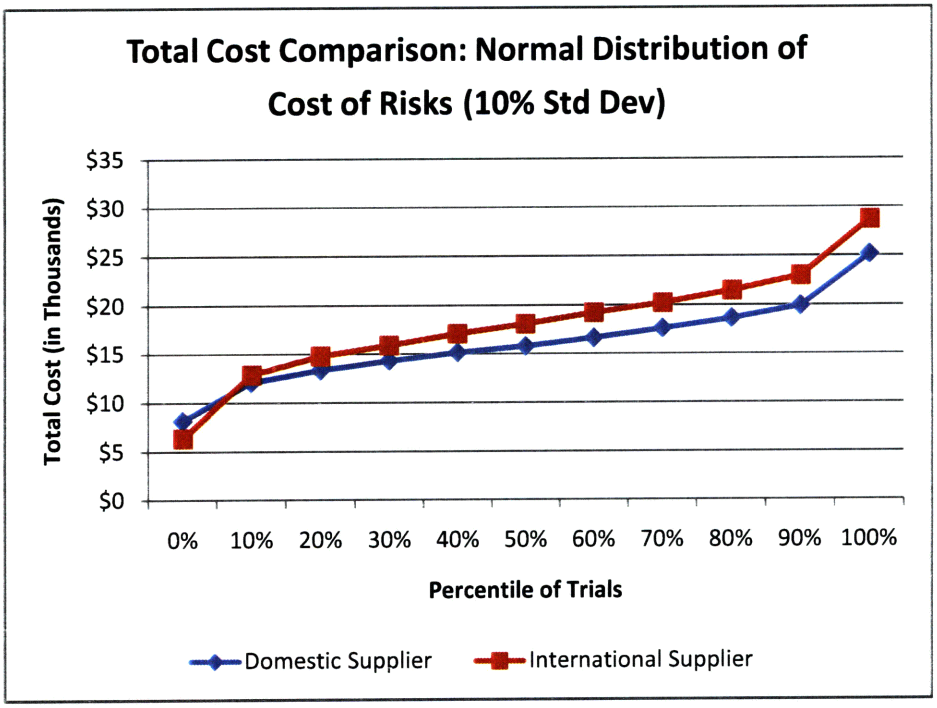

Figure 5.9 Comparison of suppliers with the assumption that costs of risk mitigation are normally distributed with a standard deviation of 10%

Figure 5.10 and 5.11 depict the contribution of each of the risk factors to the variance in total cost as the cost of risks follow a normal distribution instead of a point value. The risk factors are displayed by rank from the highest contributor the lowest. From Figure 5.10, which graphs the domestic supplier's results, we observe that the cost of supplier relationship risk has the greatest effect on the variation of total cost. On inspecting the base case set up Table 5.1, we observe that the supplier relationship risk has a low risk tolerance threshold and a high cost of mitigation. Thus the total cost variation due to supplier relationship risk is logical. The first 5 risk factors show a positive variance, implying that they have a positive correlation with total cost; i.e. as

supplier relationship risk cost increases the total cost increases. However, in the case of political and legal risk or that of terrorism, we find that the variation of the costs of these risks have little or no impact on total costs. This is valid because these risks have a very low cost of risk mitigation for the domestic supplier.

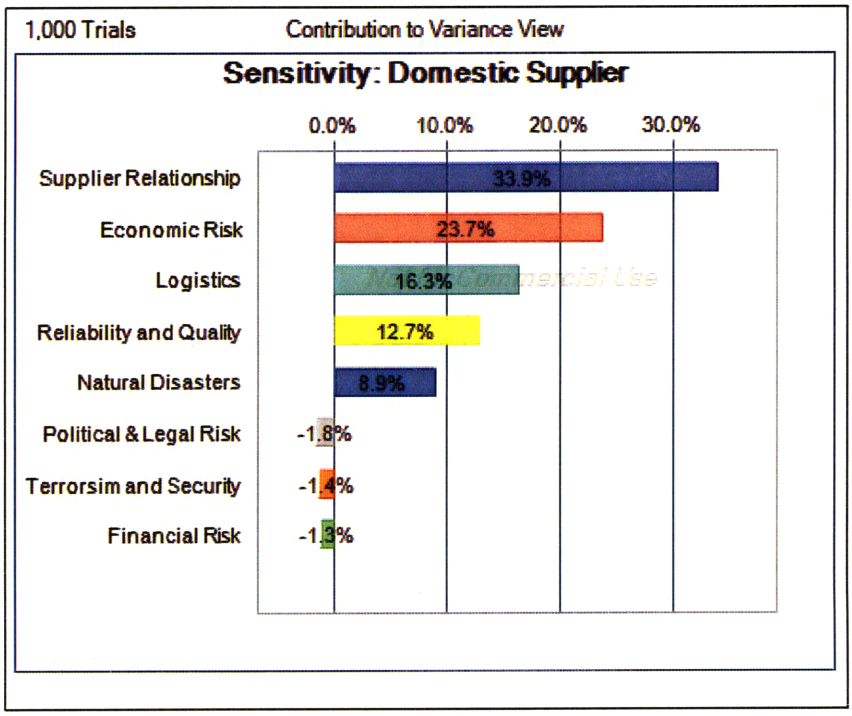

Figure 5.10 Contribution of individual costs of risk factors to the total cost of a domestic supplier

The results of a similar sensitivity analysis for the international supplier are depicted in Figure 5.11. We observe here a trend opposite to that of the domestic supplier with financial risk, terrorism and political risk factors contributing significantly to the variation in total cost.

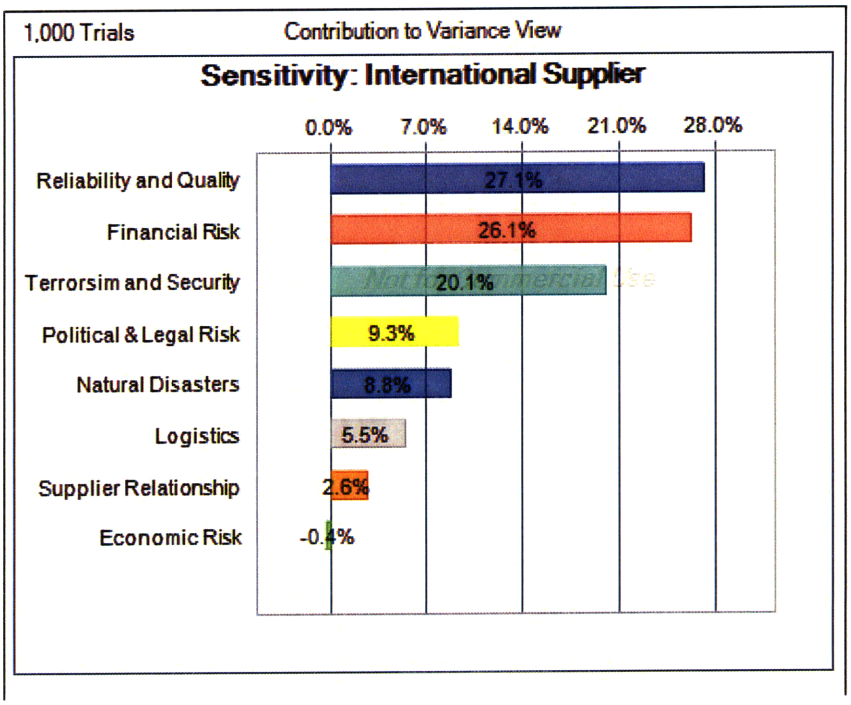

Figure 5.11 Contribution of individual costs of risk factors to the total cost of an international supplier

Another scenario was developed in which the costs of risks for the domestic supplier were assumed to be normally distributed with a standard deviation of 100%. A standard deviation of 100% implies that the costs may be double the initial estimate or more, which is possible scenario sine risk mitigation are hard to estimate and often fluctuate substantially over time. The international supplier's costs of risk are also assumed to be normally distributed but with a standard deviation of 200%. The results are depicted in Figure 5.12 and the sensitivity graphs shown in Figures 5.13 and 5.14.

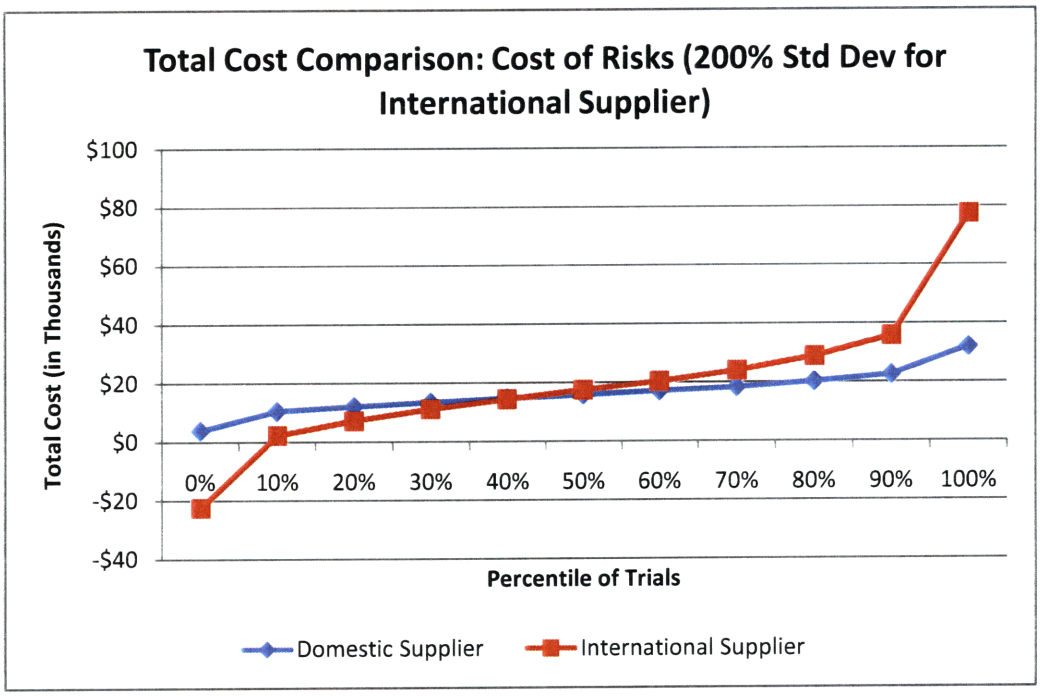

Figure 5.12 Comparison of suppliers with costs of risk mitigation normally distributed: domestic supplier with standard deviation of 100% and international supplier with standard deviation of 200%

Under conditions of higher variation of costs of risk, as simulated in this scenario, a much higher cross over percentage of 45% is observed (as compared to Figure 5.9). This implies that the international supplier would be preferred in 45% of the trials despite having a greater variation of costs. It is important to note that the normal distribution of costs implies that the costs are equally likely to be less than the expected value. This is why the total costs have a negative value in less than 10% of the trials. Though it is true that costs of risk mitigation can actually be less than expected, a negative total cost is only an academic discussion and is not realistic in practice. The possibility that costs for the international supplier may fluctuate so much below the initial estimate gives them a better risk profile, which shifts the decision threshold up.

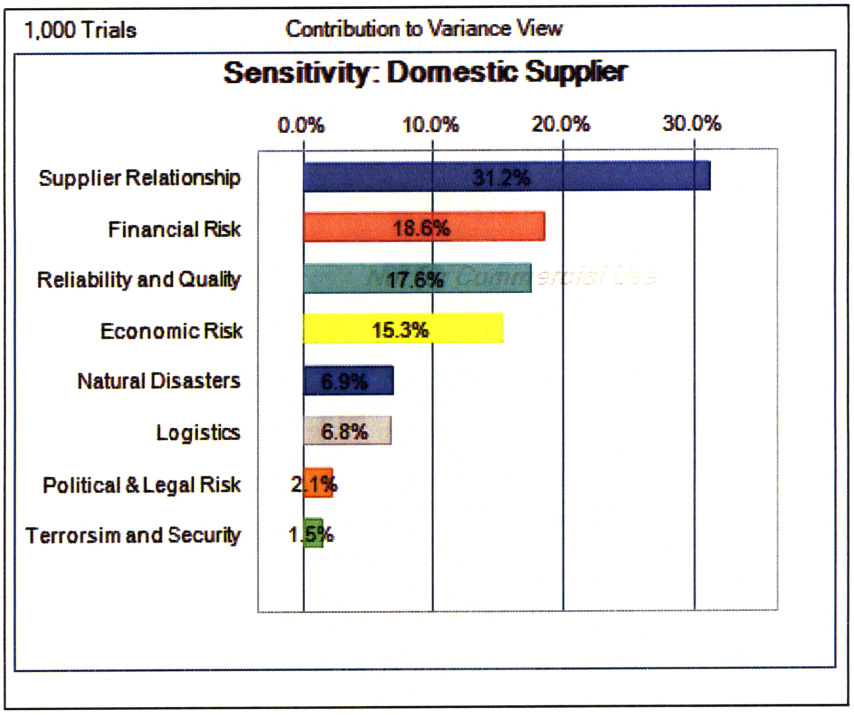

Figure 5.13 Contribution of individual costs of risk factors to the total cost of a domestic supplier with a standard deviation of 100% for costs of risk

A change in the ranking of risk factors contributing to variation in total cost is observed with the change in the standard deviations of distribution of costs of risk (Figures 5.13 and 5.14 are compared with Figures 5.10 and 5.11). While Supplier relationship risk remains as the risk factor with maximum impact on total cost for a domestic supplier, total cost is more sensitive to financial risk than economic risk when variation in cost of risk is higher. Similarly, in the case of international suppliers, Terrorism and security risks displace risks due to reliability and quality as top contributors to variations in total costs. These results imply that the total cost, and in turn the decision to source from a particular supplier, is sensitive to the variations in costs of risks. By evaluating the sensitivity analysis results, the decision maker is made aware of which risk factors are effecting the overall total cost, i.e. supplier selection. A more careful estimation of the inputs

(risk tolerance threshold and cost estimates) of these risk factors can lead to a more accurate and meaningful decision analysis.

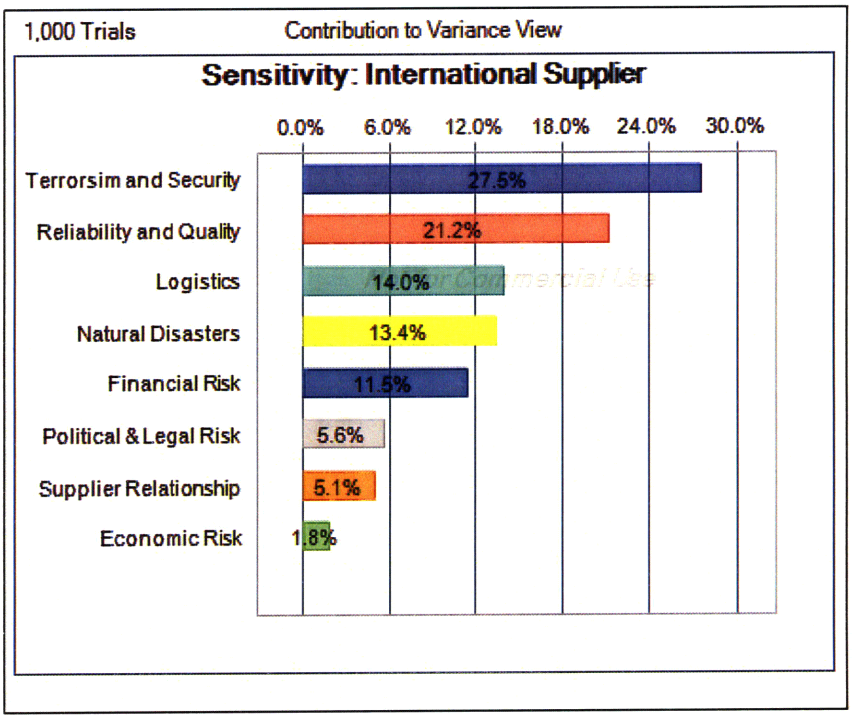

Figure 5.14 Contribution of individual costs of risk factors to the total cost of an international supplier with a standard deviation of 200% for costs of risk

5.3 Comparison of Three Suppliers

In most business scenarios, sourcing managers need to select between more than two suppliers. Therefore we now consider three suppliers: a domestic supplier, a distant international supplier and a near source supplier. The domestic supplier is located within close geographical and political quarters; for example, a supplier located in the USA. The distant international supplier is located at a distant global location and generally implies a long supply chain; for example, a supplier based in Indonesia. A near source supplier is a supplier that is located outside the

continental and political boundaries, yet closer than a distant supplier; for example, a supplier located in Mexico. These three suppliers have distinctly different risk profiles. In addition, the contractual costs of the distant and near source supplier are similar and substantially lower than that of a domestic supplier. The results of simulating such a scenario are displayed in Figure 5.15 and risk and cost set up are detailed in Table 5.4 and 5.5.

Table 5.4 Suppliers' location and contract cost specification

	Domestic Supplier	Distant International Supplier	Near Source Supplier
Location	USA (Domestic)	Indonesia (Asia)	Mexico (South America)
Contractual Cost of Part (in Thousands)	$10	$5	$7

Table 5.5 Risk profile description for 3 suppliers

Risk Factors	Domestic Supplier		Distant International Supplier		Near Source Supplier	
	Risk Tolerance Threshold	Cost of Risk	Risk Tolerance Threshold	Cost of Risk	Risk Tolerance Threshold	Cost of Risk
Economic Risk	0.6	1	0.5	2	0.5	2
Political & Legal Risk	0.9	1	0.6	3	0.75	2
Financial Risk	0.5	2	0.3	2.5	0.3	2.5
Natural Disasters	0.7	3	0.4	3	0.4	3
Terrorism and Security	0.9	1	0.35	3.5	0.6	3.5
Logistics	0.6	2	0.4	3	0.4	1
Supplier Relationship	0.5	2	0.4	2	0.4	2
Reliability and Quality	0.4	3	0.3	3	0.3	3

The near source supplier's risk profile differs from that of a distant supplier due to a higher risk tolerance threshold and lower cost of political and terrorism related risk factors. All other inputs are maintained same as that of a distant supplier. Under these conditions the results depicted in Figure 5.15 show that the distant supplier is preferred over the domestic supplier in only 10% of the trials. However the near source supplier is preferred over the domestic supplier in close to

45% of the cases. Thus it can be concluded that the domestic supplier is has steady total costs and therefore outperforms the other two suppliers in case of infrequent high risk events. However, by incurring lower costs in 45% of the trials, the near source supplier emerges as the preferred supplier over the international supplier and the best choice in low or medium risk situations.

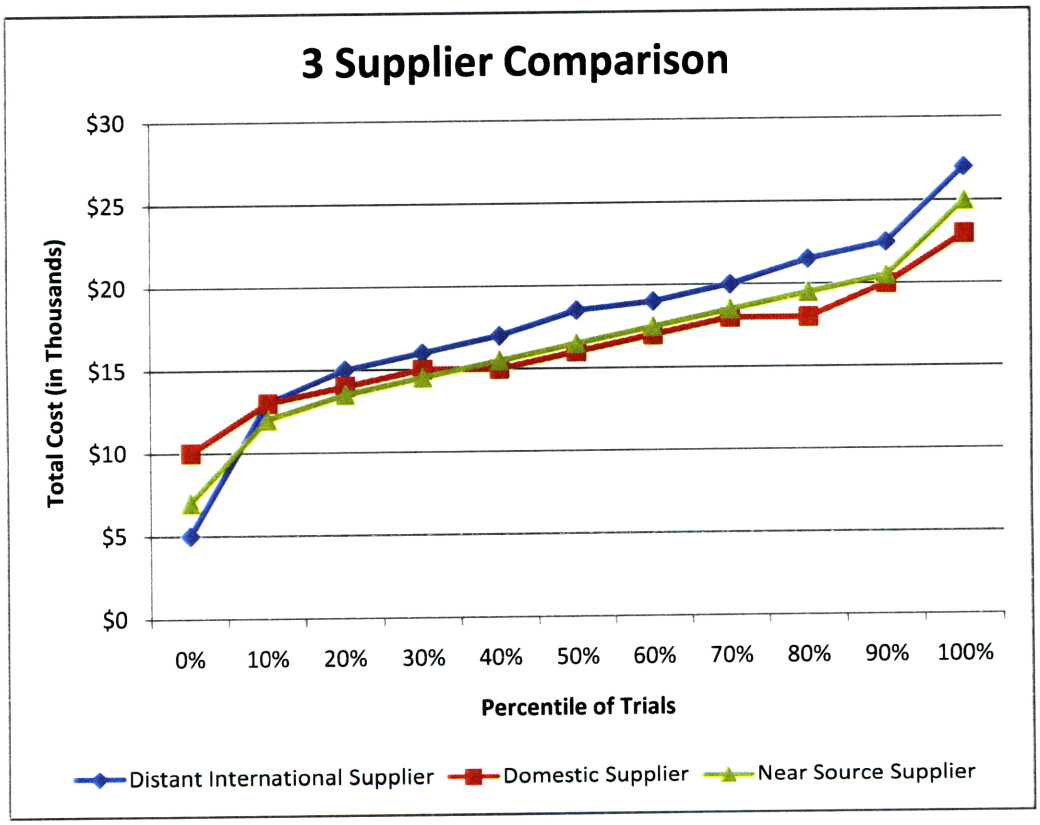

Figure 5.15 Comparison of total costs of 3 suppliers

As demonstrated in the scenarios described in this chapter, there is a distinct relationship between costs of sourcing from a supplier and the supplier's risk profile. The tool constructed for this thesis allows a decision maker to evaluate strategic sourcing decisions while including risk factors and associated costs.

6. Conclusions

6.1 Analysis Summary

The original hypothesis of this thesis was that risk-related costs create substantial increments to initial cost estimates. This makes outsourcing to a distant, global supplier economically and strategically unviable in certain risk scenarios. We confirmed the accuracy of this hypothesis through the scenario analysis documented in Chapter 4. We also developed a tool that accounts for these cost increments and can be used to make risk-based decisions on supplier selection.

It is important to consider these risk scenarios and related variations in total cost while selecting a supplier. The suggested model provides managers and decision makers with a decision support mechanism where they can simulate risk scenarios and gain intuition regarding the implications of a low frequency but high impact risk on the total cost of sourcing from a supplier. Thus the model provides a quantitative method of analyzing risks instead of the discretionary methods often utilized for risk analysis. The results of using the model are often counter-intuitive, where managers expect certain risk factors to dominate but find that the results are sensitive to an altogether different set of risk factors. This demonstrates the importance of using an unbiased tool such as the one we present to make these decisions.

Due to the unique characteristics of supplier contracts and relationships in the automotive industry, such as Just-in-Time operations, single sourcing and long term technical partnerships, optimal supplier selection is crucial. By identifying and evaluating the risk factor(s) that a supplier is most susceptible to, automotive manufacturers can make provisions for relevant mitigation plans. These provisions can be in the form of flexible contracts or developing strategic alternatives, such as developing supplier redundancy. Alternatively, provisions can be in the

form of maintaining additional safety stock or allocating funds for contingency activities, such as expediting shipments, etc.

The intended use of the model is to understand the relative difference in costs of sourcing from two or more suppliers under varying risk conditions. Therefore the focus of estimating inputs (risks and costs) should be to determine the difference between the suppliers, as opposed to investing too much time to precisely map a supplier's specific risk profile. Once the practice of including risk analysis is integrated in the supplier selection process, managers will develop a better insight into developing risk profiles for suppliers. Additionally, historical observations can be used for more accurately mapping probability of risk occurrence.

6.2 Model Extension and Application

The underlying assumption during the development of the model was that each risk factor and risk mitigation practice is independent and non-correlated. However in practice, risk factors are often subtly correlated; for example, political risk and that of war and terrorism, or financial and economic risks. By estimating this correlation and extending the existing model to include the correlation of risk factors while estimating the risk tolerance thresholds, a more accurate picture of a supplier's risk profile can be painted.

Another suggested extension to the model is in risk cost estimation. A risk mitigation plan for a particular risk factor incurs a certain cost. However, the same plan can be used with only a marginal cost increment for mitigating a different risk factor. In such a scenario it would be incorrect to assign the entire cost to one risk factor and only the marginal cost to the other risk factor. Therefore a method to proportionally divide the cost of risk mitigation would yield a more accurate measure of total cost variation with risk.

Acme Auto required a model or tool to analyze the variations in the costs of sourcing from suppliers in different global locations with unique risk profiles. The model constructed and discussed in this thesis helps them understand the changes in costs, and thus the preferred supplier, based on changes in risk related factors. Furthermore, it identifies the likelihood of a selected supplier exceeding the cost estimated in supply contracts, and in fact exceeding the cost of what initially seemed like the more expensive supplier. This model will therefore help Acme Auto forge strategic sourcing partnerships that are beneficial in the long term under varying risk conditions.

Reference List

Autry, C.W. & Bobbitt, L.M. (2008). "Supply chain security orientation: conceptual development and a proposed framework." *The International Journal of Logistics Management* (Vol 19, No.1, pp 42-64)

Blackhurst, V.J., Scheibe, P.K. & Johnson, J.D. (2008). "Supplier risk Assessment and monitoring for the automotive industry." *International Journal of Physical Distribution & Logistics Management* (Vol 38 No. 2, pp 143-165)

Blake, D. (2008). "What is a Promise from the Government Worth? Quantifying Political Risk in State and Personal Pension Schemes in the United Kingdom." *Econimica* (Vol 75, pp 342-361)

Feller, B. (2008). "Development of a Total Landed Cost and Risk Analysis Model for Global Strategic Sourcing." Thesis. Massachusetts Institute of Technology, 2008

Committee of Chief Risk Officers – CCRO (2002). "Valuations and Risk Metrics." White paper (Vol 3)

Choi, T.Y. & Krause, D.R. (2006). "The supply base and its complexity: Implications for transaction costs, risks, responsiveness and innovation." *Journal of Operations Management* (Vol 24, pp 637-652)

Chopra, S. & Sodhi, M.S. (2004). "Managing Risk to Avoid Supply Chain Breakdown." *MIT Sloan Management Review* (pp 53-61)

Damodaran, A. (2008). "Strategic Risk Taking", Wharton Publishing

Davidson, R.A. (1997). "An Urban Earthquake Disaster Risk Index." Report No. 121, The John A. Blume Earthquake Engineering Center

De Neufville, R. (1990). "Applied Systems Analysis: Engineering Planning and Technology Management." McGraw Hill Inc, New York

De Mortanges, P.C. & Allers, V. (1996). "Political Risk Assessment: Theory and the Experience of Dutch Firms." *International Business Review* (Vol 5, No.3, pp 303-318)

Erb, C.B., Campbell, H.R. & Viskanta, T.E. (1996). "Political Risk, Economic Risk and Financial Risk." *Financial Analysts Journal* (pp 29-46)

Gaonkar, R.S. & Viswanadham, N. (2007). "Analytical Framework for Management of Risk in Supply Chains." *IEEE Transactions and Automation Science and Engineering*, (Vol 4, No. 2, pp 265-273)

Johns, B. (1995). "Damage to Chip Makers Puts Sourcing in Spotlight." *Journal of Commerce* (pp 1A)

Kalos, M.H. & Whitlock, P.A. (1986). "Monte Carlo Methods, Vol I: Basics." John Wiley & Sons, New York

Khan, O. & Burnes, B. (2007). "Risk and supply chain management: Creating a research agenda." *International Journal of Logistics Management* (Vol 18, No.2, pp 197-216)

Knight, F.H. (1921). "Risk, Uncertainty and Profit", Houghton Mifflin, Boston, MA

Lester, T. (2002). "Inside Track: Making it Safe to Rely on a Single Partner." *Financial Times* (pp7)

Levy, D. (1995). "International Sourcing and Supply Chain Stability." *Journal of International Business Studies* (Vol 26 No.2, pp 343-360)

Quispez-Asin, N. (2006). "Hybrid Lattice and Decision Analysis of Real Options: Application to a Supply Chain Strategy." Thesis. Massachusetts Institute of Technology, 2006

Sheffi, Y. (2001). "Supply Chain Management under the Threat of International Terrorism." *International Journal of Logistics Management* (Vol 12, No. 2, pp 1-11)

Tomlin, B. (2006). "On the Value of Mitigation and Contingency Strategies for Managing Supply Chain Disruption Risks." *Management Science* (Vol. 52, No. 5, pp 639-657)

Webster, F. and Wind, Y. (1972). "Industrial Buying as Organizational Behavior: A Guide for Research Strategy." *Journal of Purchasing* (Vol 8, No.3, pp 5-16)

Appendix A – Sensitivity of Total Cost to variation in Risk Factor Tolerance Thresholds for the international supplier

This appendix lists all the graphs obtained during sensitivity analysis conducted on the variation of total costs with change in risk tolerance thresholds for risk factors. The risk tolerance threshold for the international supplier is set to a high value of 0.9 when exploring low risk scenarios. On the other hand, the tolerance threshold for individual risk factors is set to a low value of 0.1 when exploring high risk scenarios. The results for the sensitivity analysis of political and natural disasters risk are discussed in Chapter 5, Section 5.2.

Section A.1 - Economic Risk

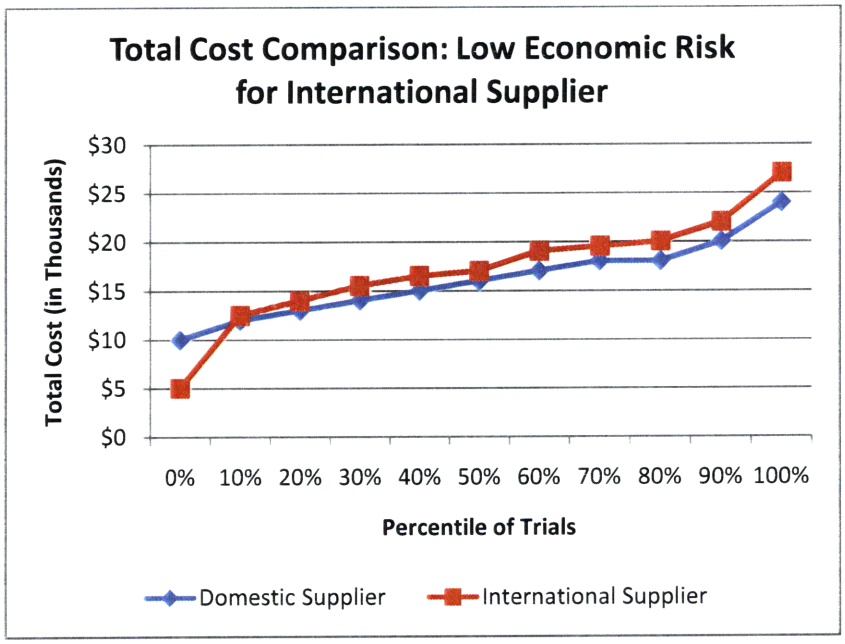

Figure A. 1 Comparison of total cost in conditions of low economic risk

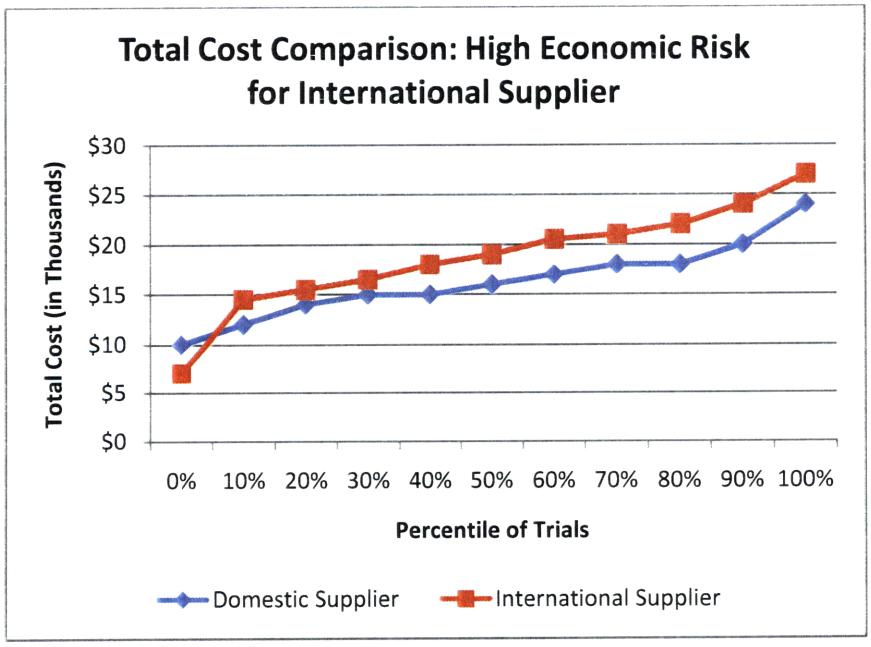

Figure A. 2 Comparison of total cost in conditions of high economic risk

Section A.2 - Financial Risk

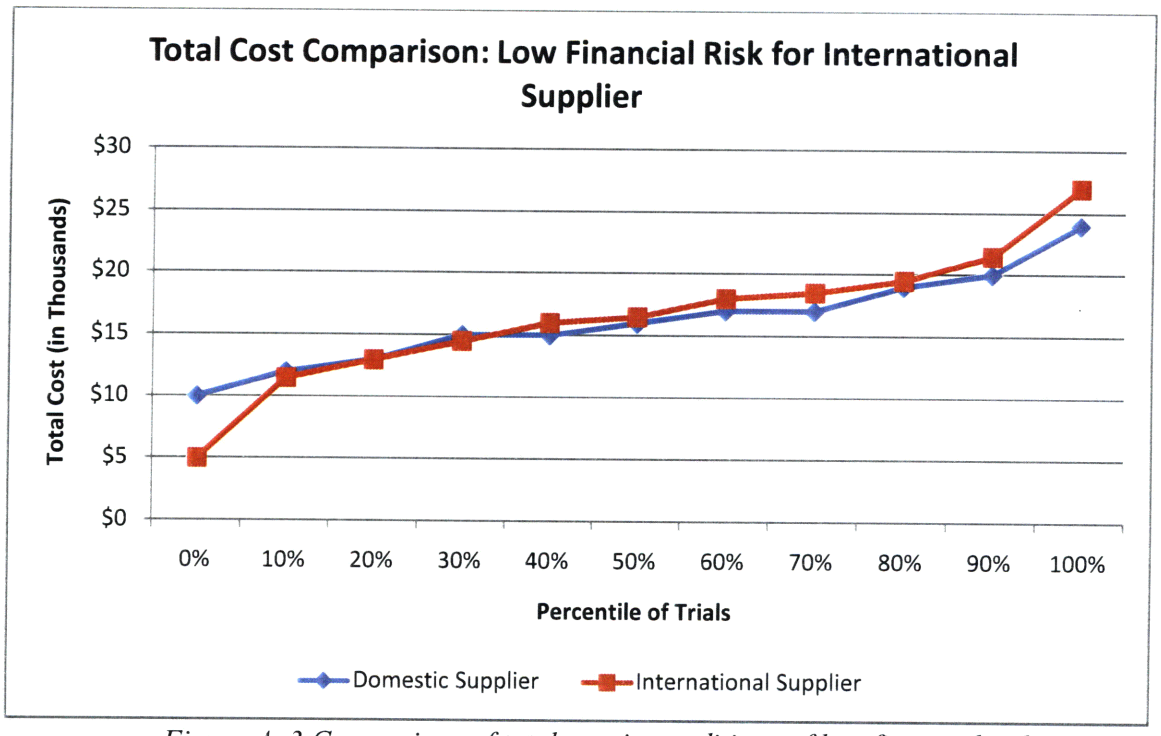

Figure A. 3 Comparison of total cost in conditions of low financial risk

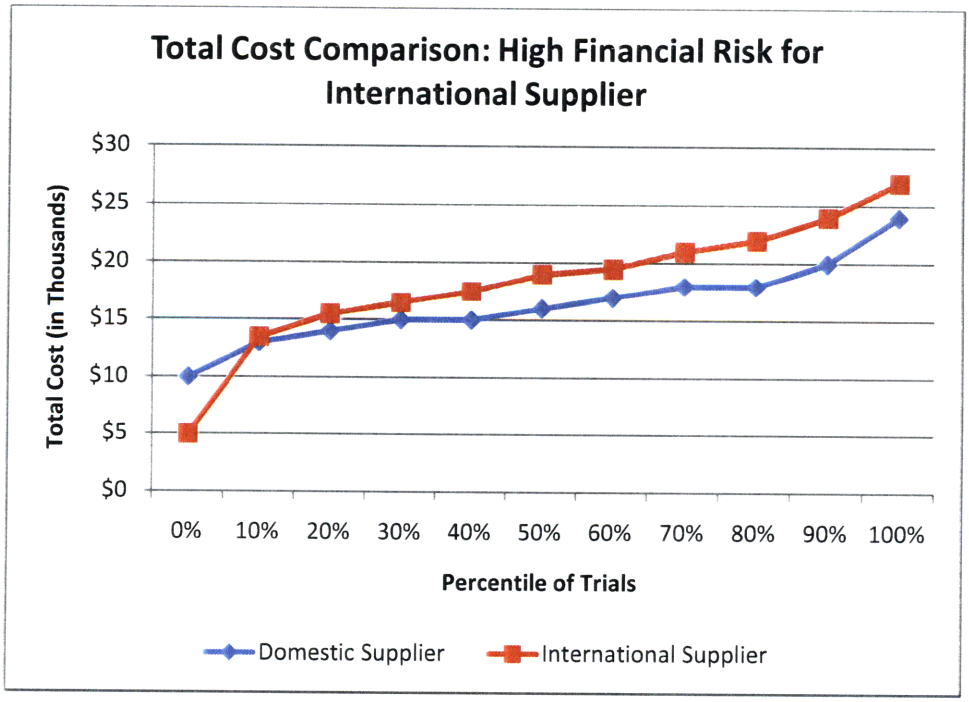

Figure A. 4 Comparison of total cost in conditions of high financial risk

Section A.3 - Risk of Terrorism and War

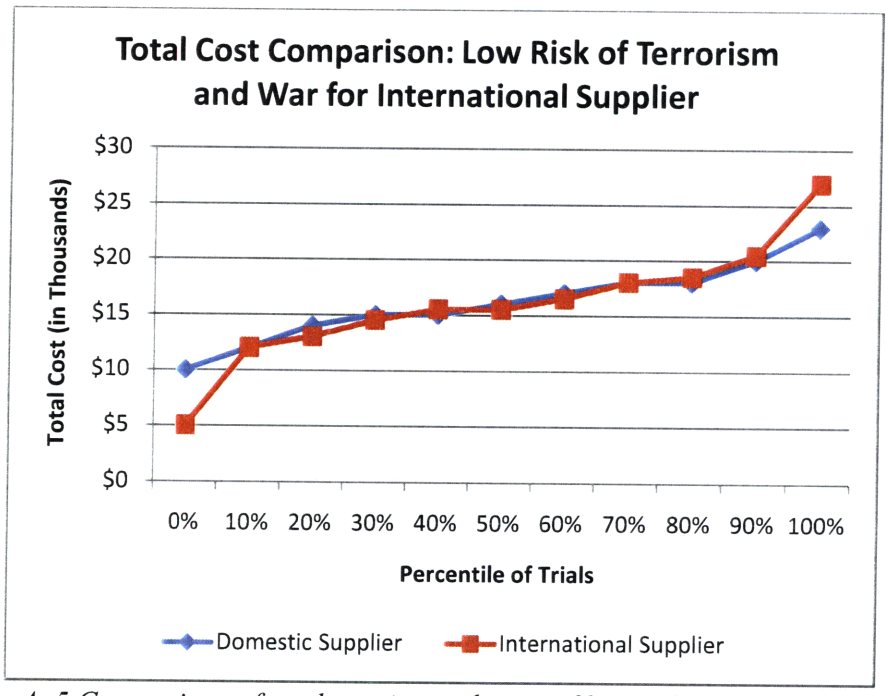

Figure A. 5 Comparison of total cost in conditions of low risk of terrorism and war

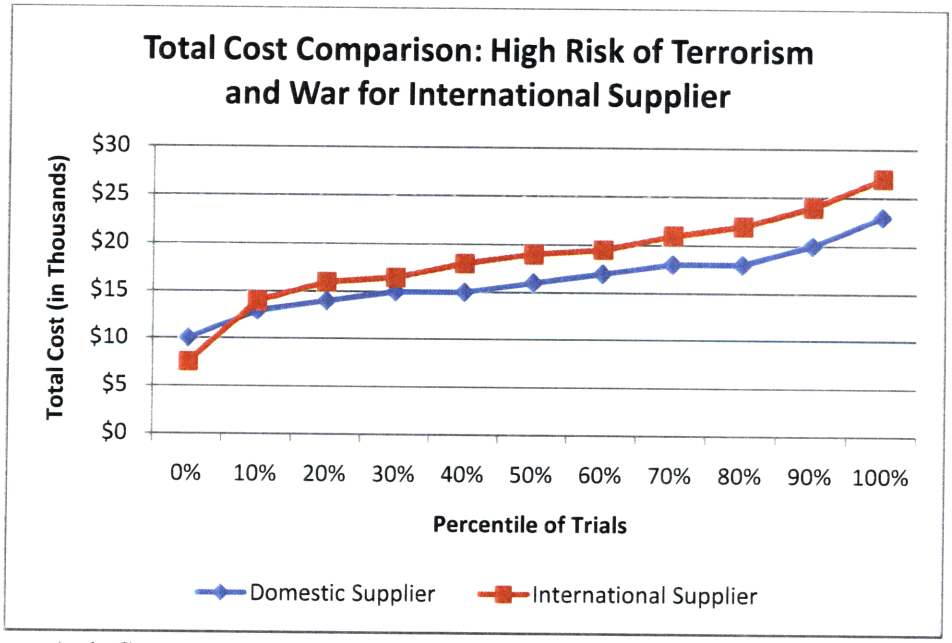

Figure A. 6 Comparison of total cost in conditions of high risk of terrorism and war

Section A.4 - Logistics Risk

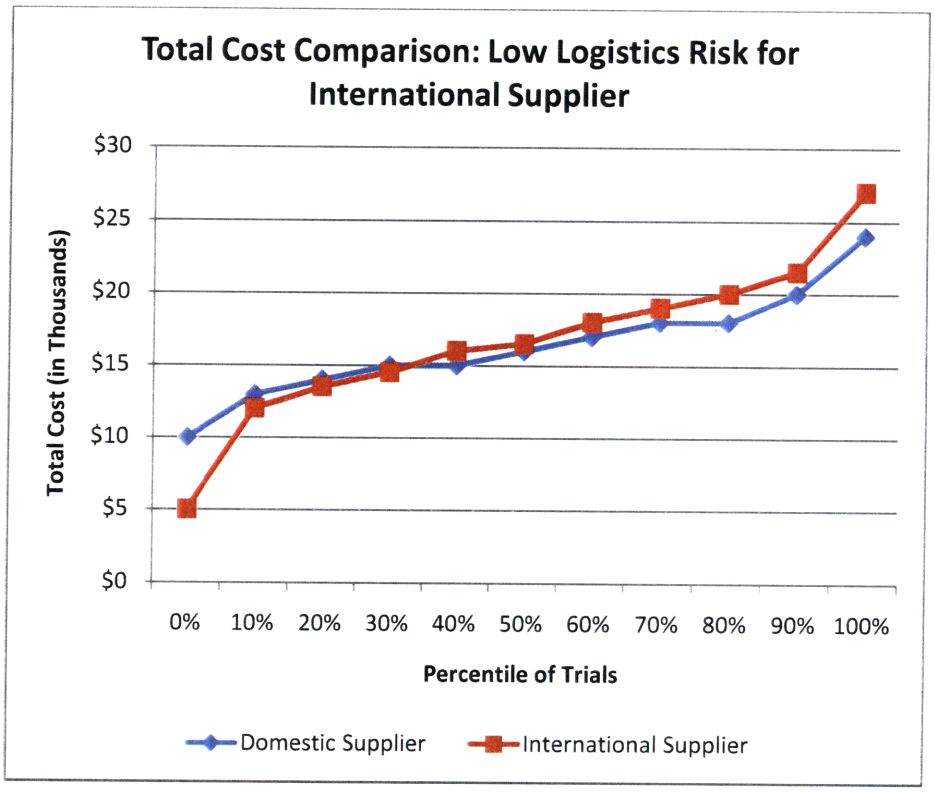

Figure A. 7 Comparison of total cost in conditions of low logistics risk

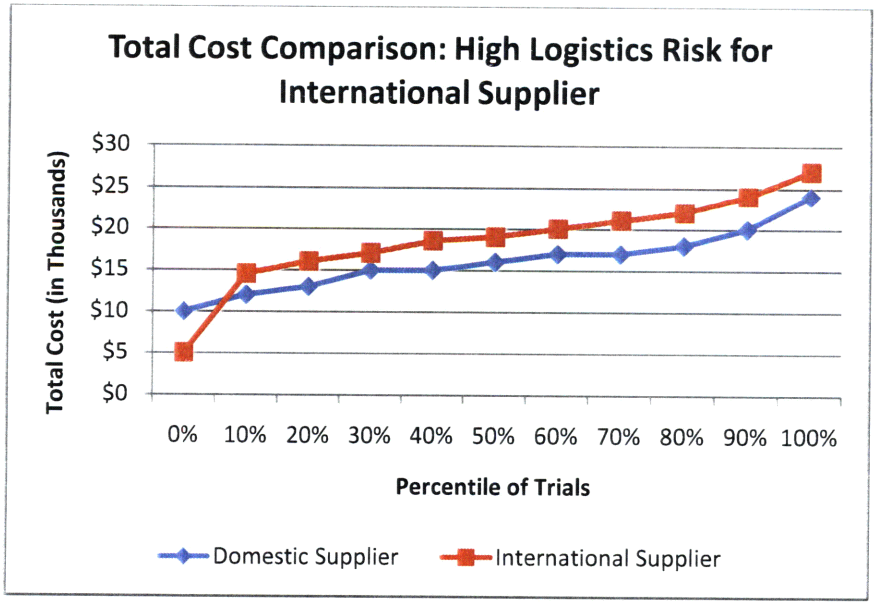

Figure A. 8 Comparison of total cost in conditions of high logistics risk

Section A.5 - Supplier Relationship Risk

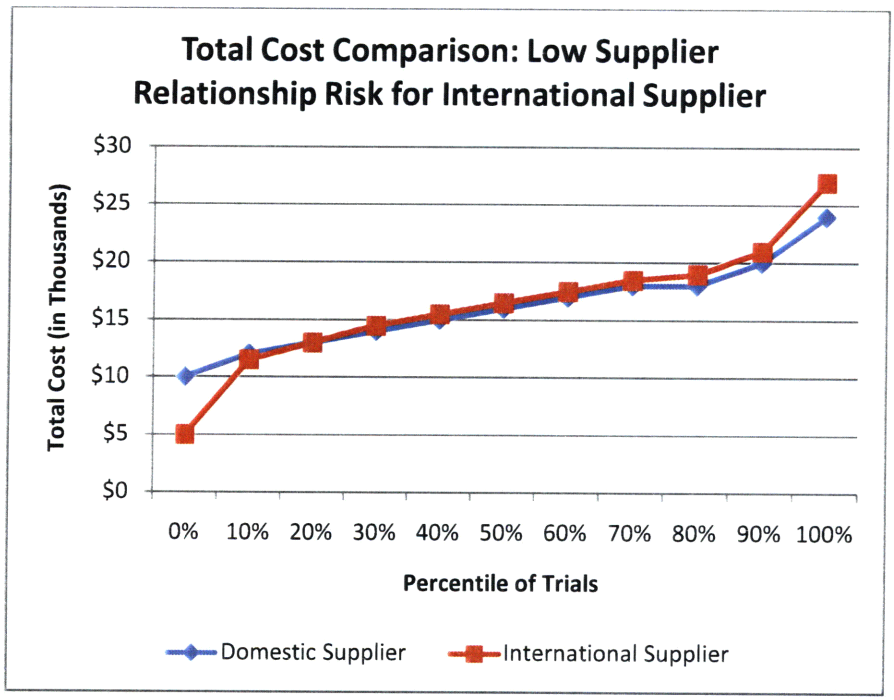

Figure A. 9 Comparison of total cost in conditions of low supplier relationship risk

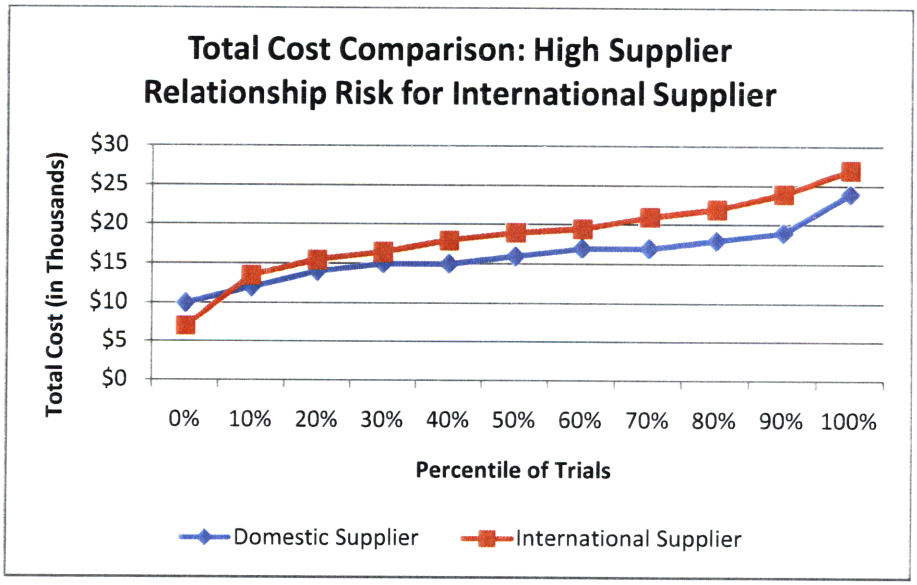

Figure A. 10 Comparison of total cost in conditions of low supplier relationship risk

Section A.6 - Reliability and Quality Risk

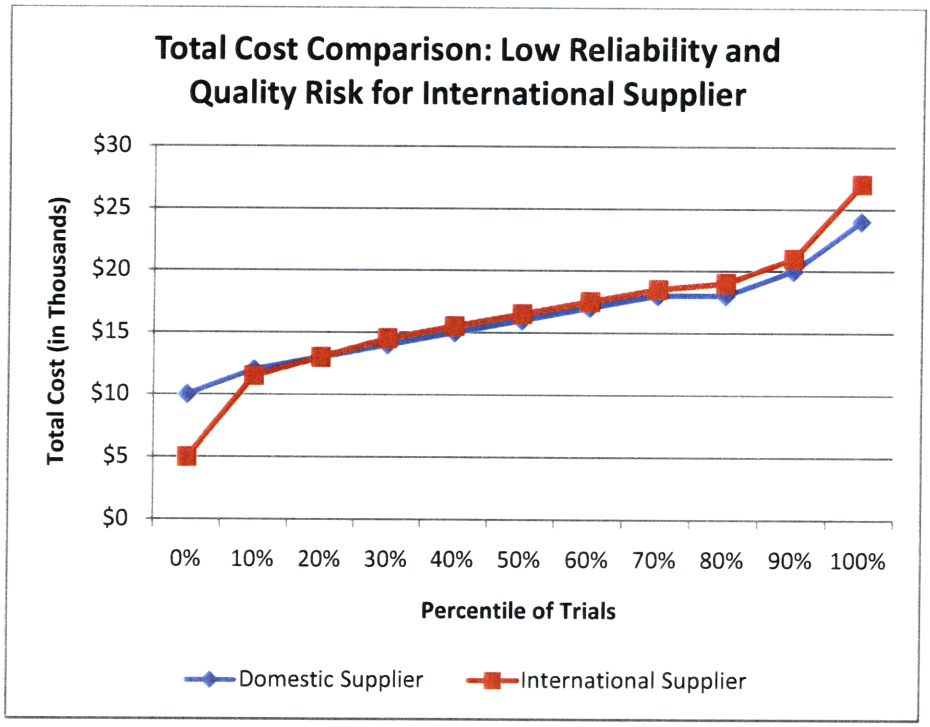

Figure A. 11 Comparison of total cost in conditions of low reliability and quality risk

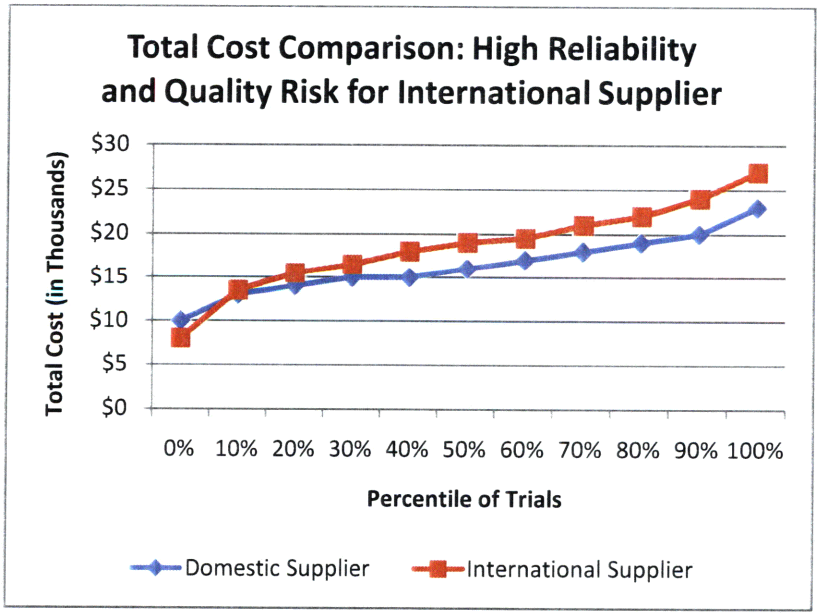

Figure A. 12 Comparison of total cost in conditions of high reliability and quality risk

Appendix B – Description of Supplier Selection Tool

This appendix chapter describes the excel based tool that was developed during the research for this thesis. It utilizes the model described in the methods section. The following sections describe various parts of the tool and its use.

Section B.1 – User Input Interface Form

The user interface form requires the user to input the following attributes for each supplier to be compared:

1. Location of Supplier: The specific geo-political location of the supplier plant/ manufacturing facility.

2. Contract Cost or Part Price:
   - This is the cost of a thousand parts as quoted in the contract.
   - It includes the cost of logistics as specified in the contract.
   - All costs are expressed in thousands.
   - All costs are expressed in a common currency, i.e. US Dollars.

3. Risk Tolerance Threshold: This is the probability of occurrence as decided by the user and its value ranges between 0 and 1.

   - For a given supplier, if the actual risk occurrence is below the threshold the cost of risk mitigation need not be incurred and only contract costs will be borne. However if the probability of occurrence of a risk factor exceeds the risk tolerance threshold, a risk related cost in addition to contract costs will be incurred.
   - In order to set the risk tolerance thresholds the user can use the help of the sources listed in Chapter 2. Sources such as Country Credit Ratings (CCR) rank countries, i.e. supplier locations based on their economic, financial and political risk. Thus based on their preferences, the user can set up default values for tolerance thresholds. For example a user can rate suppliers based in countries with ranks above 70 in the ICRG with a lower risk tolerance of say 40% probability of incurring a risk mitigation cost. However, this is only a suggested method; users can use surveys or draw on past experience to decide the risk tolerance thresholds.

4. Cost of Risk Mitigation: This is the estimated costs that will be incurred in event or possibility of risk. These can be estimated as cost of risk mitigation or cost impact in case there is no risk mitigation.
   - All costs are expressed in thousands.

- All costs are expressed in a common currency, i.e. US Dollars.
- The tool provides the user with the option of selecting from a limited set of cost ranges. For example a high cost, medium cost and low cost range for which the monetary values can be assigned based on user discretion. This implies that for one user high cost would imply ten thousand dollar for a thousand parts whereas for different organization and user high cost can imply five thousand dollars for thousand part pieces.

Figures B.1 and B.2 display the forms for entry of data for domestic an international suppliers respectively. In case of a 3 supplier comparison, another such input form is available for a near-source supplier.

Domestic Supplier	
Location	USA (Domestic)
Contractual Cost of Part	10

Risk Profile	Risk Tolerance Threshold	Expected Cost of Risk Mitigation (000's)
Economic Risk	0.6	
Political & Legal Risk	0.9	
Financial Risk	0.5	
Natural Disasters	0.7	
Terrorsim and Security	0.9	
Logistics	0.6	
Supplier Relationship	0.5	
Reliability and Quality	0.4	

Figure B. 1 User Interface for input of domestic supplier details

International Supplier	
Location	Indonesia (Asia)
Contractual Cost of Part	5

Risk Profile	Risk Tolerance Threshold	Expected Cost of Risk Mitigation (000's)
Economic Risk	0.5	
Political & Legal Risk	0.6	
Financial Risk	0.3	
Natural Disasters	0.4	
Terrorsim and Security	0.35	
Logistics	0.4	
Supplier Relationship	0.4	
Reliability and Quality	0.3	

Figure B. 2 User Interface for input of details for international supplier

Section B.2 – Model Simulation Toolkit (Back-End)

The model has been realized using Oracle Crystal Ball, Fusion Edition, and Release 11.1.1.1.00. This provides the tool with sophisticated simulation and data analysis capabilities while retaining a simple Microsoft Excel based interface. The back-end set up for the simulation is shown in Figure B.3 below.

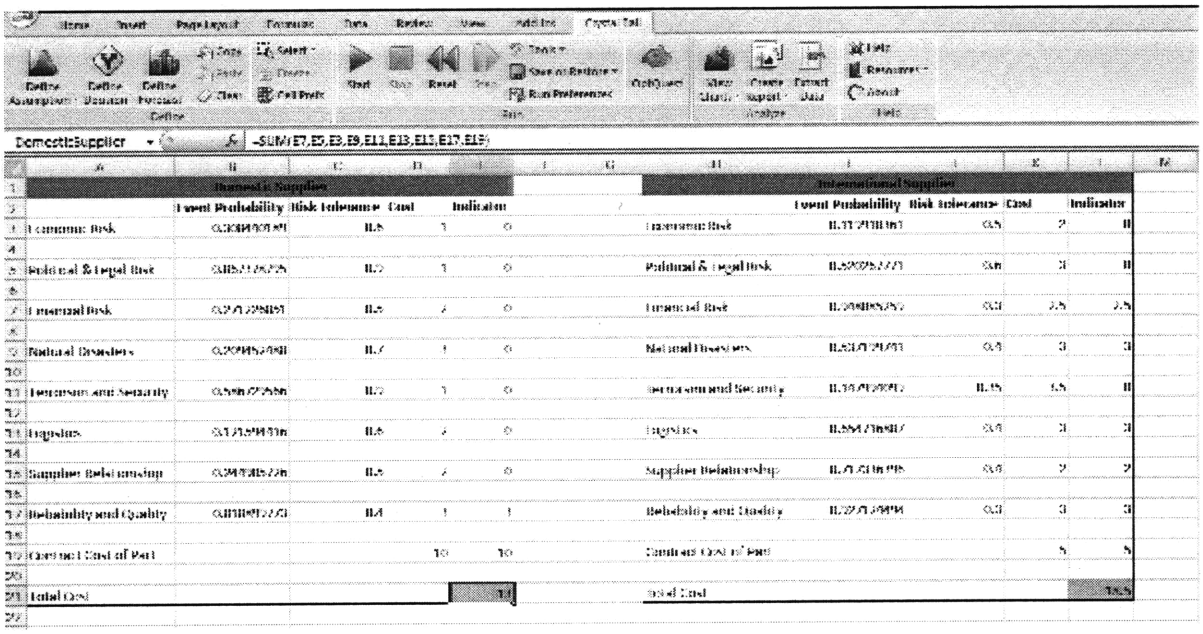

Figure B. 3 Model Simulation Setup

For each supplier the risk factors to be considered are listed. Each risk factor is described by the following parameters:

1. Event Probability: The simulation has been set up such that the probability of occurrence of each risk factor for each trial in the Monte Carlo simulation is represented by a random variable. This is achieved by using the rand() function in excel.

2. Assumptions

    a. Risk Tolerance: The risk tolerance thresholds associated with each risk factor are automatically carried forward from the user interface form.

    b. Cost: The cost is associated with a risk factor. It is the cost of mitigating the risk and is automatically carried forward from the user interface form.

3. Indicator: This parameter indicates whether the even probability is greater than the risk tolerance or not. When the event probability is greater than the risk threshold, the indicator is populated with the cost of risk mitigation.
   This is because the model is based on the theory that if the probability of occurrence of a risk event is greater than the estimated risk bearing threshold of the buyer, an additional cost has to be borne.

4. Contract Cost of Part: This value is also specified in the user interface form and automatically carried forward to the simulation setup.

5. Forecast Value

    a. Total Cost: Total cost is calculated as the sum of all the costs in the indicator column, i.e. summation of the costs that will be incurred including contract costs and costs due to risks exceeding threshold limits.

Model Setup Specifications:

1. Run Preferences:
    a. 1000 trials/samples
    b. Sampling method: Monte Carlo

Section B.3 – Running Simulations and Obtaining Results

In order to run the simulation the following steps need to be followed in sequence:

Step 1: All parameters of the User Input Form must be completed. This implies that the input data for suppliers (two or more) that need to be compared, i.e. the risk profile, contract and location details and estimated costs should be entered by the user.

Step 2: The user should now switch to the model set-up sheet in the tool click on the Start button.

Step 3: Once the model has been run, click on Extract Data option from the menu and select 'Percentiles' in the 'Extract Data Preferences' pop-up wizard that appears (Figure B.4). Leave all other selections as default.

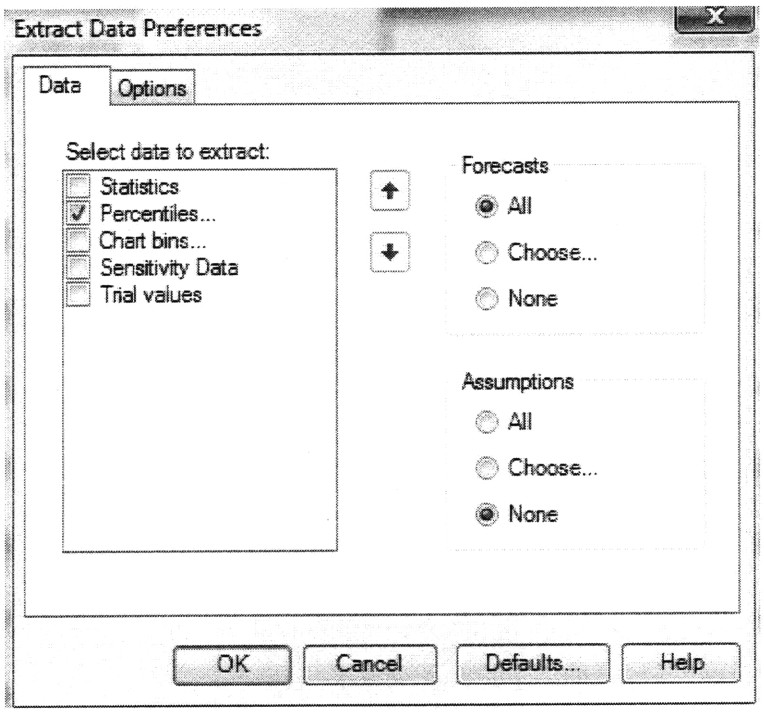

Figure B. 4 Extract Data Preferences: Select percentile

Step 4: The results are percentile of trials and the corresponding forecast value, i.e. total cost for each of the suppliers being compared. These results are extracted into a new sheet called Data. Navigate to this sheet and plot a chart or graph for the results. The cross-over of total costs, i.e. the no. of trials at which one supplier becomes more expensive than the other can be observed from the extracted data directly or from the graph (Figure B.5).

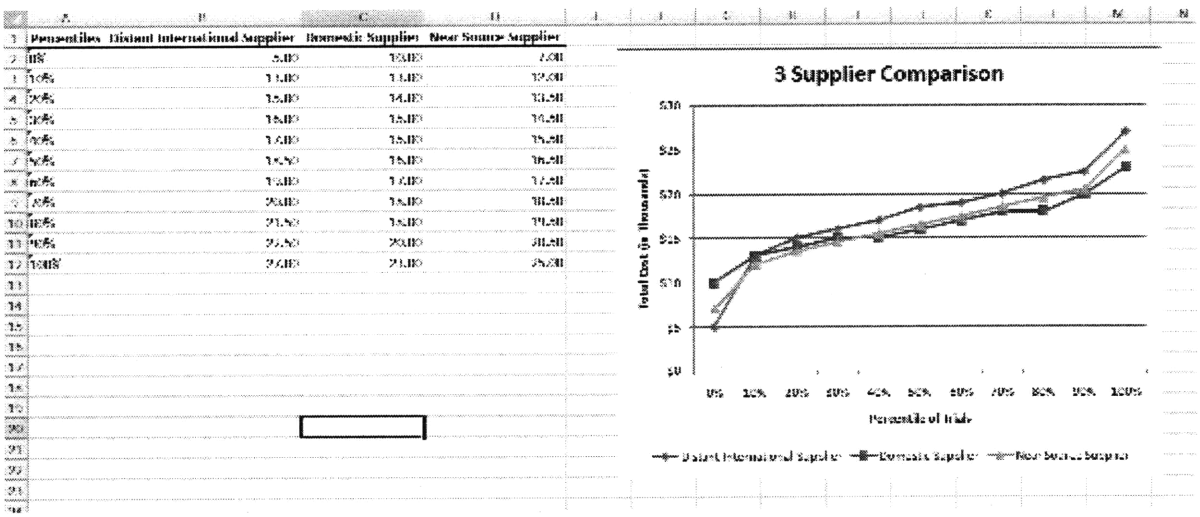

Figure B. 5 Results of Simulation

Additional Steps for developing sensitivity analysis

Step 5: Define assumptions as the parameters for which the sensitivity analysis needs to be conducted, for example the cost of risk. The distribution representing the variation of the assumption can be selected using the 'Define Assumption' wizard from Crystal Ball. Now run the simulation using the steps from 1 to 4 as listed above except that in 'Extract Data Preferences' wizard, select 'Sensitivity Data' as well as 'Percentile'.

Once the simulation has been run, the sensitivity charts can be viewed by selecting the View Charts option from the menu and selecting sensitivity charts.