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MITIGATING RISK IN SUPPLY CHAINS USING RISK ASSESSMENTS

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ABSTRACT

Supply chains are growing to be more globally intricate with more parts where there is risk. In this context, risk is defined as an undesirable event that possibly results in damage or danger to the employees, customers, and/or products. As a result, risk related events are influential in supply chain management and affect the flow of product from suppliers to the end users. In order to control and reduce risk within a supply chain, supply chain risk management (SCRM) methods have been developed to identify, track, and lessen risk. However, with all of these risk management methods, there is no tool to guide the selection and application of scenario appropriate tools. Therefore, in this thesis, supply chains and the associated risks are explored along with existing risk analysis tools. From there, the Tool Centered Risk Analysis (TCRA) framework was developed to be used by companies to identify what they would like from their risk analysis tools, how to pick the best tool for the scenario, how to collect the data and apply it to the tool, and what to analyze from the results in order to gain the most from the tool. In order to validate the TCRA framework, it was applied to an operating company within Johnson & Johnson. The company noted efficient use of time along with improvements in results with broader analysis and more developed mitigation plans to reduce risk at its manufacturers. The results from this thesis contribute the TCRA framework to select and apply the most appropriate tool(s) in order to analyze risk within a supply chain which has been validated for effectiveness.

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Chapter 1

Introduction

A supply chain can be simply described as the sequence of activities in the production and distribution of a product. Typically, the production process of a product consists of a supplier, manufacturer, and distribution center before reaching the customers. Certain suppliers and manufacturers may be located in one country while the customers are in different parts of the world. Today, as supply chains grow globally, supply chains have developed more intricately resulting in higher exposure to risk [1]. If there is a natural disaster in Europe, like the Eyjafjallajökull volcanic eruption in 2010 that disrupted transportation capabilities, it effects how a supply chain can operate. It is becoming more and more important to manage supply chains dynamically through methods such as risk management [2].

To a customer, the most important aspect about a product is its quality whether it is the reliability of a car or comfort of a piece of clothing [3]. With sophisticated supply chains and higher chance of risks and unintended events occurring, it is important to manage risk to prevent a decrease in quality or production levels. Risk can be defined as many things within a supply chain and it can vary from industry to industry or from company to company. Risks in supply chains can be defined as a possible danger, damage, loss, injury, or another undesirable consequence [4]. Once risk is defined, it can be identified within the supply chain and managed using supply chain risk management (SCRM) methods. These risk methods can be used to identify risks and their causes, and mitigate them to prevent these undesirable events from occurring.

Through this thesis, types of risks associated with a supply chain are examined in order to determine the types of SCRM methods that should be applied to successfully track and improve risky characteristics of the supply chain. This analysis is then placed within the context of the Tool Centered Risk Analysis (TCRA) framework in order to successfully manage the risk by identifying the risk and causes and potentially developing mitigation plans to reduce the risk. Finally, a case study was completed to verify the effectiveness and utility of the TCRA framework. This thesis contributes to SCRM by developing the TCRA framework and associated tools to assist in managing and reducing risk by analyzing the purpose of analysis and determining the best tool for risk analysis and management.

Research Objectives

The objective of this thesis is to identify and analyze risk assessment tools that can be used to manage and mitigate supply chain risks where networks are expanding globally through outsourcing production. Therefore, this thesis was developed to create a framework for approaching risk analysis in a supply chain in a systematic manner. The TCRA framework was developed to assist in selecting the correct tool for the scenario, collecting and applying the correct data for a tool, and analyzing the results. A case study conducted at Johnson and Johnson is then used to analyze the value of the framework based on the changes in risk management.

Chapter 2

Literature Review

In this chapter, background research will be presented on three main topics: the global supply chain, associated risks with global supply chains and production, and existing risk analysis methods and tools. The focus on managing global supply chains is important to companies today due to multinational companies have been moving away from operating independent domestic firms for each operating country towards linking together the entire supply chain in regards to decision making in the past twenty years or so [5]. With a larger global supply chain, there is more exposure to risks due to the outsourcing of manufacturing and distribution; therefore, logistics that must considered when making decisions that will affect either a part or the entire supply chain [1]. Taking both of these topics into mind, it is apparent that the risks in global supply chains need to be identified, analyzed, and mitigated through analysis methods or tools. However, there are advantages and drawbacks to each of the different methods being used that need to be examined. This prior work serves as the motivation for the creation of the TCRA framework.

Global Supply Chains

Over the past few decades, the norm of local manufacturing has shifted to global manufacturing with the attraction of cost savings [6]. According to Prasad and Babbar [7] research on global operations management, companies can benefit from utilizing the labor pool and intellectual capital in developing countries while expanding their markets. As a result, a company will utilize more global resources such as suppliers or manufacturers located in different parts of the world. An example of a typical global supply chain can be seen below in Figure 1 where suppliers, manufacturing facilities, and customers are located in different countries [8].

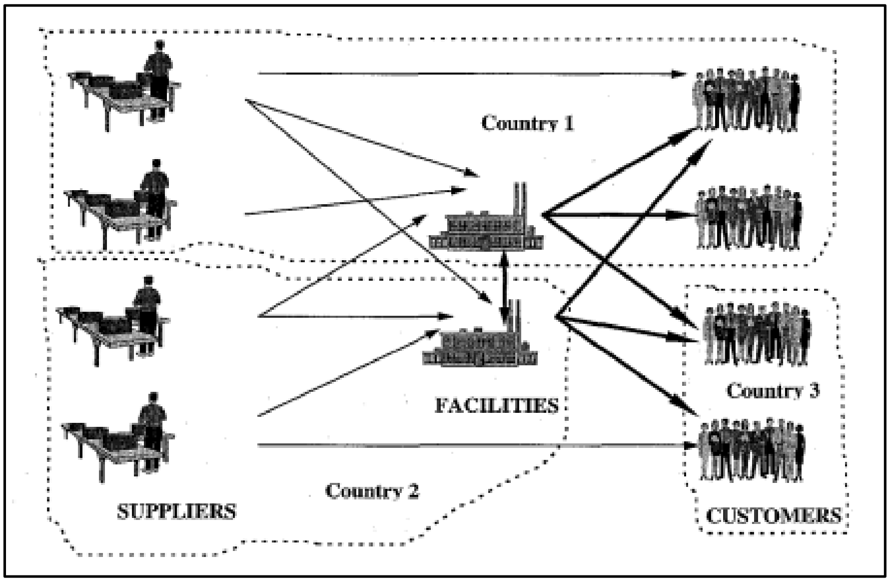


Figure 1: Typical Global Supply Chain [8]

Due to the ever-increasing globalization of the economy, global logistics systems (GLS) are becoming more prominent and significant in the management of global companies. Goetschalckx, Vidal and Dogan [9] define logistics as integrated production and distribution that considers (1) number of manufacturing plants, (2) zero, one, or more distribution echelons with distribution centers, (3) customers, (4) suppliers of components and raw materials, (5) recycling centers for used products and returned packaging containers, and (6) transportation channels that link together (1) to (5). Taking into consideration the six factors of logistics, companies form global logistics systems in order to assist and support long-term logistic visions [9].

As seen in the definition of logistics, there are many aspects to a global supply chain. With that in mind, a supply chain can be quite complex whether it is due to manufacturing outsourcing, supplier relationships, or expansion into international markets or new products [10]. Since global supply chains are multidimensional, there are greater chances of delay points and uncertainties. In addition, these global supply chains require more coordination, communication, and monitoring [11]. Christopher, Peck and Towill [6] studied global supply chains and the strategy for selecting an appropriate management system by identifying and relating supply replenishment lead-times and demand variability, see Figure 2. There are times that one of these strategies is preferred over the other, and companies should manage their supply chains appropriately in order to react rapidly when necessary.

		Demand Characteristics	
		Predictable	Unpredictable
Supply Characteristics	Long Lead Time	**Lean:** Plan and Execute	**Leagile:** Postponement
	Short Lead Time	**Lean:** Continuous Replenishment	**Agile:** Quick Response

Figure 2: Supply Chain Selection Based on Supply and Demand Characteristics [6]

While supply and demand characteristics can be used to categorize the type of supply chain a company has, there are other ways to define supply chain and its management. Supply chain management (SCM) can be classified into three categories, a management philosophy, implementation of a management philosophy, and a set of management processes [12]. Taking these three categories into mind, SCM can be defined in multiple ways depending on the author of a paper as seen in

Table 1. Typically, SCM is defined as the flow of materials from supplier to users while also managing conflicting interests of each group [13, 14] SCM increases the competitive advantage of an organization through cost leadership and differentiation of value products or services [12].

Table 1: Supply Chain Management Definitions

Definition	Author
SCM is used to integrate and manage source, flow, and control of materials across multiple tiers and functions.	Monczka, Trent and Handfield [15]
Supply chain strategy involves two or more companies within the network developing a trust and commitment to the relationship as they need to share information on demand, sales, and potential for a shift in the control of the process.	La Londe and Masters [16]
SCM synchronizes flow between supplier and customers in order to balance the conflicting goals of high customer service, low inventory management, and low unit cost.	Stevens [13]
SCM is the overall flow of materials from suppliers to end users.	Jones and Riley [14]
SCM is "…an integrative philosophy to manage the total flow of a distribution channel from supplier to the ultimate user."	Cooper and Ellram [17]

Supply Chain Risks

As an organization's supply chain grows, costs may decrease but risks increase due to responsiveness and supplier innovation [18]. Risks within the supply chain are defined and categorized differently by researchers. In this section, different breakdowns of risk will be explored. Risk in supply chains can be defined as a possible danger, damage, loss, injury, or other undesirable consequence within the supply chain [4].

According to Manuj and Mentzer [11], there are two types of risk including in supply chain: quantitative and qualitative. Quantitative risks include stock-outs, overstocking, and inadequate availability of components or materials in the supply chain. On the other hand, qualitative risks include lack of component and material accuracy, reliability, and precision.

Alternately, risk within a supply chain can come from different types of factors: environmental, industry, organizational, problem-specific, and decision-maker [19]. These five risk factors are further broken down and defined in Table 2. Some of these risks cannot be managed by a company such as natural uncertainties (i.e. hurricanes, earthquakes, flooding, etc.) and political instabilities or shifts. In addition, the five risks areas are not isolated and are often influential on one another. For example, if a competitor goes out of business (industry risk) then the company's supply chain organization will have to adjust accordingly.

Table 2: Supply Chain Risk Breakdown and Definitions

Risk Type	Description
Environmental	Environmental risks can be related to politics, economics, and the environment, including the following: political instability, government policy shifts, macroeconomic uncertainties, social uncertainties, and natural uncertanties [20]
Industry	Industry risks can be broken down into input market uncertainties, product market uncertainties, and competitive uncertainties which can be translated to changes in supply, demand, and competition [20]
Organizational	Organizational risks are firm specific and can include operating, liability, input supply, and production uncertainties [20]
Problem-specific	Problem-specific risk is related to how an organization manages their risks and the connectivity of the risks [21]
Decision-maker	Decision-maker risk takes into account the organization's rules and procedures along with the rationality of the decision-makers [22, 23]

When one looks beyond the basic supply chain network and expands into multiple sources and global networks, there are more risks associated with the supply chain. For example, Berger, Gerstenfeld and Zeng [24] looked into the risk associated with multiple suppliers, the authors identified five risk areas for multiple suppliers including inventory and/or supply disruptions, technology access disruption, price escalation, and quality issues. These variables can often conflict when trying to optimize the number of suppliers a company utilizes.

Lastly, Käki, Salo and Talluri [25] define risk as disruptions in the supply base which are high-impact events which can have an adverse impact on the supplier's performance. High-impact events are unexpected and can cause a dysfunction of a supplier, which propagates throughout the network. Many events relate to those risks in Table 2, such as a supplier becoming a competitor or a natural disaster such as volcanic eruption. The severity of a network disruption can be affected by the supply network design, specifically its complexity, density, and node criticality [26]. A supply network is made up of nodes and arcs, basically supply, production, and distribution sites (nodes) that are connected by production process (arcs). As there are more sites or more connections, the network becomes more complex and dense. If a larger event occurs at the production site in a more complex network, it will affect the rest of the supply chain with reduced supply or inventory depending on the stage of the production process.

Risk Analysis Tools

Taking into consideration the different parts of supply chain risk and how complex a global supply chain can be, it is important that risks are evaluated and managed effectively. Within supply chain management, there is a subset of supply chain risk management (SCRM) which has been rapidly developing in academics as well as industry due to the increased globalization of supply chains and organizations' interests [1]. SCRM focuses on the coordination and collaboration of processes across different functions within a supply chain network [27]. Research has been completed in defining, operationalizing, and mitigating risk using SCRM but there are still many aspects to be further researched including bringing the three areas together [28].

Risk analysis can be defined as identifying the threats, analyzing the vulnerability of the threats, and recommending mitigation plans for reducing risk [29]. Pai, Kallepall, Caudill and Zhou [30] classified risk analysis into three categories: vulnerability assessment, consequence analysis, and countermeasure analysis and implementation. Vulnerability assessment consists of threat asset identification and susceptibility analysis, which identifies threats against assets (i.e. infrastructure elements) and the probability of it occurring. Then consequence analysis assesses the potential damage associated with each threat based on severity, safeguards in place, and physical characteristics of the asset. Finally, the results of the other categories are used in countermeasure analysis and implementation by developing new safeguards and their analysis of effectiveness versus cost. These categories can be used as a base for how to approach SCRM.

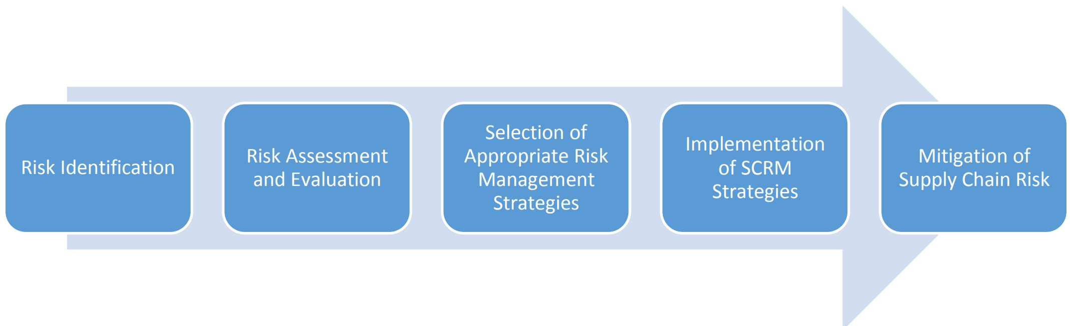


Figure 3: A Five-Step Process for Global SCRM and Mitigation [11]

On the other hand, Manuj and Mentzer [11] propose a five-step model for managing and mitigating risk that covers the three categories of risk analysis (Figure 3). The model is as followed: (1) risk identification, (2) risk assessment and evaluation, (3) selection of appropriate risk management strategies, (4) implementation of SCRM strategy(s), and (5) mitigation of supply chain risks. Using this model, risks are identified, categorized, and then assessed based on a decision analysis or a case study. After being evaluated, the management strategy is selected, which could include postponement, hedging, or security, and then implemented using management and organization learning. Finally, mitigation is prepared for unforeseen risk events. This model can be used as a basic framework that allows organizations to further tailor their risk management strategies with specific analysis tools. Risk analysis tools can be broken down into qualitative, semi-quantitative, and quantitative methods which will be further explored in the following subsections [31].

Table 3: Risk Analysis Tools Comparison

Method (Tool)	Description	Applicable Situations	Pros	Cons	References
What-if Method	Identify scenarios in which risks may be eliminated or minimized	• Identify risks and causes	• Quick • Ability to integrate into other tools	• Requires experienced team • Scenario based • Unstructured • Qualitative data	Stamatis [32]
Checklists	Set of prepared questions to analyze a situation and stimulate discussions	• Identify risks and causes	• Quick • Structured • Ability to integrate into other tools	• Scenario based • Qualitative data • Requires experienced team	Stamatis [32]
Failure Mode Effects Analysis (FMEA)	Identifies problems and assesses effectiveness of remedial actions	• Identify risks and causes • Develops remedial actions	• Structured form • Improvement identified • Quantitative and Qualitative data	• Requires experienced team • Time consuming • Scenario based • Not effective at identifying multiple causes in single event	Gilchrist [33]
Bow-Tie Risk Analysis (Cause-Consequence Analysis)	Relates the likelihood and impact of risk to what can cause an event to occur and the consequences of the event	• Identify causes and consequences of risks	• Quick • Requires knowledgeable team • Quantitative and Qualitative data • Visual results • Intuitive to create and understand	• Time consuming • Scenario based • Can result in expansive network	Brown [34]
Comprehensive Outsource Risk Evaluation (CORE)	Identifies and prevents risks from suppliers through 19 designated risks	• Identifies risks and causes	• Comprehensive • Requires knowledgeable team • Quantitative and Qualitative data • Quick	• High cost for system • Results' accuracy dependent on training and trust	Michalski [37]
Monte Carlo	Simulates inputs of likelihood of event and its consequences as risk curves of an event occurring	• Identifies probability of risk occurring	• Combines likelihood and magnitude for results • Creates framework for adjusting inputs	• Requires experienced team • Time consuming • Quantitative data • Dependent on input probability distribution • Does not identify causes	Brown [34]
Bayesian Networks (BN)	Models probability distributions and dependencies of risk variables in network.	• Identifies probability of risk occurring	• Shows relationship between characteristics	• Time consuming • Requires experienced team • Quantitative data • May be inaccurate due to estimated parameters	Kao, Huang and Li [40]

The tools for risk analysis are summarized in Table 3, and it can be seen that there are gaps present for each method. How does a company know what tool to use for their supply chain? The benefits for certain methods may be the parts missing in other methods, and therefore it may be beneficial to apply multiple tools to supply network by creating a blended approach to combine the benefits of both tools.

Qualitative Risk Analysis Tools

The qualitative method of risk analysis defines levels of judgement for the probability of a threat and its severity based on different scales such as rare to almost certain or low to high [31]. With high levels of uncertainty and multiple factors, qualitative approaches to risk analysis based on managerial risk may be more appropriate in order to manage risk [27]. Qualitative risk methods include the what-if method and checklist method. Both of these tools can be applied to other analysis tools whether they are qualitative, semi-quantitative, or quantitative [32].

What-If Method

The what-if method is conducted by experienced analysis, engineers, and operations experts who can identify scenarios in which risks may be eliminated or minimized, and its success is dependent on the knowledge, thinking processes, experiences, and attitudes of the team members. The analysis can be organized by dividing the facility into nodes or sections or by major items of equipment. For example, a production line is analyzed for risks using the what-if method by exploring potential scenarios in which different parts of the line went down. What would happen if the line feeder were jammed? Or, what if an employee was injured on the job or was sick and called out of work? Overall, it is the least structured analysis and therefore takes the least amount of time [32].

Checklists

Another qualitative risk analysis tool is checklists. The checklists are sets of prepared questions that analyze a situation and stimulate thinking and discussions in which the questions are often in a what-if form. Many of these questions are straightforward and can be answered based on facts (Figure 4). Occasionally, some of the questions will be subjective and may be skewed by the employee completing the checklist based off his or her experience. Unfortunately, the checklists are not all-inclusive of all risks as no one can predict all options and risks of a situation [32].

Facility Location Checklist

Area of Concern or Question	**Response**	**Recommendations**
Location of Motor Control Center (MCC)		
1. Is the MCC easily accessible to operators? 2. Are circuit breakers easy to identify? 3. Can operators safely open circuit breakers? Have they been trained to do so? 4. Is the MCC designed NOT to be an ignition source? Are doors always closed? Is no-smoking policy strictly enforced? 5. Is the MCC designed to be a safe haven?		

Figure 4: Sample Checklist Method Format [32]

Semi-Quantitative Risk Analysis Tools

Unlike qualitative risk analysis tools, semi-quantitative tools replace the judgement levels of qualitative methods with numerical values [31]. Two semi-quantitative risk analysis tools are

Failure Mode Effects Analysis (FMEA) and bow-tie risk analysis method which look at potential risks and problems and their respective effects and potential mitigations.

Failure Mode Effects Analysis (FMEA)

Item/Function	Potential Failure Mode	Potential Effect(s) of Failure	SEV	Potential Cause(s) of Failure	OCC	Current Design Controls (Prevention)	Current Design Controls (Detection)	DET	RPN	Recommended Actions
Hand Brake S/S: Provides the correct level of friction between brake pad assembly and wheel rim to safely stop bicycle in the required distance, under all operating conditions.	Insufficient friction delivered by hand brake subsystem between brake pads and wheels during heavy rain conditions.	Bicycle wheel does not slow down when the brake lever is pulled potentially resulting in accident.	10	Cable Binds due to inadequate lubrication or poor routing	4	Hand Brake Design Guide #123	Bicycle system durability test # 789	2	80	**Redesign hand brake cable routing to reduce friction and make system insensitive to lubrication degradation**
										Modify bicycle durability testing to include periodic brake cable checks for binding
				External foreign material reduces friction	2			3	60	
				Cable breaks	6	Cable material selection based on ANSI #ABC.	Bicycle system durability test # 789	4	240	**Require cable DFMEA/PFMEA from cable supplier approved by All-Terrain FMEA team.**
										Based on results of Cable DFMEA, develop cable strength test and modify cable design to improve strength
				Brake Lever breaks	1	Hand Brake Design Guide #123	Bicycle system durability test # 789	1	10	
				Selected brake pad material does not apply required friction to wheel	2			2	40	

Figure 5: Hand Brake FMEA Analysis [32]

According to Gilchrist [33], FMEA identifies problems and assesses the effectiveness of remedial actions when applied during the development stage of a process or machining. The FMEA consists of a standardized form that prioritizes failure modes and effects in order to determine targeted areas of prevention improvement. Gilchrist [33] also notes that FMEAs can be quantitative when mathematical failure rate models are combined with statistical failure mode ratio databases. The FMEA tool requires a strong team with wide cumulative experience in order to accurate complete the form with a wide variety of data and can be quite time consuming as a result [32]. In Figure 5, a hand brake is analyzed using FMEA, and the potential failures, effects of failure, and causes were identified in order to develop the recommended action plans. In addition, the FMEA method is not effective at identifying combinations of equipment failures that lead to accidents [32].

Bow-Tie Analysis/Cause-Consequence Analysis

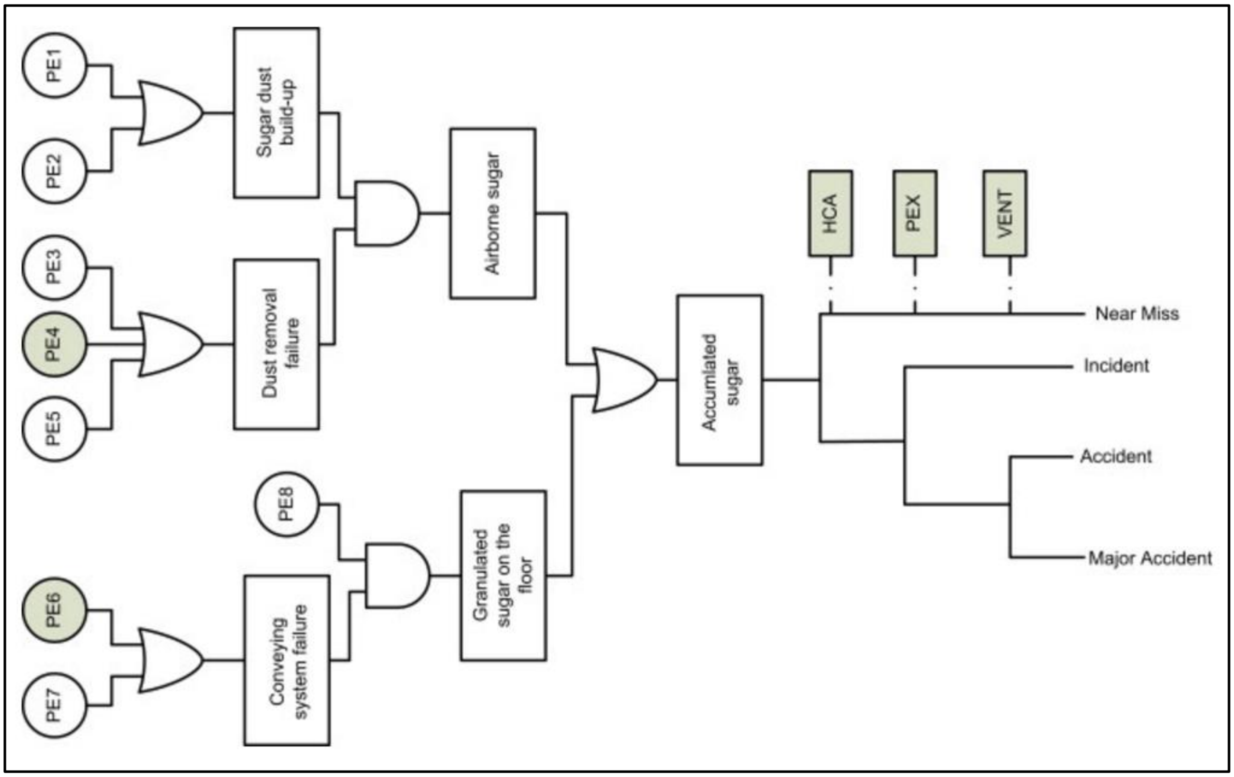


Figure 6: Bow-Tie Analysis of Sugar Factory Explosion [35]

The bow-tie risk relates the likelihood and impact of risk to what can cause an event to occur and the consequences if it does occur. It combines fault tree analysis (FTA) and event tree analysis (ETA), which examines a system event of interest connected to component failures including data on the failure and repair. On the other hand, ETA looks into possible causes starting at system level and working down through subsystem, equipment, and component levels [32]. This analysis method is very visual and intuitive to create and understand for less experienced individuals [34]. Khakzad, Khan and Amyotte [35] applied the bow-tie analysis method to a sugar refinery explosion resulting in the visual breakdown of the explosion causes along with the explosion consequences, see Figure 6.

Comprehensive Outsource Risk Evaluation (CORE)

The final semi-quantitative method is the result of Microsoft developing and implementing their own risk analysis tool, the comprehensive outsource risk evaluation (CORE) in order to identify and prevent problems at their suppliers rather than react and solve problems after they occur [36]. This was developed because Microsoft wanted to be aware of suppliers' business decisions and their effect on Microsoft as well as standardize their criteria for judging different suppliers [37]. In order to achieve this, the CORE system identifies 19 risks that are categorized into infrastructure, business controls, business value, and relationship which are then judged objectively and subjectively with weights depending on the importance to long-term business planning. The CORE system may result in high costs for maintaining large amounts of data about the suppliers, and the results' accuracy is based on the training and trust of the managers and suppliers.

Quantitative Risk Analysis Tools

The remaining type of risk analysis tools is quantitative based where the data collected is applied to the tool by applying simulation methods to calculate the probability of a threat and its impact. Often times, quantitative methods are more time consuming and may require more expertise in the area of analysis. In addition, the data inputted into these methods should be as accurate as possible. These methods can include the Monte Carlo technique and Bayesian networks (BN) [31].

Monte Carlo Simulation

The Monte Carlo simulation method takes inputs, such as the likelihood of an event and its consequence, as random inputs that are defined by probability distributions [34]. From there, a risk curve is created based on the combined value of the likelihood and consequence magnitudes. The key benefit of Monte Carlo simulations is the ability to calculate the probability of an adverse event occurring, which can be used for determining the preemptive, management approach for the event [38]. If the distributions are incorrect, then the results of this simulation method may not be useful. Often times Monte Carlo methods are the last approach applied to complicated problems because of the uncertainty involved and as a result the unreliable results [39]. This tool will create the framework for a specific process in which the inputs may be changed [34].

Bayesian Networks (BN)

On the other side of quantitative methods, Kao, Huang and Li [40] applied Bayesian networks to model probability distribution and dependencies of risk variables in the supply chain. In a BN, the nodes represent different aspects of the supply chain while the arcs represent the relationship between two nodes and how an event at one will affect the other. BNs are useful for industrial risk management because it can account for many dependencies, but it can be inaccurate due to estimated parameters [25]. A BN is helpful for understanding interactions between elements, but often times the effort to create a BN outweighs the benefits.

Motivation

After completing the literature review, it became apparent that while there are many definitions of risk and risk analysis tools, there is no framework or tool available to use to select the best risk analysis tool and apply it. Stamatis [32] explored the varying tools that can be applied to analyze risk but does not connect the tools to one another or explore the decision process of selecting the most applicable tool. In addition, Manuj and Mentzer [11] developed a five-step model that managed and mitigated risks. However, it does not assist in the risk analysis tool selection. Based on the findings of this section, a new framework for selecting and applying an effective risk analysis tool for a company's scenario would be beneficial.

Chapter 3

Methodology

With so many options today, how does a company apply the correct tool to get the results it is looking for? The TCRA framework was developed as part of this thesis work in order to provide the steps necessary to select, apply, analyze, and evaluate risk assessment tools so that a company can obtain the best results to further improve its supply chain. This framework was created in order to allow for application in multiple industries and situations with minimal research. The TCRA framework (Figure 7) will be outlined in the following subsections with each step's inputs and outputs.

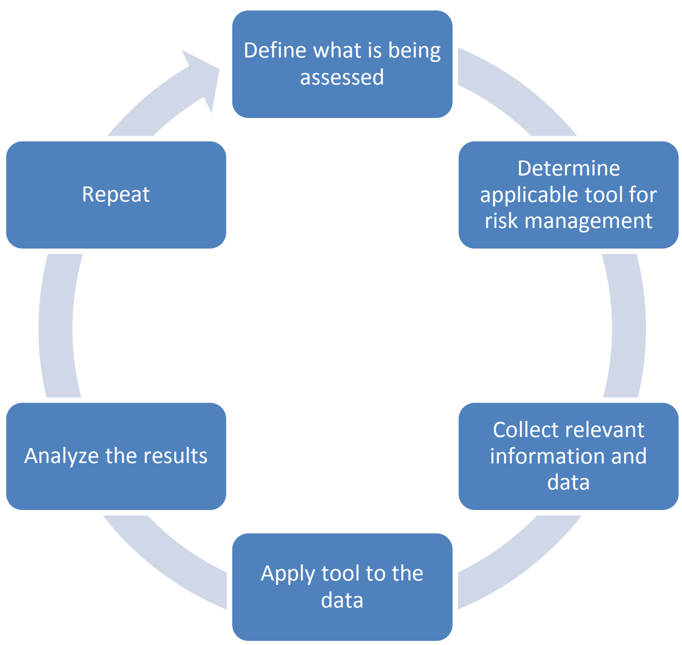


Figure 7: Tool Centered Risk Analysis Framework

Step 1: Define what is being assessed

The first step in the TCRA framework is to define what is being assessed. The purpose and scope of what is being assessed, specifically related to what risk is being managed, are included in the definition formed in this step. As it was found from the research completed on global supply chains, there are multiple parts to the supply chain, such as a number of manufacturing plants or suppliers, and each part carries its own set of risks. Risk assessments and management can be applied to the whole supply chain network, a small portion of it, competing supplier or manufacturers, and internal plants. With the cause and scope of the risk assessment, the purpose and functionality of the results becomes clearer. The results can be used to identify where risk is located within the network, or they can be used as a framework for risk mitigation.

It is important to understand the environment in which a risk assessment is being completed. Is it the result of a reoccurring problem, an upcoming change, or an annual evaluation of the supply chain organization? By identifying the risk before it happens, a company is able to stay ahead of it and manage it proactively rather than reactively which could more costly initially but over more cost efficient in the long run.

Step 2: Determine applicable tool for risk management

After determining what is being assessed within the supply chain, the information is used to select the most applicable tool. When considering risk assessment tools, there are many facets to consider. First, the tool must fit the desired purpose with regard to the type of subsequent results and how they can be analyzed. Also, the necessary data and personnel for the tool should be accessible in order to accurately complete the assessment. Once that is determined, a tool can be identified and selected to analyze risk. Using Table 4, different risk tools defined within the literature review in Table 3 are summarized by means of identifying attributes. The results of this table are applied in the decision tree in Figure 8, which evaluates which risk tool could be applied based on the scenario for risk analysis. Each tool provides different result and requires different types of data, teams, and time to complete. Some of the tools may take a few hours to complete while others may longer. In addition, some of the tools require an experienced team that knows explicit details about multiple parts of the process or supply chain along with additional skills and knowledge to apply and analyze the risk analysis tool. On the other hand, other tools require a management team that has an understanding of the process or supply chain from the overview perspective.

Table 4: Tool Selection Requirements

Method (Tool)	Purpose	Data Requirements	Timing Requirements	Team Requirements
What-if Method	Identify risks and causes	Qualitative	Quick	Experienced Team
Checklists	Identify risks and causes	Qualitative	Quick	Management Team
Failure Mode Effects Analysis (FMEA)	Identify risks and causes and develops remedial actions	Qualitative and Quantitative	Laborious	Experienced Team
Bow-Tie Risk Analysis (Cause-Consequence Analysis)	Identify causes and consequences of risks	Qualitative and Quantitative	Laborious	Management Team
Comprehensive Outsource Risk Evaluation (CORE)	Identify risks and causes	Qualitative and Quantitative	Quick	Management Team
Monte Carlo Simulation	Identifies probability of risk occurring	Quantitative	Laborious	Experienced Team
Bayesian Networks (BN)	Identifies probability of risk occurring	Quantitative	Laborious	Experienced Team

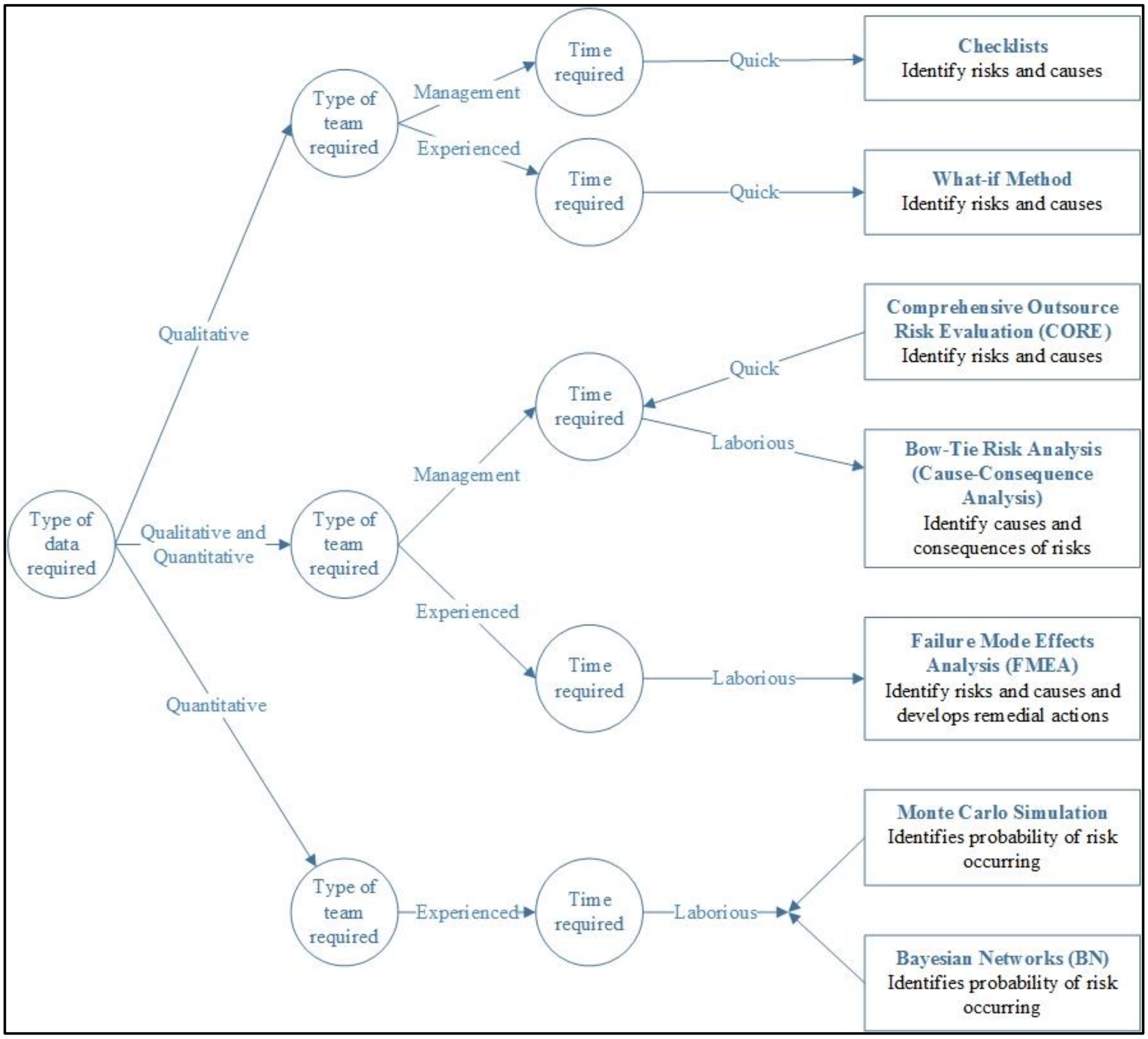


Figure 8: Tool Selection Decision Tree

It may be necessary to select multiple tools in order to get the desired type of results, and in this case, the tools can be used separately or merged to create one risk analysis tool. At this point, a company may choose to develop its own risk analysis tool based on the tools in Table 4. Using Figure 8, a company can also identify tools that included aspects that it required and adapt certain characteristics to create a tool that fulfills the company's requirements. Based on the developed tool, a company will need to define what information is required to successfully apply the tool.

Step 3: Collect relevant information and data

Once the tool(s) have been chosen for risk analysis, information for the input data needs to be collected. The tools are broken down by qualitative, semi-quantitative, and quantitative analyses, and as a result, qualitative and/or quantitative information will be required. Qualitative information on a supplier or manufacturer can include descriptions about the working conditions, relationship between the company and the supplier or manufacturer, and process details. Occasionally, qualitative data can be affected by bias based on the employees experience with the supplier or manufacturer that could influence the overall results of the analysis. On the other hand, quantitative data will be based on numbers collected throughout the process that cannot be influenced by potential bias from the employee collecting the data. Quantitative data includes information on quality, such as non-conformances and complaints, as well as value of parts or products supplied and history with government regulations. For the most part, the information can be collected by the team using their areas of knowledge. But, some of the information collected may require cross-functional assistance, specifically related to quality or environment, health, and safety (EH&S). Throughout the data collection process, it is important to ensure that all relevant data to the assessment is being collected and as accurately as possible.

Step 4: Apply the tool to the data

During this stage of the TCRA framework, a company can apply the gathered information to a single assessment, multiple tools, or an adapted tool. The information gathered in the previous step will be applied in different manners depending on the tool selected in Step 2. Some of the risk assessments may have a standard layout or form for the information, such as the checklist and FMEA methods. However, other tools may be formatted based on probability calculations of a specific event, which includes Bayesian networks and Monte Carlo simulations, and therefore the data collected must be analyzed first for distributions before being applied to the model. Often times, this portion of the TCRA framework will be the most time consuming. For some tools, such as CORE and Monte Carlo, once the tool is applied initially, any updates may require fewer adjustments and therefore less time because the framework was already created. Applying the tool is the most important stage of the TCRA framework because if applied incorrectly, the results and following analysis will be skewed and inaccurate as well.

Step 5: Analyze the results

After applying the tool and extracting the results, a company should apply the results as desired to the supply chain network. Most assessment tools will identify risks and potentially their causes, but beyond that, a company will choose how to use this information to its best capabilities. The results may be used as a tracking tool for potential risks, or they can be used for mitigation plans for risks. There are situations in which the results of one area of analysis can be applied to another application preemptively based on similar conditions. Overall, the analysis results should be analyzed for patterns or improvements and applied to the respective risks.

Step 6: Repeat

Now that the analysis has been applied to a company's supply chain, is the risk analysis complete? Typically, it is not because risk is always present within a system and conditions change over time which creates different areas of risk. The risk assessment and analysis process is cyclical and should include periodic updates to ensure the awareness and stability of a company's supply chain. Therefore, after analyzing the results of one analysis, a company should have a plan in place to repeat the process after a set amount of time or is instigated by an event occurring. As the process is repeated and the results are compared, the risks in the supply chain are either managed to prevent exacerbation of the problem or reduced over time.

Chapter 4

Case Study

After developing the TCRA framework, the structure needed to be verified and analyzed for effectiveness. In order to validate this, a case study was completed which allowed for comparisons between the current state of SCRM in a company and how that changed with the application of the TCRA framework. This section details the application and utility of the TCRA framework.

Company Selection: Johnson and Johnson

What company comes to mind when "caring for the world, one person at a time…" is mentioned? Many would say Johnson & Johnson (JnJ) because the company revolutionized surgeries with the idea of sterilization of medical instruments in the late 1800's and bandages and has created everyday household products since its inception. They developed products that range from baby oil to diabetic pumps to over the counter medicines. JnJ is made up of over two hundred fifty operating companies in more than sixty countries, which translates to a very extensive supply chain network in which some operating companies utilize some of the same suppliers. The JnJ operating companies are broken down into three sectors: pharmaceuticals, medical devices, and consumer healthcare (Figure 9). While the JnJ culture crosses sectors into all of the operating companies, each operating company has its own business practices. As JnJ continues to grow, corporate offices have started exploring ways to standardize some of these business practices within sectors and potentially across sectors as well. Currently, each operating company has its own method for managing risk within its supply chain, which could result in multiple analyses of suppliers with inconsistent results.

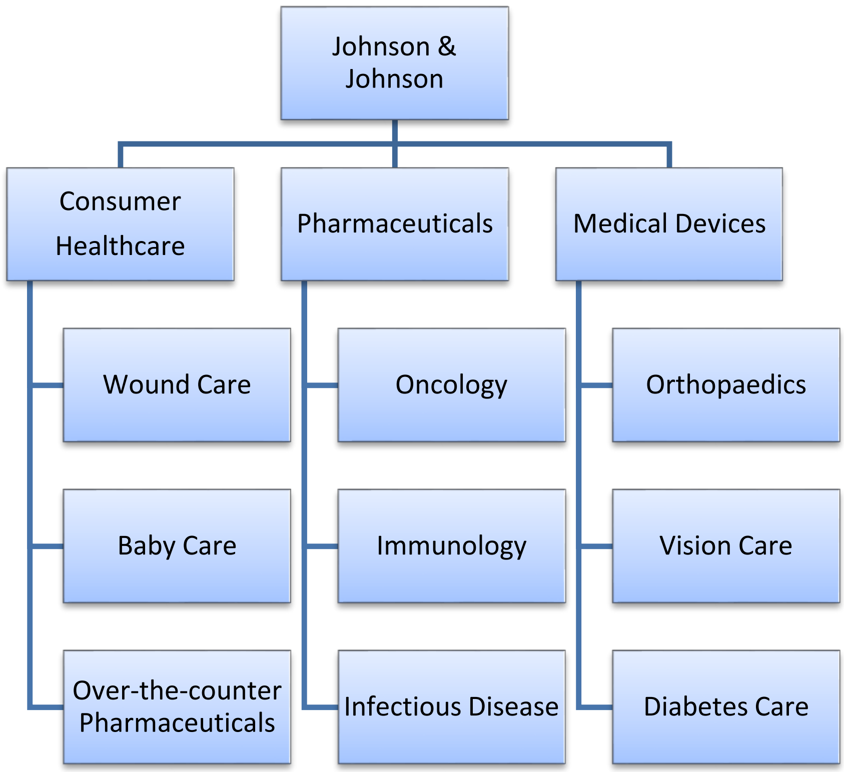


Figure 9: JnJ Company Structure

Step 1: Define what is being assessed

To validate the *TCRA* framework, an operating company within JnJ's consumer healthcare sector, referred to as Company X in order to abide by confidentiality agreements, was examined. Currently Company X has multiple risk assessments for each supplier including a Quality Risk Assessment (QRA) and an EH&S assessment. Individual assessments are updated by their respective departments on different time cycles. For example, the QRA is updated on an annual basis whereas the EH&S has more static results so it is only updated every two years. In addition, each assessment only analyzes risk within its area of expertise. Importantly, they had no method to bring these results together for a complete understanding of the risk associated with the company's suppliers. Therefore, the TCRA framework provided Company X with the ability to create a tool with an all-inclusive view of their risk.

Before the TCRA framework could be applied, it is important to understand some background on Company X. It produces its goods using its own in-house manufacturing plants as well as outsourcing the production to third-party manufacturers. Within the company, the production methods are referred to as internal and external manufacturing, respectively. Although Company X produces its products internally and externally, for this case study of the TCRA framework only external manufacturing network (EM) was examined. Because both manufacturing methods contain risk, the internal plants' risks were more easily managed once identified whereas the external manufacturer's risks were out of Company X's control. With an EM, Company X is working with the EM to mitigate risk, but at the same time, Company X and the EM may not agree on all business practices and production management methods. Therefore, an effective risk analysis tool would provide Company X with evidence to complete projects to reduce risks at an EM.

In all, there are 30 EM sites, whose accounts are managed internally by a team consisting of an employee in operations, in quality assurance, and in technical operations. Thus, this case study focused on providing an overall risk score and business value score of each of the 30 sites. The risk score needed to take into account different areas of managing the EM and combine them together into one summarizing score. The business value score was defined as how much product does the EM make for Company X. In addition, Company X set the following requirements for the developed tool.

- Associate the risk score to how important an EM is to them based on its business value

- Compare EMs’ risk and value scores
- Identify potential risks and their causes
- Facilitate the creation of mitigation plans to alleviate risks
- Track the risk score over multiple update cycles to ensure that the risks are being moderated

Based on these outlined needs, Company X proposed an update for its risk management for the EM network, which resulted in the TCRA framework being applied.

Step 2: Determine applicable tool for risk management

After outlining its needs, Company X needed to select the appropriate tool to apply to the situation. Originally, there were assessments being completed on certain aspects of an EM but none of these brought the results together to see the overall risk profile of an EM. By determining the correct tool, Company X was able to meet all of the requirements set out in Step 1.

After examining Table 3 and Table 4, no single existing tool was the apparent choice for application for Company X. For example, FMEA identified risks and causes while creating remedial action plans, but FMEA is event specific and may not take into consideration multiple causes from different areas of the EM. While the what-if and checklist methods were appealing because they could be completed quickly, they are very scenario based and therefore do not take into consideration the entire EM’s risks. Finally, while Microsoft’s CORE tool contained most of the characteristics of an applicable tool to Company X’s requirements, could be applied quickly, and took into consideration both objective and subjective data that was qualitative and quantitative, it only identified risks and causes without developing mitigation plans.

For Company X, it was more useful to create a unique analysis tool in order to meet all of its needs, which was called the Risk Value Priority Assessment (RVPA). Based on CORE matching majority of the characteristics to make a successful analysis of risk, it was used as a framework for Company X’s unique tool. Company X accumulated the list of risks by examining different aspects of its relationship with an EM to discover different risks and categorize them. Just as the CORE system identified 19 risks, Company X recognized there are more than 30 risks in working with an EM and the manufacturing process of its products. The 30 risks originated from different areas within the EM that something could go wrong and jeopardize Company X’s supply of products and therefore sales. The identified risks varied from the amount of inventory the EM carried to how responsive the EM was to a request from Company X, see Table 5

Instead of categorizing the risks as CORE does into four categories, Company X categorized its 30 risks into eight categories: business importance, business performance, business continuity, manufacturing process, EH&S, corporate governance, quality, and relationship. Each of the risks identified in these categories were converted to a standardized question that could be asked across multiple EMs within the network. Table 5 provides a further breakdown these categories with a description and the information required. When the risk is minimized in all of the categories, it signifies that the EM is a reliable source for high quality products. In addition to the categories of risk, Company X wanted to track the changes in the RVPA scores over the past year using the updates completed semiannually, in March and October, in order to stay aligned with the financial plan updates.

Table 5: Categorical Breakdown

Category	Description	Information Required
Business Importance	How important is this EM to Company X's overall production?	• Value of Sales of products manufactured by this EM • What market does the EM's products go?
Business Performance	How does the EM perform in regards to finance and production?	• How important is Company X's business to the EM? • Is the EM financially viable? • Does the EM perform to Company X's standards and schedules? • What is the timing to replace a rejected batch?
Business Continuity	Can the EM handle Company X's demands and unexpected events?	• What is the EM's production capacity and safety stock? • Can a natural event (i.e. floods) affect production? • Is any of the equipment in danger of failing?
Manufacturing Process	What types of risks are part of the manufacturing process?	• How the manufacturing process risks scored in the technical capabilities assessment? • Does the EM produce bulk and/or packaged goods?
EH&S	What is the EM's environment based on within the plant and the area it is located?	• Is the EM if good condition (appearances, personnel, environmental protective measures, etc.)? • How does the EM influence the community and vice versa? • What is the EM's EH&S risk profile? • Have there been any recent incidents or government enforcements?
Corporate Governance	How is the EM structured and managed internally and does I comply with JnJ corporate policies?	• Does the EM comply with corporate policies A and B? • What type of corporate structure does the EM have including employment practices?
Quality	What is the EM's history in regards to the quality of the produced items?	• What is the EM's regulation, audit, non-conformance, and complaints history? • How long is Company X's relationship with the EM? • What is the QRA score for the EM?
Relationship	How strong is the relationship between Company X and the EM?	• What is the relationship with the EM (i.e. transparency, responsiveness to issues)? • Are the EM's agreements up to data and in order?

With the exception of the value of sales for the EM, all of the questions asked in the RVPA are multiple choice where the ideal situation is "C" and the worst situation is "A". Multiple choice questioning was chosen over open-ended and ranking questions to standardize the responses across the network so that the sites were comparable. With open-ended questions, the management team could have answered many ways but it would be difficult to calculate a score or compare across sites. In addition, ranking responses could lead to higher levels of subjectivity and bias by ranking the responses as neutral or ambiguous. With multiple choice questions, they force a response within a set focal area.

For the RVPA, each question provided an answer that represented low (or no) risk, medium risk, and high risk. Each response option was associated with a value used to calculate the score for the question. The low risk responses, which were typically represented by the "C" response, were given a value of zero, the medium risk responses ("B") were equivalent to five, and high risk responses ("A") were equivalent to nine. The RVPA can be seen in Appendix A with altered questions due to confidentiality agreements.

After assigning values to the responses for individual responses, the categorical scores needed to be calculated. Each category was made up of multiple questions, which were each given an importance weight. Together the weighted scores calculated the overall categorical score (Table 6). The weights for individual questions ranged from not important to very important, zero to three, respectively. A four-point scale was selected in order to prevent a neutral option from being selected. Certain questions with the RVPA were included in order to build up to other questions or to provide information about the EM that may be taken into consideration when developing a mitigation plan, and therefore, these questions were given a weight of zero.

$$Score = value * multiplier \qquad \text{Equation (1)}$$

$$Categorical\ Value = \sum category\ question\ scores \qquad \text{Equation (2)}$$

From Table 6, which summarizes the number of questions asked within each category and the potential maximum score of each respective category, it can be seen that the maximum score for each section varies significantly. With a range of 144 and a standard deviation of 43.534, it was decided that the values for the sections needed to be normalized before calculating the categorical risk and value scores. The categorical scores are the standardized category values in order to prevent skewness in the value based on the varying values. Both the overall risk and value scores were of equal importance to Company X; therefore, they needed to have the same maximum value. There were seven categories within the risk score that were weighted equally, and the total of the categories are equivalent to the business importance score. In order to differentiate different scores, the maximum score for the risk and value scores were defined as 140. When calculating the categorical risk scores, the normalized values were multiplied by 20 (Equation 1) whereas the categorical value score was calculated by finding the product of the normalized value and 140 (Equation 2). Asa result, both the risk and value scores have a maximum score of 140.

$$Categorical\ Risk\ Score = 20 * \frac{Category\ Total\ Score}{Potential\ Maximum\ Score} \qquad \text{Equation (3)}$$

$$Categorical\ Value\ Score = 140 * \frac{Business\ Importance\ Category\ Total\ Score}{Potential\ Maximum\ Score} \qquad \text{Equation (4)}$$

Table 6: Categorical Score Breakdown

Category	Number of Questions	Potential Maximum Score	Potential Maximum Normalized Score
Business Importance	2	36	140
Business Performance	4	90	20
Business Continuity	4	81	20
Manufacturing Process	2	54	20
EH&S	9	171	20
Corporate Governance	4	63	20
Quality	8	27	20
Relationship	4	108	20
Total	**37**	**630**	**140 (value), 140 (risk)**

The overall risk score is the summation of the following categorical scores: business performance, business continuity, manufacturing process, EH&S, corporate governance, quality, and relationship. The business importance was calculated into the business value instead of the risk score because it took into consideration how much of Company X's products the EM produces along with what markets it effects based on its production levels.

$$Risk\ Score = \sum Category\ Risk\ Score \qquad \text{Equation (5)}$$

I created the RVPA within Microsoft Excel by applying some macros. Refer to Appendix A for the format of the RVPA. Once the tool was created and formatted with relevant questions, updates with new information should be completed more quickly. In addition, the questions within the RVPA can be adjusted as policies, processes, or circumstances change.

Step 3: Collect relevant information and data

Before the TCRA framework was applied to Company X, multiple departments collected similar information regarding the EM separately to complete their respective risk assessments. For example, the quality department would look at the production process and reports on non-conformances and complaints, and in addition, the technical operations department would look at these details to determine malfunctions in the process. With the application of the TCRA framework, some of the duplicate research on some of the risks was reduced as Company X's management team for an EM worked together to gather the data. By doing so, the time spent on risk analysis at Company X was overall reduced while still collecting the correct data efficiently.

To complete the assessment successfully, a large variety of data was collected across multiple departments in order to provide information for all eight categories. A specific individual, the facilitator, was in charge of ensuring that the RVPA data was collected completely. The EM management team of three from operations, quality assurance, and technical operations worked together to confirm that current and accurate data was provided for the assessment. Within the manufacturing process, EH&S, and quality categories, there are individual assessments that were completed separately that answer specific questions within their respective categories. The facilitator collected specific data for all of the EM sites in order to provide it to the management teams efficiently. The facilitator contacted the finance department for the value of sales for each EM site along with its financial viability. The final portion of the data required for the assessment was the past assessment scores in order to track changes over the past two updates. The total time to collect the data for a single site was approximately one to two hours. For confidentiality purposes, the data presented for this case study has been changed from Company X's actual operations.

Step 4: Apply the tool to the data

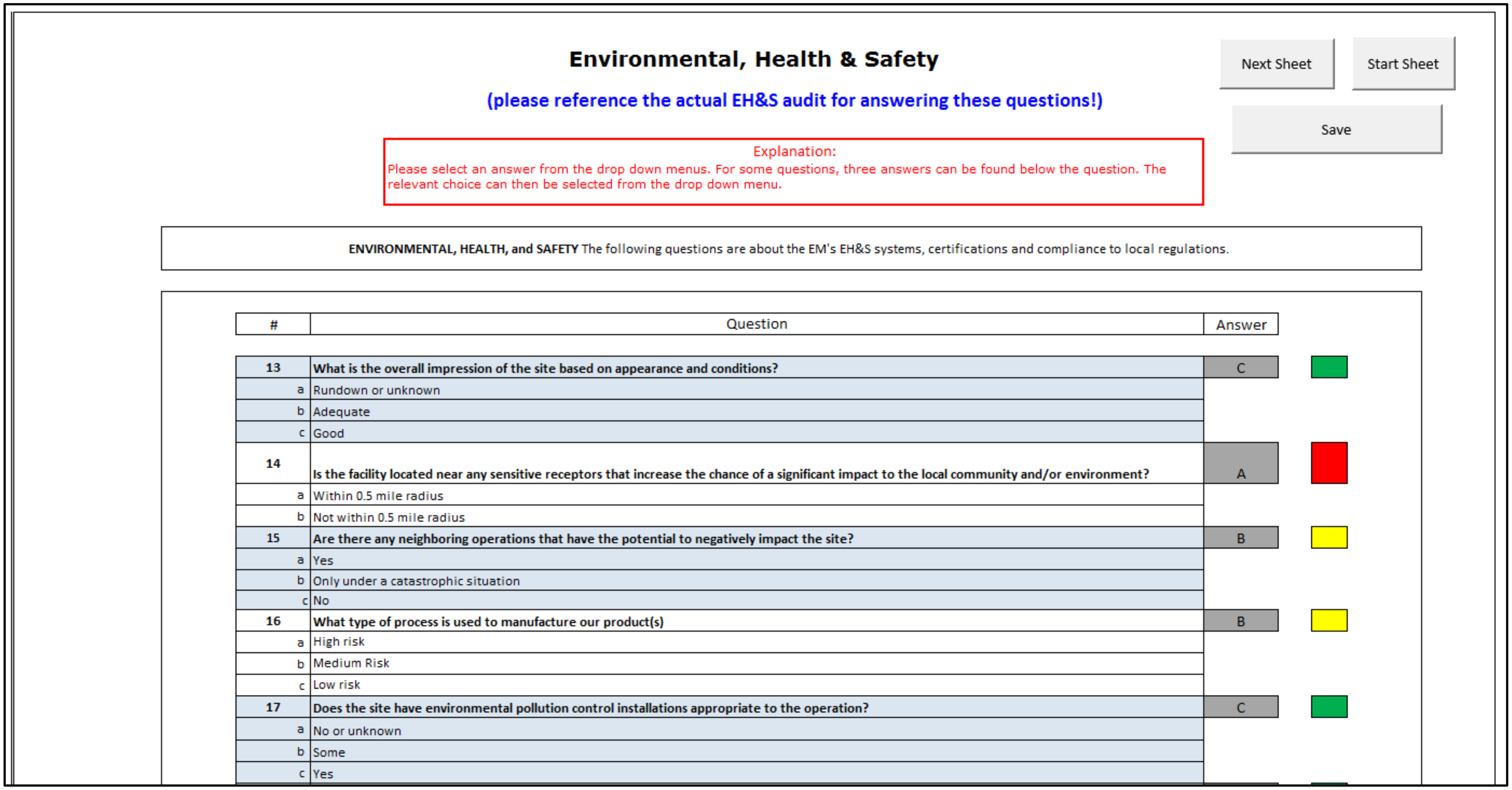
Initially, Company X was applying similar information that was collected potentially multiple times for multiple assessments. Each department was taking the time to complete the multiple assessments that would only cover a portion of Company X's interactions with the EM. The quality department was only applying and analyzing the risks within quality without examining risk due to the manufacturing processes that produce quality products. Because of the TCRA framework, Company X can now bring together the application of the multiple assessments into a single assessment to gain a better understanding of the risks associated with an EM. With the RVPA, risks associated with the manufacturing process can be related to the relevant quality risk so that the departments can work together to mitigate both risks simultaneously.

Typically, the data was collected simultaneously with applying the tool to ensure that the information was accurate and the qualitative data was agreed upon by the team. To demonstrate the application of the RVPA for Company X, it was applied to a single EM, EM#1. As mentioned in Step 2, the RVPA was formatted to consist of multiple-choice questions. This allowed qualitative questions to be converted to a quantitative result used in the results calculations. The management team for each EM sat together going through the RVPA to answer all of the questions for each category. A sample of one of the categories, EH&S, can be seen in Figure 10. Within each category's questions, the answers displayed the level of risk associated with the provided response.

Once all of the data was entered into the tool, the results were populated based on the weights and calculations defined in Step 2. In Appendix B, the resulting question values, weights, and scores are displayed by categories. The assessment resulted in two scores, the value and risk scores, which both range between 0 and 140. In addition, the sales revenue was marked in the results as a reference to how much revenue the EM is producing for Company X.

The value score was based solely on the business importance section. It was preferred to have a higher value score, which represents higher product sales being produced at the site. The remaining sections, disregarding the past assessment scores, were used to calculate the risk score with each category being worth up to 20 points. A lower risk score was more ideal as it represented a lower chance of risks occurring or smaller consequences of an event occurring.

A summary of the category scores, risk scores, and value score along with the overall risk and value scores for EM #1 can be seen in Table 7. The risk score was found to be 48.42 with a value score of 124.44. For the RVPA, a lower risk score is preferred while a higher value score is optimal. This EM has a high value score, which means that it produces a lot of revenue producing products, but the score is neither low nor exceptionally high. The results in Figure 11 break down the risk and value scores by the categories. In addition, the scores are color coded into low, medium, and high risk using green, yellow, and red, respectively.



Environmental, Health & Safety

Next Sheet | Start Sheet | Save

(please reference the actual EH&S audit for answering these questions!)

Explanation:
Please select an answer from the drop down menus. For some questions, three answers can be found below the question. The relevant choice can then be selected from the drop down menu.

ENVIRONMENTAL, HEALTH, and SAFETY The following questions are about the EM's EH&S systems, certifications and compliance to local regulations.

#	Question	Answer
13	**What is the overall impression of the site based on appearance and conditions?**	C
a	Rundown or unknown	
b	Adequate	
c	Good	
14	**Is the facility located near any sensitive receptors that increase the chance of a significant impact to the local community and/or environment?**	A
a	Within 0.5 mile radius	
b	Not within 0.5 mile radius	
15	**Are there any neighboring operations that have the potential to negatively impact the site?**	B
a	Yes	
b	Only under a catastrophic situation	
c	No	
16	**What type of process is used to manufacture our product(s)**	B
a	High risk	
b	Medium Risk	
c	Low risk	
17	**Does the site have environmental pollution control installations appropriate to the operation?**	C
a	No or unknown	
b	Some	
c	Yes	

Figure 10: EM #1 RVPA EH&S Category Page

Table 7: EM #1 Categorical Score and RVPA Score Results

Category	Category Score	Risk Score	Value Score
Business Importance	36	n/a	140.00
Business Performance	15	3.33	n/a
Business Continuity	20	4.94	n/a
Manufacturing Process	42	15.56	n/a
EH&S	53	6.20	n/a
Corporate Governance	10	3.17	n/a
Quality	27	20.00	n/a
Relationship	45	8.33	n/a
Total	**n/a**	**61.53**	**140.00**

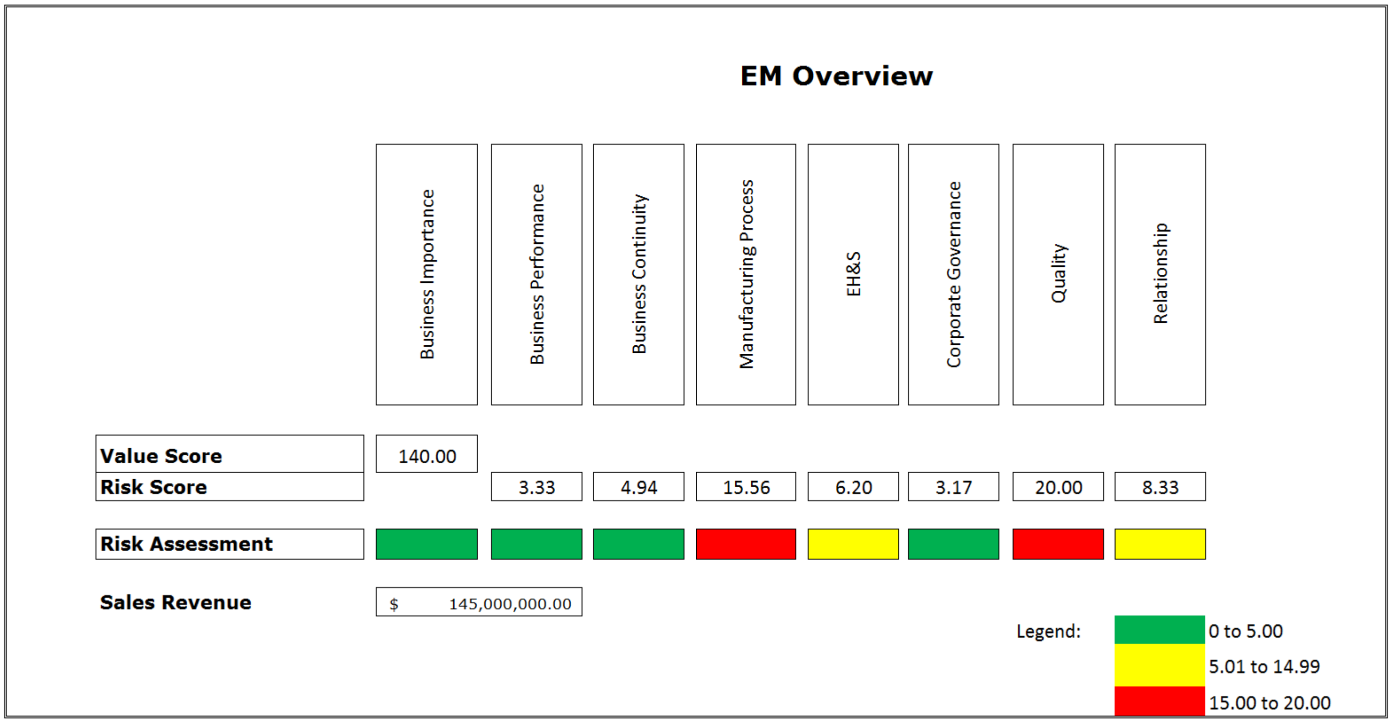


Figure 11: EM #1 RVPA Visual Results Overview

Step 5: Analyze the results

Using the RVPA tool, I analyzed the risk at the 30 EM sites both individually and holistically. The results of the RVPA were compared based directly upon the results, tracked over time using a bubble chart, or even as a whole network with all of the results in a single bubble chart. The bubble chart was set up so that the value score was compared against the risk score.

Previously, Company X would analyze each individual risk assessment within its respective department. Often times, the results of the assessments would not cross to other areas of the business, and therefore, the bigger picture in regards to risk at an EM site was never put together and many of Company X's requirements were not fulfilled. After applying the TCRA framework, Company X was able to meet its risk analysis needs by comparing risk and value scores against each other and across the network, identifying potential risks and their causes, and facilitating the development of mitigation plans.

After applying the tool on all 30 EMs, I analyzed the results. Each site had the ability to look at its individual results using the results section in the RVPA which displays the numerical breakdown of the risk and value scores (Figure 11) and a graphical view of the results (Figure 12). Using these site specific results, I tracked the site's risk and value over the past year, compared it to the average risk and value scores, and identified categories of high risk. Using the results and analysis, Company X was able to adjust the management or relationship with the site and/or create mitigation plans for the risks.

In Figure 12, the multiple bubbles on the chart represent the progression of the site over the past year. The value score is plotted against the risk score and the size of the bubble is based on the value of sales for the EM. Company X used this tracking to support its decisions to change production levels produced at that site. It can be seen that the value of the EM has stayed consistent over the year, but the risk score fluctuated in October 2014 (Table 8). Based on this movement, I extrapolated that there may have been an incident between March and October 2014 that increased the EM's risk score that was then mitigated between October 2014 and March 2015. The Company X management team of the EM was working on reducing the risk at the site.

Table 8: Past and Current RVPA Scores

	March 2014	October 2014	March 2015	Average Over Time	Standard Deviation
Risk Score	48.06	58.79	48.42	51.76	6.0937
Value Score	124.44	124.44	124.44	124.44	0
Sales	$175,000,000	$150,000,000	$130,000,000	$151,666,666,.7	$22,546,248.76

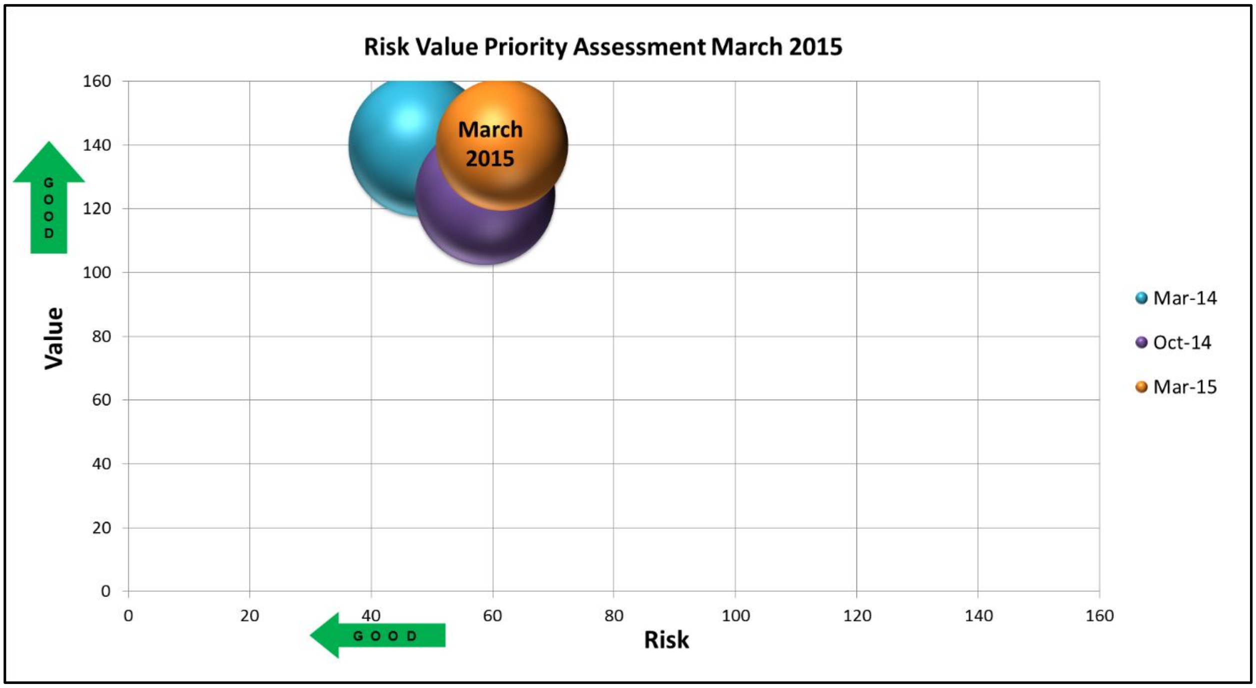


Figure 12: EM #1 Semiannual Results Comparison Bubble Chart

Based on the results in Figure 11, quality score was identified as an area of high risk for the EM. Therefore, a deep dive into the quality category was conducted in the RVPA to determine what the cause of its high-risk score was. In this case, the cause of this high score was a high score on the QRA completed by Company X's quality assurance team. From there Company X looked into the QRA and found the causes of its high score. For this EM, it was found that transparency and responsiveness along with non-conformances was the cause of the high-risk score in both the QRA and RVPA. Once the cause was identified, Company X began work on developing a mitigation plan. This included more meetings with the EM to track progress, sending a technical operations team member to examine the process to determine where the non-conformances were occurring on the line and improve the process.

Once the risks were identified, the tool was set up to facilitate Company X creating action plans in the mitigation section (Figure 13). In this section, when a category is classified as medium or high risk, individual questions for that category can be further examined. To continue with analyzing the quality category, which was rated as high risk, its segment in the mitigation section can be seen in Figure 13. There were five questions rated medium risk and one as high risk. For the most part, the risk in this section could be managed by developing a mitigation plan for the issue. The production process is the only part of this category that cannot be alleviated through risk management easily as the process can only change so much until it changes the product properties. On the other hand, non-conformances and responsiveness at the site can be managed through increased oversight and improvement projects in the manufacturing line that will increase the quality of goods being produced. Company X outlined a basic action plan, potential result, and new potential answer to the questions regarding non-conformances and responsiveness (Figure 13). This allowed Company X to see how mitigation could affect the risk score for the EM site.

Beyond looking at the individual EM results, the network of 30 EMs was analyzed comprehensively. Taking the results of all the sites, a bubble chart was created with the results from all of the sites. The chart (Figure 14) compared the sites' risk and value scores against the other sites'. The highlighted bubble in green represents EM #1, which was calculated in the previous steps. From the chart, it was identified that this EM has one of the highest business value scores and the value of sales was approximately the average of all of the sites. It is important to note that EM #1 also had one of the highest risk scores. In addition, based on the 95% confidence intervals found in Table 9: EM Network AnalysisTable 9, the risk score and value score of EM #1 fell outside the confidence interval which Because of this, EM #1 was more important to Company X because there was a larger risk in its production process if an incident occurred at this site affecting its production. Company X could reduce risk by investing more money in projects at this site, monitor the site more vigilantly, or ensure that there is a backup option for this EM. An extreme measure that could occur is Company X exiting from this EM as a contract comes to an end by transferring production to other EM sites or even internally.

		Original Answer		Question	Action Plan	Potential Result	Potential Answer	
QUALITY	26	B		Regulatory History			B	
	27	C		Last Internal Audit performance			C	
	28	B		Complexity of Manufacturing/Packaging Operation				
	29	B		Responsiveness	Increase comunication with the site by implementing reoccuring meetings	Improved response time on issues at the site	C	
	30	B		Non-Conformances	Examine the production line to determine where the defects are entering the process	Remove non-confromance batches or improve process to reduce number of non-conformances	C	
	31	B		Complaints			B	
	32	C		History with Third Party			C	
	33	A		What is the risk based on the QRA?			A	

Figure 13: EM #1 Quality Mitigation Section with Action Plans

Table 9: EM Network Analysis

	Average	Standard Deviation	95% Confidence Interval
Risk Score	29.33	14.80	(23.95, 34.72)
Value Score	99.55	28.85	(89.05, 110.05)
Sales	$94,583,333	$134,257,965.83	($45,719,317.64, $143,447,349.03)

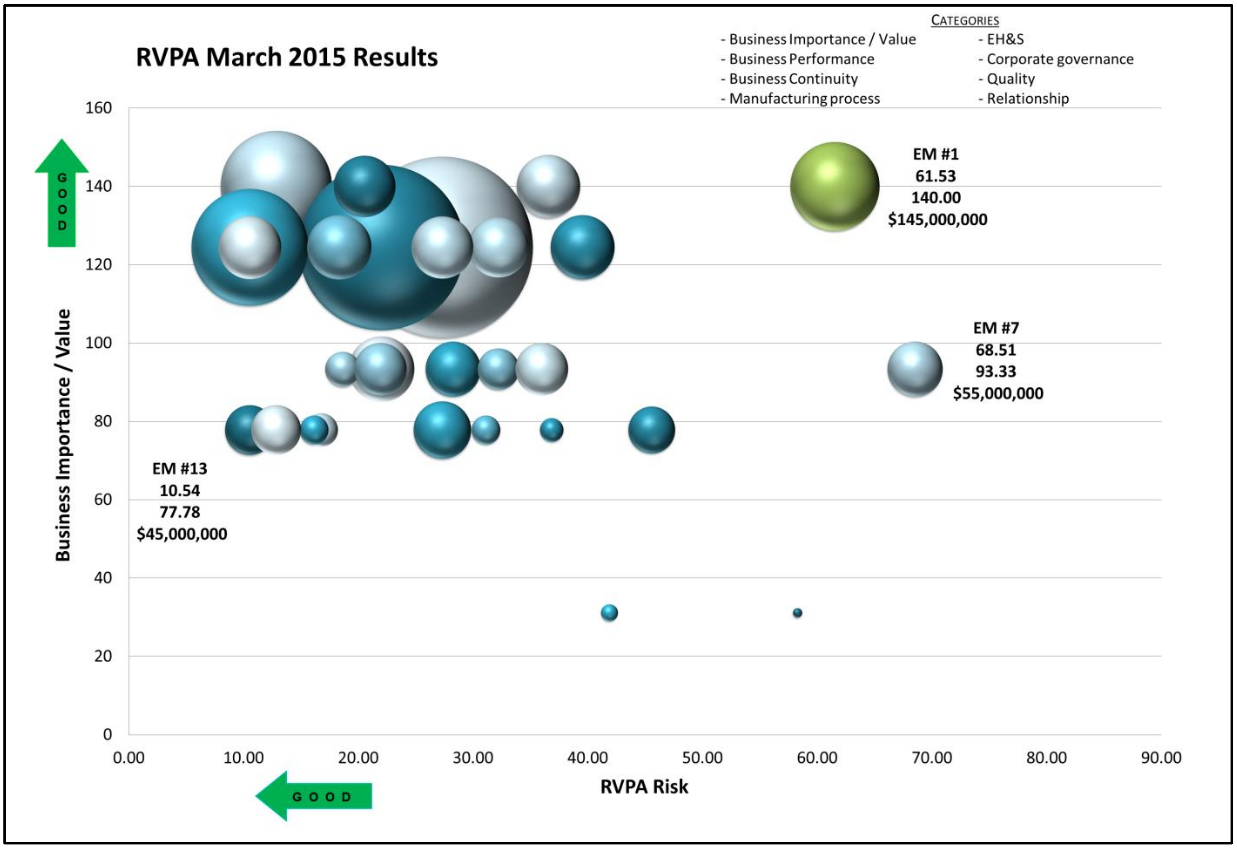


Figure 14: RVPA Network Results

Step 6: Repeat

Now that a set of formatted steps for the overall analysis of the EM network sites was developed, Company X can now update the RVPA during the semiannual updates in March and October. Previously, Company X was completing different risk analyses on different time schedules with some occurring semiannually or every two years. Nevertheless, with the help of the TCRA framework, Company X is now able to regulate the updates of the information to remain consistent within the company and with the EM sites.

Once the sites have been compared and strategic planning has been initiated to reduce risk or adjust production, Company X is at the final step in the TCRA framework, repeat. The assessment likely led to changes in Company X's external manufacturing network, which leads to potential changes in risk levels at each site. Company X will manage these changes by updating the assessment on semiannual basis in March and October. Using the results of the update, Company X will also track changes in risk and value of each manufacturer and relate the sites' changes.

Case Study Discussion

Before the TCRA framework was applied to Company X through this case study, the company was undertaking extraneous work in order to track risks at EM sites by completing risk analysis on different areas of the business for each EM but not bringing the results together. In addition, once the results were identified, the results were not used to improve the state of risk at the site. Based on this, Company X outlined the following requirements for the updated risk analysis tool that was created as a result of the TCRA framework:

- Associate the risk score to how important an EM is to them based on its business value
- Compare EMs' risk and value scores
- Identify potential risks and their causes
- Facilitate the creation of mitigation plans to alleviate risks
- Track the risk score over multiple update cycles to ensure that the risks are being moderated

Company X used the TCRA framework to develop a tool that fulfilled its needs by identifying what tools did or did not meet those needs and adjusting the tools to create its own risk analysis tool. The RVPA examined multiple risks across different areas of the business including business importance, business performance, business continuity, manufacturing process, EH&S, corporate governance, quality, and relationship. Within each category, different potential risks were identified and categorized based on chances of an event occurring and potential impacts of the event. The final result of the RVPA summarized the risk and value of each of the EM sites.

The results of the RVPA were used to identify risks and develop mitigation plans to improve the risk score based on the causes of the risk. In addition, the risk and value of the site were tracked over the past year, or two updates (March and October) to see if the risk was being managed at the site. In addition, the RVPA simplified examining the network of 30 sites by creating a bubble chart of the entire network. From there, the sites' scores were compared and sites with abnormally high risk scores were identified as target sites for improvement or change in relationship. Company X utilized the TCRA framework to create a tool that fit its needs and gained knowledge about risks and areas of improvement or increased supervision.

The TCRA framework improved Company X's risk analysis for it external network, but there are many more applications for the framework withinin Company X. In the future, the framework could be applied to Company X within its internal network of plants in order to identify areas of risk. In addition, the results could be further expanded upon by Company X to see how changes in production levels at sites within the network would affect the risk at individual sites and across the network as well.

Chapter 5

Conclusion

The purpose of this thesis was to examine types of risks associated with a supply chain in order to determine the types of risk management methods that should be applied to successfully track and improve risk characteristics of the supply chain. The main contributions of this thesis lie in:

- Identification of different types of risk within a supply chain
- Identification and analysis of existing risk analysis tools
- Development of the TCRA framework
- Verification of the effectiveness of the TCRA framework

As markets grow internationally, supply chains are also expanding globally. With increasing supply chain sizes, the costs of manufacturing goods decrease, but the risk associated with using multiple suppliers or outsourcing manufacturing increases. Risk within a supply chain originates from five factors: environmental, industry, organizational, problem-specific, and decision-maker. Each of these factors interact with another and cause the effect of an event in one area to permeate throughout a supply chain.

Because of the increased interest in supply chain risks and their effect, SCRM has also been developing rapidly in both the academic and industry fields. Part of the research being completed on SCRM studies defining, operationalizing, and mitigating risk [28]. Every company may define risk differently and approach managing and mitigating risk uniquely. There are existing methods for analyzing risk that are categorized into qualitative, semi-quantitative, and quantitative methods. Each of the risk tools or methods provide a different type of result and require different types of data, input from employees.

Within this thesis, a framework was developed to initiate risk management for a supply chain by applying an appropriate risk analysis tool, which provides the desired results. The TCRA framework allows a company to determine what is being assessed in regards to risk analysis. From there, the applicable tool is chosen based on the defined needs, and if there is no existing tool that fits the needs, the company can create a new tool based off of existing tools. Based on the selected tool, the relevant data is collected by the appropriate team, which is then applied to the tool. Using the results of the tool, the company analyzes the results such as determining the risks, their causes, and their effects, and developing mitigation plans.

Using the TCRA framework, Company X, an operating company within JnJ, analyzed their risk in its external manufacturing network. After defining its requirements for the tool, Company X determined there was no singular tool that fit its needs. As a result, it developed its own tool using CORE as an example for its structure. Its risk analysis tool, the RVPA, analyzed all parts of Company X's interactions and investment with each EM. The management team for each EM worked together to gather accurate information and to answer the questions with the RVPA. After completing the assessment, each team was able to analyze what areas of the business had high risk and what the causes of risk were. This also allowed the team to develop a mitigation plan to reduce risk at the site. Beyond analyzing the risk at individual sites, Company X compared risks across its EM network to identify sites that posed a danger to its product supply.

With the application of the TCRA framework, Company X was able to meet its needs in regards to risk analysis. In addition, redundant work was prevented as teams worked together to collect information one time instead of multiple times. Instead of completing multiple risk assessments that were department specific, Company X brought all of the assessments together to create a comprehensive view of risk at its EM sites.

The TCRA framework provided a strong basis for risk analysis within a supply chain. It ensured that customers were receiving the quality products they desired. It can be applied to an outsourcing network as Company X did, but it can also be applied to suppliers. Beyond that, a company can apply the TCRA framework internally at its own manufacturing sites to analyze and lessen risks that pose a threat to production. Potential applications for the TCRA framework could also include analyze risk outside of a manufacturing environment. For example, it can be used to analyze risk within a corporate environment in regards to interdepartmental interactions. In addition, it could be applied within the service industry to examine risk from receiving supplies and managing employees to providing a service to customers, such as the food or entertainment industries. There are multiple areas of potential development for the TCRA framework.

Appendix A

EM #1 RVPA Tool

Business Importance/Value

Explanation:
Please select an answer from the drop down menus. For some questions, three answers can be found below the question. The relevant choice can then be selected from the drop down menu.

BUSINESS IMPORTANCE/VALUE The following questions are about product sales. If multiple products are manufactured at the EM, the answer shoud be the sum of all sales or take into account all products.

#	Question	Answer	
1	**Enter the most current Value of Sales (VOS) represented by the product(s) manufactured by this EM?**	$145,000,000	$
2	**Does this EM supply products to a regional or world-wide market?**	B	
a	US or Canada		
b	Global or US and Canada		

Figure 15: Business Importance/Value RVPA Category

Business Performance

Explanation:
Please select an answer from the drop down menus. For some questions, three answers can be found below the question. The relevant choice can then be selected from the drop down menu.

#	Question	Answer
3	**What % of the total EM capacity does Company X's business represent with the site?**	C
a	> 50%	
b	< 5%	
c	5% to 50%	
4	**What is the financial viability of the EM?**	C
a	Poor or unknown	
b	Poor but improving	
c	Good	
5	**Does the EM meet our product demand and delivery schedule in the past 12 months?**	B
a	Rarely	
b	Occasionally struggles	
c	Often	
6	**What is the timing for the EM to make up rejected or aborted products?**	C
a	> 60 days	
b	30-60 days	
c	< 30 days	

Figure 16: Business Performance RVPA Category

Business Continuity

Explanation:
Please select an answer from the drop down menus. For some questions, three answers can be found below the question. The relevant choice can then be selected from the drop down menu.

#	Question	Answer
7	**What is the EM's current production capacity?**	B
a	Almost at max capacity or unknown	
b	Adequate capacity but should be improved	
c	Able to handle demand and more	
8	**What is the EM's risk to suffer from flood, drought, geophysical or a combination of these?**	B
a	Near more than two of the elements	
b	Near one of the elements	
c	Not located near any of of the elements	
9	**What is the Safety Stock and backup supplier availability?**	C
a	High risk and no backup supplier	
b	Moderate risk and time to setup backup supplier	
c	Low risk and backup supplier available	
10	**What is the Critical Equipment Status?**	B
a	No immediate access to backup parts	
b	Immediate access to backup parts	

Figure 17: Business Continuity RVPA Category

Manufacturing Process

Explanation:
Please select an answer from the drop down menus. For some questions, three answers can be found below the question. The relevant choice can then be selected from the drop down menu.

Manufacturing Process The following questions are about the portion of the product's manufacturing process performed by the EM.

#	Question	Answer
11	**The risk determined by the final technical risk score is?**	B
a	High Risk	
b	Medium Risk	
c	Low Risk	
12	**How much of the product manufacturing process is the EM responsible for?**	A
a	The EM is responsible for the entire manufacturing process	
b	The EM is responsible for some subset of the total process	
c	The EM is responsible for a tertiary process	

Figure 18: Manufacturing Process RVPA Category

Environmental, Health & Safety

(please reference the actual EH&S audit for answering these questions!)

Explanation:
Please select an answer from the drop down menus. For some questions, three answers can be found below the question. The relevant choice can then be selected from the drop down menu.

ENVIRONMENTAL, HEALTH, and SAFETY The following questions are about the EM's EH&S systems, certifications and compliance to local regulations.

#		Question	Answer
13		What is the overall impression of the site based on appearance and conditions?	C
	a	Rundown or unknown	
	b	Adequate	
	c	Good	
14		Is the facility located near any sensitive receptors that increase the chance of a significant impact to the local community and/or environment?	A
	a	Within 0.5 mile radius	
	b	Not within 0.5 mile radius	
15		Are there any neighboring operations that have the potential to negatively impact the site?	B
	a	Yes	
	b	Only under a catastrophic situation	
	c	No	
16		What type of process is used to manufacture our product(s)	B
	a	High risk	
	b	Medium Risk	
	c	Low risk	
17		Does the site have environmental pollution control installations appropriate to the operation?	C
	a	No or unknown	
	b	Some	
	c	Yes	
18		Does the site have appropriate engineering, personal protection and administrative controls to prevent overexposures of employees to hazardous chemicals and situations?	C
	a	No or unknown	
	b	Yes but require improvements	
	c	Yes	
19		Does the EM have assigned personnel and programs to manage EH&S risks?	C
	a	No or unknown	
	b	Yes, but only part of employees' role and responsibilities	
	c	Yes	
20		What is overall EH&S risk profile ?	C
	a	Low risk	
	b	Medium Risk	
	c	High risk	
21		Does the site have a recent history of major incidents, accidents or Governmental enforcement actions.	B
	a	Yes and not reported	
	b	Yes but reported	
	c	No	

Figure 19: EH&S RVPA Category

Corporate Governance

Explanation:
Please select an answer from the drop down menus. For some questions, three answers can be found below the question. The relevant choice can then be selected from the drop down menu.

CORPORATE GOVERNANCE, FACILITY LOCATION, LABOR, AND ETHICS The following questions are about Corporate Governance, geopolitical risks, and business ethics norms related to their location.

#	Question	Answer
22	**Does the EM comply with Policy A?**	B
a	No or unknown	
b	Yes	
23	**What is the Corporate Structure and Governance of the EM?**	B
a	Small private company or public company with poor reputation	
b	Large private company or public company with weak oversight but good reputation	
c	Large public company with good reputation	
24	**The labor and employment practices at the EM can be describes as:**	C
a	Poor or noncompliant with government laws	
b	Weak or partially compliant with government laws	
c	Strong and complaint with government laws	
25	**Does the EM comply with Policy 2?**	B
a	No	
b	Yes	

Figure 20: Corporate Governance RVPA Category

Quality

(please reference the actual Quality Risk Assessment to answer these questions!)

Explanation:
Please select an answer from the drop down menus. For some questions, three answers can be found below the question. The relevant choice can then be selected from the drop down menu.

QUALITY The following questions are about product and process quality.

#		Question	Answer
26		**Regulatory History**	B
	a	Government action within the past 48 months and/or a repetitive pattern of regulatory inspection observations.	
	b	Isolated or non-patterned Regulatory inspection observations within the past 24 months	
	c	No governemnt action within the past 48 months and/or Regulatory inspection observations within the past 24 months.	
27		**Last Internal Audit performance**	C
	a	Unacceptable or major observations	
	b	Acceptable and major observations	
	c	Acceptable and no major observations	
28		**Complexity of Manufacturing/Packaging Operation**	B
	a	High	
	b	Medium	
	c	Low	
29		**Responsiveness**	B
	a	Unresponsive	
	b	Sometimes Responsive	
	c	Responsive	
30		**Non-Conformances**	B
	a	High percentage	
	b	Medium percentage	
	c	Low percentage	
31		**Complaints**	B
	a	>1% justified complaints	
	b	<1% justified complaints	
	c	No justified complaints	
32		**History with Third Party**	C
	a	New product AND new EM	
	b	New product OR new EM	
	c	Existing product and EM	
33		**What is the risk based on the QRA?**	A
	a	High Risk	
	b	Medium Risk	
	c	Low Risk	

Figure 21: Quality RVPA Category

Relationship

Explanation:
Please select an answer from the drop down menus. For some questions, three answers can be found below the question. The relevant choice can then be selected from the drop down menu.

RELATIONSHIP The following questions are about the relationship between the External Manufacturer (EM) and J&J Quality Assurance, Operations, and Technical Operations.

#		Question	Answer
34		**What is the relationship with the EM?**	C
	a	Poor partnership with EM	
	b	Developing partnership with EM	
	c	Good partnership with EM	
35		**What can be said about EM's contracts and agreements?**	B
	a	Missing or noncompliant	
	b	Not current	
	c	Current and compliant	
36		**How much transparency do we have into critical information and data at the EM?**	B
	a	No availability or accuracy	
	b	Limited availability or accuracy	
	c	High availability or accuracy	
37		**How well does the EM respond to issues, and problem solving?**	B
	a	Rare or inadequate responses	
	b	Occassional or adequate responses	
	c	Consistent or comprehensive responses	

Figure 22: Relationship RVPA Category

Past RVPA Scores

Explanation:

Please enter the scores from the past two RVPA refreshes in order to track the changes in the site's score. Please reference the completed RVPAs here.

#	Question	Answer	
37	Enter the Risk Score Total from the March 2014 RVPA?	48.06	
38	Enter the Value Score for Business Importance from the March 2014 RVPA?	140	
39	Enter the sales revenue from the March 2014 RVPA?	$170,000,000	$
40	Enter the Risk Score Total from the October 2014 RVPA?	58.79	
41	Enter the Value Score for Business Importance from the October 2014 RVPA?	124.44	
42	Enter the sales revenue from the October 2014 RVPA?	$165,000,000	$

Figure 23: Past Scores RVPA Category

Appendix B

EM #1 Detailed Results Breakdown

			Value	Weight	Total Score
BUSINESS IMPORTANCE/VALUE	1	$145,000,000	9	3	27
	2	B	9	1	9
BUSINESS PERFORMANCE	3	C	0	3	0
	4	C	0	2	0
	5	B	5	3	15
	6	C	0	2	0
BUSINESS CONTINUITY	7	B	5	3	15
	8	B	5	1	5
	9	C	0	3	0
	10	B	0	2	0
MANUFACTURING PROCESS	11	B	5	3	15
	12	A	9	3	27
ENVIRONMENTAL, HEALTH & SAFETY	13	C	0	1	0
	14	A	9	2	18
	15	B	5	3	15
	16	B	5	3	15
	17	C	0	3	0
	18	C	0	3	0
	19	C	0	1	0
	20	C	0	2	0
	21	B	5	1	5
CORPORATE GOVERNANCE	22	B	0	3	0
	23	B	5	2	10
	24	C	0	1	0
	25	B	0	1	0
QUALITY	26	B	5	0	0
	27	C	0	0	0
	28	B	5	0	0
	29	B	5	0	0
	30	B	5	0	0
	31	B	5	0	0
	32	C	0	0	0
	33	A	9	3	27
RELATIONSHIP	34	C	0	3	0
	35	B	5	3	15
	36	B	5	3	15
	37	B	5	3	15

		Total Score from Category	Highest Possible Score from Category	Risk Total	Value Total
Category Totals	Business Importance/Value	36	36	n/a	140.00
	Business Performance	15	90	3.33	n/a
	Business Continuity	20	81	4.94	n/a
	Manufacturing Process	42	54	15.56	n/a
	EH&S	53	171	6.20	n/a
	Corporate Governance	10	63	3.17	n/a
	Quality	27	27	20.00	n/a
	Relationship	45	108	8.33	n/a

Figure 24: RVPA Detailed Results Page

BIBLIOGRAPHY

[1] Rao, S., and Goldsby, T. J., 2009, "Supply Chain Risks: a Review and Typology," The International Journal of Logistics Management, 20(1), pp. 97-123.

[2] Wieland, A., and Marcus Wallenburg, C., 2012, "Dealing with supply chain risks: Linking risk management practices and strategies to performance," International Journal of Physical Distribution & Logistics Management, 42(10), pp. 887-905.

[3] Blanchard, D., 2010, Supply chain management best practices, John Wiley & Sons.

[4] Harland, C., Brenchley, R., and Walker, H., 2003, "Risk in supply networks," Journal of Purchasing and Supply management, 9(2), pp. 51-62.

[5] Cohens, M. A., and Mallik, S., 1997, "Global supply chains: research and applications," Production and Operations Management, 6(3), pp. 193-210.

[6] Christopher, M., Peck, H., and Towill, D., 2006, "A taxonomy for selecting global supply chain strategies," The International Journal of Logistics Management, 17(2), pp. 277-287.

[7] Prasad, S., and Babbar, S., 2000, "International operations management research," Journal of Operations Management, 18(2), pp. 209-247.

[8] Vidal, C. J., and Goetschalckx, M., 1997, "Strategic production-distribution models: A critical review with emphasis on global supply chain models," European Journal of Operations Research, 98(1), pp. 1-18.

[9] Goetschalckx, M., Vidal, C. J., and Dogan, K., 2002, "Modeling and design of global logistics systems: A review of integrated strategic and tactical models and design algorithms," European Journal of Operations Research, 143(1), pp. 1-18.

[10] Wagner, S. M., and Neshat, N., 2010, "Assessing the vulnerability of supply chains using graph theory," International Journal of Production Economics, 126(1), pp. 121-129.

[11] Manuj, I., and Mentzer, J. T., 2008, "Global Supply Chain Risk Management," Journal of Business Logistics, 29(1).

[12] Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., and Zacharia, Z. G., 2001, "Defining supply chain management," Journal of Business logistics, 22(2), pp. 1-25.

[13] Stevens, G. C., 1989, "Integrating the supply chain," International Journal of Physical Distribution & Materials Management, 19(8), pp. 3-8.

[14] Jones, T., and Riley, D. W., 1985, "Using Inventory for Competitive Advantage through Supply Chain Management," Internation Journal of Physical Distribution and Materials Management, 15(5), pp. 16-26.

[15] Monczka, R., Trent, R., and Handfield, R., 1998, Purchasing and Supply Management, South-Western College Publishing, Cincinnati, OH.

[16] La Londe, B. J., and Masters, J. M., 1994, "Emerging logistics strategies: blueprints for the next century," International journal of physical distribution & logistics management, 24(7), pp. 35-47.

[17] Cooper, M. C., and Ellram, L. M., 1993, "Characteristics of supply chain management and the implications for purchasing and logistics strategy," The International Journal of Logistics Management, 4(2), pp. 13-24.

[18] Choi, T. Y., and Krause, D. R., 2006, "The Supply Base and Its Complexity: Implications for Transaction Costs, Risks, Responsiveness, and Innovation," Journal of Operations Management, 24(5), pp. 637-652.

[19] Ritchie, B., and Marshall, D., 1993, Business Risk Management, Chapman & Hall, London.

[20] Miller, K., 1991, "A framework for integrated risk management in international business," Journal of Internation Business Studies, 23(2), pp. 311-331.

[21] Bettis, R. A., and Hall, W. K., 1982, "Accounting determined risk and accounting determined return," Academy of Management Journal, 25(2), pp. 254-264.

[22] Wilson, D., 1982, "Electricity and resistance: a case study of innovation and politics," Organizational Studies, 3(2), pp. 119-140.

[23] Simon, H. A., 1977, The New Science of Management Decisions, Prentice-Hall, Englewood Cliffs, NJ.

[24] Berger, P. D., Gerstenfeld, A., and Zeng, A. Z., 2004, "How many suppliers are best? A decision-analysis approach," Omega, 32(1), pp. 9-15.

[25] Käki, A., Salo, A., and Talluri, S., 2013, "Disruptions in supply networks: a Probabilistic Risk Assessment approach."

[26] Craighead, C., Blackhurst, J., Rungtusanatham, M. J., and Handfield, R. B., 2007, "The Severity of Supply Chain Disruptions: Design Characteristics and Mitigation Capabilities," Decision Sciences, 38(1), pp. 131-156.

[27] Olson, D. L., 2011, Supply chain risk management: tools for analysis, Business Expert Press.

[28] Ho, W., Zheng, T., Yildiz, H., and Talluri, S., 2015, "Supply chain risk management: a literature review," International Journal of Production Research, 53(16), pp. 5031-5069.

[29] Geoffrey, W. H., and Robert, S. S., 1997, "Risk Analysis Techniques," Disaster Recovery Journal.

[30] Pai, R. R., Kallepall, V. R., Caudill, R. J., and Zhou, M., 2003, "Methods toward supply chain risk analysis," Proc. Systems, Man and Cybernetics, 2003. IEEE International Conference on, pp. 4560-4565.

[31] Cagliano, A. C., De Marco, A., Grimaldi, S., and Rafele, C., 2012, "An integrated approach to supply chain risk analysis," Journal of risk research, 15(7), pp. 817-840.

[32] Stamatis, D., 2014, Introduction to risk and failures: Tools and methodologies, CRC Press.

[33] Gilchrist, W., 1993, "Modelling failure modes and effects analysis," International Journal of Quality & Reliability Management, 10(5).

[34] Brown, J. J., "Supply Chain Risk Management - The Complexities of Managing Risks in Complex Global Supply Chains," Thomas Reuters.

[35] Khakzad, N., Khan, F., and Amyotte, P., 2012, "Dynamic risk analysis using bow-tie approach," Reliability Engineering & System Safety, 104 pp. 36-44.

[36] Zsidisin, G. A., Ellram, L. M., Carter, J. R., and Cavinato, J. L., 2004, "An analysis of supply risk assessment techniques," International Journal of Physical Distribution & Logistics Management, 34(5), pp. 397-413.

[37] Michalski, L., 2000, "How to identify vendor risk," Pharmaceutical technology, 24(10), pp. 180-184.

[38] Burtescu, E., 2012, "Decision Assistance in Risk Assessment-Monte Carlo Simulations," Informatica Economica, 16(4), p. 86.

[39] Brandimarte, P., 2014, Handbook in Monte Carlo simulation: applications in financial engineering, risk management, and economics, John Wiley & Sons.

[40] Kao, H.-Y., Huang, C.-H., and Li, H.-L., 2005, "Supply chain diagnostics with dynamic Bayesian networks," Computers & Industrial Engineering, 49(2), pp. 339-347.

ACADEMIC VITA

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EDUCATION

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Johnson & Johnson, Fort Washington, PA *December 2014-July 2015*
McNeil External Manufacturing Operations Co-op

- Facilitated weekly production performance metrics and communications to leadership and Board of Directors
- Managed and communicated monthly scorecards for external manufacturing sites used in quarterly business reviews
- Generated purchase orders in Ariba system to support external manufacturing production
- Created tools to support planning and managing production utilizing SAP reports
- Improved risk assessment tool used to analyze external sites and suppliers risk and develop mitigation action plans
- Coordinated events for the external manufacturing network including monthly staff meetings

Brite Lab Research Group, Penn State *October 2012-Present*
Engineering Design Research Assistant

- Conducted various studies on design innovation, analyzed results and data to examine the decision making process for selecting designs to be prototyped, and contributed to a conference paper

Dunkin Donuts Franchise, Huntingdon Valley, PA *2007-December 2014*
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Tech Tutors, Penn State *January 2014-Present*

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