The Application of Failure Mode and Effect Analysis to Evaluate Risks Associated with Outsourcing Decisions

By

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ABSTRACT

The goal of this thesis is to develop a tool for analyzing the risks associated with outsourcing decisions for corporations. The thesis explores the current methods of choosing suppliers to outsource, as well as issues and risks that need to be considered in the decision. A need arose for a tool to standardize the process of choosing a supplier and help the decision team consider more aspects than the bid price.

This need gave the opportunity to develop a tool based on Failure Mode and Effect Analysis (FMEA). The typical FMEA was researched and analyzed for its ability to be an effective tool in outsourcing risk decisions. Small alterations on the typical FMEA were made to provide a relevant tool to analyze outsourcing risks. This new process, deemed Outsourcing Risk FMEA, was described in detail.

The Outsourcing Risk FMEA was put to the test through a case study. The case study analyzed Boeing Commercial Airline's 2003 decision to outsource a section of its 737 Vertical Fin production to Korea Aerospace Industries. This study provided an example of how the analysis could be applied. Further research into the proof of the analysis's effectiveness is necessary. This research can be conducted by receiving feedback from teams using this analysis in their outsourcing decisions. The feedback would then be used to improve the process. Outsourcing Risk FMEA provides a structured, standard solution to the problem of analyzing the risks associated with outsourcing.

This thesis was performed in conjunction with Leaders for Manufacturing graduate student Victor Mroczkowski's MBA and MS thesis.

Thesis Supervisor: Warren P Seering
Title: Co-Director of Leaders for Manufacturing Program

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Finally, I would like to thank Pedzi Makumbe for his insight into my project. Pedzi provided a wealth of knowledge into the outsourcing field, and willingly shared his findings for his own thesis. He took time out of his schedule to provide feedback, suggestions and expertise on my progress.

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1 INTRODUCTION

This chapter presents the background for this thesis. Section 1.1 provides background on outsourcing, including the issues and risks companies consider. Section 1.2 describes why it is important to consider these risks and issues. Section 1.3 discusses the motivation for developing this risk decision tool for outsourcing. Finally, section 1.4 is a brief outline of the rest of the thesis.

1.1 Outsourcing

1.1.1 Definition of Outsourcing and Process

Outsourcing is the process of subcontracting parts of a company to a third-party. Virtually all areas of the company can be outsourced (except for upper-level management). Some "functions are being outsourced with more regularity, such as computer services, benefits administration, telephone customer support, and records management" (Bragg xi). Outsourcing provides many benefits to companies including "the shift from domestic to global economy, from manpower to technopower, from company-led to consumer-driven market forces, from an industrial economy to a knowledge economy" (Brown xii).

The process to decide to outsource varies depending on the company. Each company conducts its own research about firms that could be good potential suppliers. After this is done, a common part in the process is a request for proposal (RFP).

> The RFP gives the supplier background information about the company and its industry, describes the function it wishes to outsource, the specific tasks to be taken on by the supplier, current transaction volumes, the company's expectations for performance, and a deadline for when the RFP must be received at the company (Bragg 15)

RFPs help the company by bringing in potential suppliers. Companies then evaluate these suppliers based on the bids they have received and any other attributes they deem appropriate.

1.1.2 Issues to Consider while Outsourcing[1]

As part of his doctoral thesis in Engineering Systems at the Massachusetts Institute of Technology, Pedzisayi Makumbe has been conducting interviews about the issues that companies consider when making the decision to outsource. These issues mostly come from the automotive industry, and were used in developing the risk decision tool.

Cost. The most important issue is that the supplier can make the part/provide the service the company needs within the company's budget. This issue is most heavily considered (and sometimes the only issue that is considered) when making the outsourcing decision.

Elimination of Duplication. This issue exists for multi-national companies. Companies do not want to be manufacturing the same product in two different places just because they have facilities in those two places. They can outsource domestic manufacturing to a foreign manufacturing site, especially if that site is already producing the product (just not to the same scale).

Capability. The company is concerned about the personnel at the supplier site. This includes having the quantity of people to produce the parts needed and also the quality of people to understand the complications that may occur during production.

Manufacturing Capability. The company wants to ensure that the supplier has the resources to run production of the subcontracted part.

Best Technology Available. If the supplier has a better way of producing the part, then it is beneficial for the company to take advantage of that technology. The company cannot possibly be the leader in manufacturing of every part that goes into its complex products. Outsourcing a part to a supplier with lots of experience in that particular field is then a smart choice.

[1] The section is paraphrased from the research for Pedzisayi Makumbe's thesis. See References.

Quality. The company needs to make sure that the product being produced by the supplier can meet specifications and standards.

Capacity. The company is concerned about the supplier's capacity to produce a product as well as deliver a product on time.

Access to Customer Culture. Multinational corporations sell their products all over the world. In this case, having a production center in a country where their product is being sold is valuable for learning about the customer to which they are marketing.

Historical Reasons. If the company has a history of outsourcing to a certain supplier that has met their expectations, they have a strong reason to continue their relationship.

Reliability. The supplier must be reliable in their delivery of goods and in meeting product specifications, short from any extenuating circumstances.

Business Negotiation. Most outsourcing contracts are rewarded through business deals. The ability of the supplier to negotiate is useful for them in trying to obtain contracts.

Logistics. The difficultly of working with the supplier, whether that be communications or delivery, is also taken into account when deciding when to outsource.

1.1.3 Risks Resulting from Outsourcing[2]

Along with these issues, there are many risks involved in outsourcing. Victor Mroczkowski is a graduate student in MIT's Leaders for Manufacturing (LFM) program. As part of his Masters of Mechanical Engineering and Business Administration, he developed a list of risks that are commonly associated with outsourcing. These risk were used in the development of the risk decision tool.

[2] This section was paraphrased from Victor Mroczkowski's thesis, for which this thesis is a complement. See References.

Controllable. Controllable risks are those that a company can detect with some degree of certainty before the event happens and can mitigate to some level. Controllable risks can occur on the strategic, operational and financial side in all parts of the business: supply side, company, and customer side.

Examples of strategic risks would be a relationship-specific investment for the supply side, intellectual property breach for the company, and labor dispute for the customer side. Examples for operational risks include supplier failure to deliver amount needed for the supply side, transportation delays for the company, and inaccurate forecasts for the customer side. For the financial risks, examples are supplier bankruptcy for the supply side, higher cost of logistics for the company, and accounts receivable not reliable from the customer side.

Uncontrollable. Uncontrollable risks are those that the company cannot detect in any way. They include freak accidents like natural disasters and terrorist acts. They also include political factors, such as turmoil in the country the supplier operates, exchange rate fluctuations, new regulation and/or legislation preventing the supplier from delivering, and financial recession. These are all factors that the company cannot control, but they do affect their outsourcing relationship with the supplier.

1.2 Importance of Issues and Risks in Outsourcing Decisions

According to Steven Bragg in his book, *Outsourcing*, "the most common approach [for choosing a supplier] is to scan through the bids for the lowest price, and immediately award the contract to that supplier. However, this approach ignores a number of factors that should be researched prior to awarding a contract" (Bragg 18-9). These "other" factors are the ones discussed above, as well as many others. If companies do not take these factors into account when making their decision to outsource, they are risking hiring an unfit supplier. These risks have the potential to cost the company more than what the next lowest bidder with better resources may have offered.

1.3 Motivation for This Study

The purpose of this thesis is to explore a way to aid companies in the risk area of the outsourcing decision process, so they do not fall into the trap of choosing the lowest bidder. This thesis is in conjunction with Mroczkowski's thesis for the LFM program, entitled *Integrated Decision Support Model for Global Sourcing*. His focus is to develop an Integrated Decision Support Model which companies will be able to use to aid their decision making process. In this model, the strategic, operational, financial, and risk factors of an outsourcing decision are taken into consideration. The tool provides a numerical method for deliberating these factors, and acts as a structured tool for discussion. He worked with The Boeing Company in their Commercial Airlines division (BCA) to develop this project.

My part in the project is to focus on the risk side of the Integrated Decision Support Model. By using information from Mroczkowski's thesis about BCA, I hope to develop a tool that will help guide BCA in their discussions about outsourcing. The tool I will be using is a modified version of Failure Mode and Effects Analysis (FMEA). FMEAs are typically used in design engineering. However, throughout this thesis, I will explore how the FMEA can be used in the outsourcing risk framework. I will also provide a detailed description of Outsourcing Risk FMEA, my modified FMEA application. Outsourcing Risk FMEA will be used in a case study about Boeing's 737 Vertical Fin, as a complement to Mroczkowski's case study in his thesis. From this case study, I will explore what can be improved upon for other uses as well as how this will benefit companies in their outsourcing decisions.

1.4 Thesis Outline

In Chapter 2, I will discuss the background of Failure Mode and Effects Analysis (FMEA), as well as it's potential to be used in a risk framework. The Boeing Company's current practices are described, as a set up for the case study. In Chapter 3, I will outline the process of developing FMEA to apply to risk decisions. This chapter will also include a description of my version of FMEA for risk analysis. Chapter 4 will highlight a case study about BCA's 2003 decision to outsource their 737 vertical fin to Korea Aerospace Industries (KAI). This is an extension of Mroczkowski's case study. Chapter 5 will have conclusions about the process of this thesis and a summary of the paper.

2 FAILURE MODE AND EFFECT ANALYSIS (FMEA)

Chapter 2 includes a background look into FMEA. Section 2.1 will outline the steps taken in a typical FMEA process. Section 2.2 highlights some of the current applications of FMEA. Section 2.3 briefly discusses The Boeing Company's current framework for outsourcing decisions and risk analysis. Section 2.4 weighs the advantages and disadvantages of using this analysis as a tool for outsourcing decisions, as well as looks into similar work done in this application of FMEA.

2.1 Typical FMEA

2.1.1 Definition of FMEA

"Preventing process and product problems before they occur is the purpose of Failure Mode and Effect Analysis" (Beauregard 4). The technique was first seen in the aerospace industry in 1962 as a "method of reliability analysis, risk analysis and risk management" (Aldridge 387). It has since then broadened into other engineering disciplines, where it has been applied to products, services, and management. Dyadem Press has put out multiple guidelines for FMEA in various industries. They state that the three main focuses of FMEA are:

- The recognition and evaluation of potential failures and their effect;
- The identification and prioritization of actions that eliminate the potential failures, reduce their chances of occurring, or reduce their risks;
- The documentation of these identification, evaluation and corrective activities so that product quality improves over time. (Dyadem 5-1)

FMEA has a step-by-step process that a chosen team follows. There are many variations on the exact steps that are followed. The next sections provide an outline of the steps that are seen most often in each type of FMEA.

2.1.2 Step 1: Assemble a Team

The team is an important aspect of the FMEA process. It must include a variety of perspectives, and each person needs a solid understanding of the product being discussed. FMEA is never to be done by one person because of personal bias. According to

Stamatis, "discussion continues until the team reaches a decision that every member accepts and will implement...the team capitalizes on diversity among members to reach a better decision than they could produce independently" (Stamatis 97).

2.1.3 Step 2: Complete Header of FMEA Worksheet

This step is important in FMEA to correctly identify the part being looked at. It brings everyone one on the same page. Figure 1 shows an example of what the template might look like for an FMEA analysis.

Figure 11-1: Sample D-FMEA Worksheet

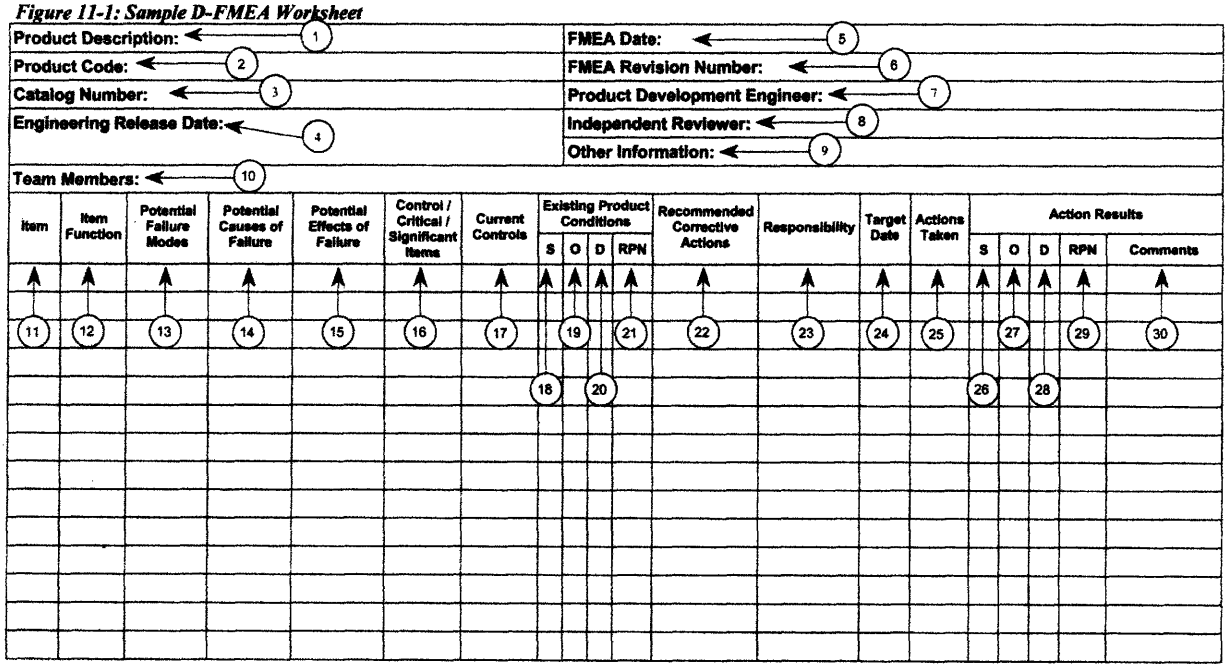

Figure 1. Example of Design FMEA Worksheet (Dyadem 11-10)

2.1.4 Step 3: Identify Design Functions

In this step, the engineer outlines all the functions of the subsystem, part or process that the team is analyzing. "For the function to be effective, it must be identified in detail with a statement that is (1) concise, (2) exact, and (3) easy to understand" (Stamatis 114).

2.1.5 Step 4: Identify All Possible Failure Modes for Each Function

The next step in the FMEA process is to identify how the function listed above can fail. There must be at least one failure mode for each function listed, but there is usually more than one failure mode. "The emphasis is on the engineer who must try to anticipate how the design being considered could possibly fail, not whether or not it will fail" (Stamatis 137).

2.1.6 Step 5: Identify Potential Effects of the Failure Modes

The next step in the process is to identify the potential effects of each failure mode. This step gets the team thinking about how the company will be affected by the failure mode, which will help the team decide on a severity rating.

2.1.7 Step 6: Critical Characteristics

This step is usually for design, product, or process FMEAs. The purpose of this column is to flag the team to a critical characteristic, such as meeting safety hazards, or compliance with government standards. Typically, a "Y" for yes, or "N" for no is placed in this column to indicate to the team that this mode needs to have a plan of action at the end of the analysis.

2.1.8 Step 7: Severity Rating (S)

From looking at the effects of each failure mode, the team can generate a severity rating score. The rating is on a 1-10 scale. An example for the severity score scale is shown in figure 2 below.

Effect	Rank	Criteria
None	1	No effect.
Very slight	2	Customer not annoyed. Very slight effect on product performance. Nonvital fault noticed sometimes.
Slight	3	Customer slightly annoyed. Slight effect on product performance. Nonvital fault noticed most of the time.
Minor	4	Customer experiences minor nuisance. Minor effect on product performance. Fault does not require repair. Nonvital fault always noticed.
Moderate	5	Customer experiences some dissatisfaction. Moderate effect on product performance. Fault on nonvital part requires repair.
Significant	6	Customer experiences discomfort. Product performance degraded, but operable and safe. Nonvital part inoperable.
Major	7	Customer dissatisfied. Product performance severely affected but functionable and safe. Subsystem inoperable.
Extreme	8	Customer very dissatisfied. Product inoperable but safe. System inoperable.
Serious	9	Potential hazardous effect. Able to stop product without mishap—time-dependent failure. Compliance with government regulation is in jeopardy.
Hazardous	10	Hazardous effect. Safety related—sudden failure. Noncompliance with government regulation.

Figure 2. Example of Detection Criteria for Design FMEA (Stamatis 141)

2.1.9 Step 8: Identify Potential Causes for Failure Modes

Identifying the potential causes for failure modes is as important as identifying the effects. It forces the team to think about what events act as a catalyst to the failure. From these causes, the team will have a better idea of how often the failure occurs, helping them decide the Occurrence rating.

2.1.10 Step 9: Occurrence Rating (O)

After looking at what causes a failure mode, the team rates the likelihood of the failure mode taking place. The rating is on a 1-10 scale. An example of the occurrence score scale is shown in figure 3 below.

Occurrence	Rank	Criteria	CNF/1000
Almost impossible	1	Failure unlikely. History shows no failures.	<.00058
Remote	2	Rare number of failures likely.	.0068
Very slight	3	Very few failures likely.	.0063
Slight	4	Few failures likely.	.46
Low	5	Occasional number of failures likely.	2.7
Medium	6	Medium number of failures likely.	12.4
Moderately high	7	Moderately high number of failures likely.	46
High	8	High number of failures likely.	134
Very high	9	Very high number of failures likely.	316
Almost certain	10	Failure almost certain. History of failures exists from previous or similar designs.	>316

Figure 3. Example of Occurrence Criteria for Design FMEA (Stamatis 144)

2.1.11 Step 10: Existing Control Mechanisms for Failure Modes

In this step, the team identifies ways the company can detect a failure mode before it fails and/or before it is sent to the customer. This is useful for the team to use as references in Step 11.

2.1.12 Step 11: Detection (D)

After going over the existing control mechanisms, the team rates how likely the controls will detect the failure before the product is released to the next step. The next step could be taking the product to the customer, production, etc. The rating is on a 1-10 scale. An example of the detection score scale is shown in figure 4 below.

Detection	Rank	Criteria
Almost certain	1	Has the highest effectiveness in each applicable category
Very high	2	Has very high effectiveness
High	3	Has high effectiveness
Moderately high	4	Has moderately high effectiveness
Medium	5	Has medium effectiveness
Low	6	Has low effectiveness
Slight	7	Has very low effectiveness
Very slight	8	Has lowest effectiveness in each applicable category
Remote	9	Is unproven, or unreliable, or effectiveness is unknown
Almost impossible	10	No design technique available or known, and/or none is planned

Figure 4. Example of Detection Criteria for Design FMEA (Stamatis 149)

2.1.13 Step 12: Risk Priority Number (RPN)

The next step is to calculate the Risk Priority Number. Equation (1) shows how the RPN is calculated.

$$RPN = S \text{ x } O \text{ x } D \qquad (1)$$

S refers to the Severity rating, *O* refers to the Occurrence rating, and *D* refers to the Detection rating. The RPN is calculated for each failure mode. The team then discusses each failure mode starting with the highest priority number. The highest RPN correlates itself to the highest risk failure mode.

2.1.14 Step 13: Recommended Action

The next step in the FMEA process is to brainstorm actions that will mitigate the risk of each failure mode. The team discusses what the company can do to improve the RPN (lowering the number). The team must keep in mind the resources of the company. "Example actions include DOE (design of experiments), design revision, and test plan revision" (Breyfogle 368).

2.1.15 Step 14: Assign Responsible Person/Target Date

A member(s) of the team is then assigned to complete the plan of action. This is an important step in accountability for the FMEA. A target date is also selected for the team to meet again and discuss the actions taken.

2.1.16 Step 15: Action Taken

At the next meeting, the plan of action teams report their activities and the resulting action taken for each failure mode is documented.

2.1.17 Step 16: Recalculate RPN

After the FMEA team discusses the new actions that were taken, they brainstorm new Severity, Occurrence, and Detection ratings. They revise the RPN; it should be lower than the previous RPN now that actions have been taken to mitigate this failure. This completes the FMEA process.

2.2 Current FMEA applications

2.2.1 Product/Design FMEA

This is the most common application of FMEA. It uses FMEA as a way of looking at the full design of a product and trying to find its failure modes before it is put into its first production run. "The threshold of the first production run is important, because up to that point modifying and/or changing the design is not a major problem. After that point, however, the customer gets involved through...some...kind of formal notification" (Stamatis 129). For this type of analysis, Stamatis recommends a team of

engineers (system, reliability, test, material, process, design) and a marketing representative.

2.2.2 System/Concept FMEA

This application of FMEA is used for analyzing the subsystems of a product in the early stages of design and provides a good check for the design in terms of redundancy. The result of this analysis is the input for the Design FMEA. "The goal of system FMEA is to define and demonstrate a proper balance among operational (in other words, effectiveness and performance) and economic factors" (Stamatis 108). For this process, Stamatis recommends a smaller team of engineers (system, reliability, test, and design) and a marketing representative.

2.2.3 Process FMEA

Process FMEA analyzes where failures may occur in the manufacturing and assembly processes. This helps to indentify necessary manufacturing controls before problems cause large bottlenecks. "The process FMEA should ideally commence with the design FMEA available...the design intent can be transferred through to the manufacturing stage...with an already determined process route and early enough to allow time to implement any specific controls" (Aldridge 398). The results of process FMEA is another process, which may have to be iterated through another FMEA until it is refined enough (Stamatis 158). The recommended team for this analysis includes slightly different engineers (quality, reliability, tooling, process, design) as well as any responsible manufacturing operators (Stamatis 182).

2.2.4 Application FMEA

Application FMEA is used both upstream and downstream of the product production cycle (Dyadem 13-1). The downstream supplier side uses this analysis to identify failures that would occur when sending the product specifications to suppliers. The upstream side looks at customer applications of the product and how the company can eliminate confusion.

2.2.5 Service FMEA

In this application of FMEA, the team analyzes the services available to the customer before they are actually put in use. This is important so that the service responds efficiently when necessary. "The goal, purpose, and/or objective of the service FMEA is to define, demonstrate, and maximize solutions in response to quality, reliability, maintainability, cost, and productivity as defined by the design specifications and the customer" (Stamatis 189). The recommendations for this team are a department head and supervisor as well as personnel involved with the service (Stamatis 208).

2.2.6 Machine FMEA

Machine FMEAs are used by suppliers to identify the possible failure modes of the machines used to make the parts required. The supplier uses this to identify how a product may have potential failure modes due to a machine failing in the process of making it.

2.3 Boeing's Outsourcing Plan

2.3.1 Current Plan[3]

The Boeing Company has a subdivision called Global Partners that is responsible for making outsourcing decisions for the company. Global Partners recent focus is on developing long term strategic relationships with a close group of suppliers.

Currently Boeing's outsourcing plan includes a heavy emphasis on cost factors. They use accounting-based cost metrics to make their sourcing decisions, while keeping the minimum requirements for quality and delivery in mind. However, there is no one single cost plan. For different decisions, different costs are considered. Boeing's plan also lacks consideration for those factors that are not quantitatively measured in a cost manner.

2.3.2 Risk Tools

[3] This section was paraphrased from Victor Mroczkowski's thesis, for which this thesis is a complement. See References.

In discussions with Mroczkowski, I have found that Boeing does have a system of detecting risk that is based on the severity and occurrence of that risk. They use this to control their process steps in manufacturing, if they reduce this rating below a certain level. The design is considered successful and not looked at again. Figure 5 shows what a risk diagram might look like for Boeing (this diagram is based on my own rendering and not the material of the Boeing Company).

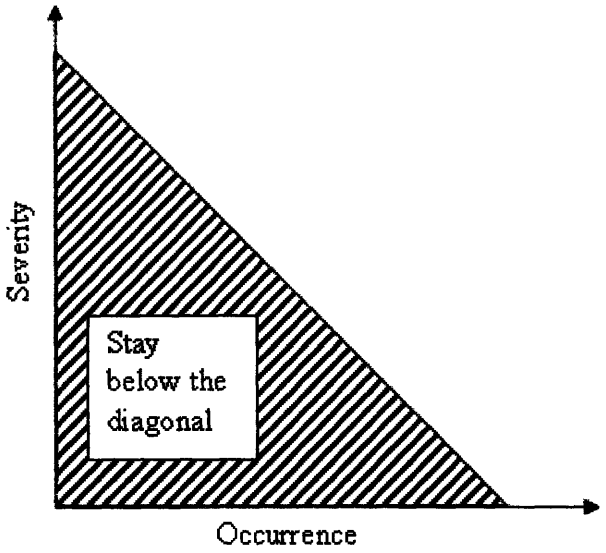

Figure 5. Author's Example of Boeing's Risk Analysis

2.4 Potential of FMEA as Tool for Analyzing Outsourcing Risks

2.4.1 Advantages

There are multiple advantages to using the FMEA for analyzing risks with outsourcing. FMEA is a tool that is used in many engineering applications. Boeing is an engineering company and has probably used this tool, or something similar in the past, so there is a level of familiarity. FMEA also has similar criteria to one of Boeing's existing processes for risk analysis, with the severity and occurrence ratings being something that Boeing already uses. This analysis would provide Boeing with a systematic, structured way of approaching the risks associated with outsourcing. Currently, they do not have a method of doing this. So not only does this method force the company to address the risks (especially the more qualitative ones), it also provides a standard method that the

company can use across all disciplines. The outcome of the analysis is a prioritized list. It inherently does not make decisions for the company, but instead lets the company know which areas should be considered more when making these decisions. The team atmosphere of FMEA is also very helpful. FMEA gathers multiple people for various views on the product being analyzed. Instead of a decision being made by only one person, or with multiple people in the same discipline, more employees are involved in the decision with multiple viewpoints that will enhance the process. FMEA also forces the team to collect data, so that they can better understand the issues. This data can be referenced in other decisions, as well as provide justification to the decision that was made.

2.4.2 Disadvantages

While there are a lot of reasons why this analysis would be beneficial in making outsourcing decisions, there are also some disadvantages. The analysis has not previously been used in this manner at The Boeing Company. Therefore, it could be prone to rejection as it is a new analysis in a company that relies heavily on past protocol. The process described in the second part of this thesis will probably need more refinement to cater to the company's needs. In that respect, immediate adoption of the analysis would be impossible. FMEA also does not provide a decision tool. It only gives a list of factors are the most important in making the decision. If the company wants a conclusive decision tool, this would not be able to provide that.

2.4.3 Current Ideas in this Area

There is an article about applying FMEA in an outsourcing risk framework. Cliff Welborn, an associate professor at Middle Tennessee State University in Murfreesboro, published an article in the *Quality Progress* August 2007 issue about using FMEA to help make outsourcing decisions. He uses the same process described in Section 2.2 for a typical FMEA. However, he argues that using a 1-5 scale rather than a 1-10 scale is easier for the team. An example of his analysis is shown in figure 6 below.

Risk	Opportunity	Probability	Severity	Risk priority number
Cost				
Unforeseen vendor selection cost	2	4	2	16
Unforeseen transition cost	2	4	2	16
Unforeseen management cost	4	4	3	48
Lead Time				
Delay in production start-up	2	4	4	32
Delay in manufacturing process	5	3	2	30
Delay in transportation of goods	4	2	2	16
Quality				
Minor cosmetic/finishing defect	5	4	1	20
Major cosmetic/finishing defect	5	2	2	20
Component will not fit with mating parts—requiring rework	5	2	4	40
Structural defect—function failure	5	1	5	25

Figure 6. Example Analysis of Risk Outsourcing FMEA from Welborn's Paper (Welborn 18)

While Welborn does present the initial idea to use the FMEA framework to evaluate outsourcing risks, he does not justify his ideas to use a 1-5 scale or to not change any other part of the FMEA process. My analysis will build upon his idea to use this, but with the justification for the changes I have made to the FMEA process.

3 DEVELOPMENT OF OUTSOURCING RISK FMEA

This chapter goes into depth of the development process for Outsourcing Risk FMEA. Section 3.1 weighs the pros and cons of using the existing FMEA framework or developing a new one. Section 3.2 discusses the deviations from the existing FMEA framework. It describes the decisions made at the beginning of the development process and the justifications for the deviations from the typical FMEA. Section 3.3 gives a detailed description of the procedure of performing an Outsourcing Risk FMEA. Section 3.4 discusses the results a company should expect with this FMEA, and how to use the results.

3.1 Existing FMEA versus New FMEA

3.1.1 Existing FMEA

The main advantage of using the existing framework is familiarity. In the engineering world, FMEA is consistently used in new product development. It provides a safety check to designers so that they can prevent obvious failures from occurring in the product. Another advantage is that FMEA is being used more frequently in the process side of engineering. Whether it is a manufacturing process or a customer service process, there are now many applications of this analysis. Adding an application of FMEA for outsourcing decisions is not as implausible with the advent of process- and service-oriented FMEAs.

However, the distinct disadvantage of using existing FMEA is that it may not be asking the right questions about the issues addressed. Failure modes of products are very different than risks involved in outsourcing. A product has measurable and physical failure modes, such as crack propagation and time to obsolescence. However, risks, such as strategic positioning and delivery failure, do not have concrete measurements. The question then becomes whether Severity, Occurrence, and Detection are the right criteria to use to judge these risks. It might also be a hard adjustment for engineers working on the analysis to change their frame of reference from product design to outsourcing decisions.

3.1.2 New FMEA

The main advantage of a new FMEA structure is that the criteria can be redefined. Severity, Occurrence and Detection can be altered in both the type of the criterion and how they are scored to create a new analysis. The team can then know for certain that they are evaluating their outsourcing decision on criteria customized to this type of risk analysis.

The disadvantage of a new FMEA is confusion. Because engineers are familiar with the existing frameworks for FMEAs, they would probably jump to conclusions about how to go through this analysis without paying careful attention to the directions. Also new tools for decision making are hard to introduce to a company because they are accustomed to practicing a certain type of decision making.

3.2 Development of Outsourcing Risk FMEA

3.2.1 Decision

After weighing the advantages and disadvantages, I decided to create an Outsourcing Risk FMEA that held true to the existing FMEA framework, but with some minor changes. This decision was a compromise between the two ideas presented above. Sections 3.2.2 and 3.2.3 describe the similarities to existing FMEA frameworks and the small changes made for the Outsourcing Risk FMEA.

3.2.2 Criteria

As an exercise to make the decision of how to format this analysis, I took myself through the process of what needs to be considered when making outsourcing decisions. I decided to look at three risks: political turmoil in country of production, quality of produced part not within specifications, and delivery not on time. Appendix A outlines my thought process in analyzing these three risks. I thought about what questions needed to be asked about these issues. Looking over the questions being asked about this these issues, I saw some underlying themes. First off, these risks needed to be measured with by the degree of consequences that resulted. Another theme was how frequently the risk happened. A very serious risk that happened less frequently would possibly not need as

much consideration as a less serious risk that occurred very often. There was also a theme of having the information to understand the consequences of these risks.

These general themes coincided well with the criteria of existing FMEA. This made my decision very easy. I decided to use the same criteria for this analysis. The only area of some dispute was with the Detection criterion. For product FMEA, Detection refers to the company's ability to expose a failure before it gets to the customer. The company can detect failure modes in products by performing tests and by setting up controls. However, it is very difficult to detect an outsourcing risk before it happens. Controllable risks, such as labor relations or poor quality products, are a little easier to anticipate. Controls can be set to mitigate these risks (e.g. quality checks in production lines). However, with uncontrollable risks, such as natural disasters, it is extremely hard to perceive when these risks might occur.

For these reasons, the Detection criterion of the typical FMEA was reformatted for the Outsourcing Risk FMEA. In this analysis, the Detection criterion refers to a level of knowledge of the consequences. The team members performing the FMEA will think about their current level of understanding, as well as the availability of information to enhance their level of understanding. If they do not know a lot about the effects of a risk, and the information is not easy to obtain, that risk will have a high Detection rating. This criterion is aligned better with outsourcing risks than the old Detection criterion. The old version dealt with the company's ability to see the failure after the product existed in some form. The new criterion deals with the company's ability to foresee the consequences of risks. This aligns with the idea of this analysis being done prior to the outsourcing decision.

3.2.3 Process

When looking at the process for the existing FMEA, it was relatively straightforward. Most of the steps made sense in terms of thinking about outsourcing risks. The only steps that did not make sense occurred at the end. The goal of product FMEA is to identify the main failure modes and mitigate them. The existing FMEA calls for the team to appoint a person in charge of mitigating the failure mode. The team then meets again at an agreed time and decides on a new RPN for the failure mode. The

Outsourcing Risk FMEA is performed before the outsourcing decision is made. The risks discussed are not realized. Therefore, it would be difficult to completely mitigate these risks, especially those that are uncontrollable (i.e. natural disasters, terrorism, etc.). Furthermore, the goal of Outsourcing Risk FMEA is only to figure out which risks need to be considered heavily in the outsourcing decision. Because of these differences, I decided to reformat the last steps of FMEA.

Instead of the typical mitigation and reevaluation, I choose to reorganize the FMEA worksheet. The first table is called the Prioritization Table. Figure 7 shows the table. Appendix B also contains both tables developed for Outsourcing Risk FMEA. It uses the first half of the FMEA framework, and then stops after the RPN has been calculated.

Team Members:

Name of Part to be Outsourced:

Name of Considered Supplier:

PRIORIZATION TABLE

Issues (Controllable, Uncontrollable)	Risk (based on issues)	Causes of Risks	Effects of Risk	Severity (S)	Occurrence (O)	Detection (D)	RPN

Figure 7. Outsourcing Risk FMEA Prioritization Table for Risk Analysis

At this point in the regular analysis a person would be assigned to mitigate the risks. However, in my modified analysis, the team moves on to the next table. This is the Mitigation Table, shown in figure 8.

Team Members: _____

Name of Part to be Outsourced: _____

Name of Considered Supplier: _____

MITIGATION TABLE

Prioritized List	Plan of Action (without considering resources)	Feasibility of Plan of Action

Figure 8. Outsourcing Risk FMEA Mitigation Table for Risk Analysis

This table lists the risks in order of highest RPN to lowest RPN. After listing, the team brainstorms all possible ways to mollify those risks, not taking the company's resources into account. By not taking the company's resources into account, the ideas will be the best conceivable plans of actions, not the best just for the company. After coming up with these actions, the team decides which of the actions are feasible based on the company's resources. The number of feasible mitigations will help the team decide the potential of this supplier.

3.3 Outsourcing Risk FMEA Procedure Description

Appendix C provides an instructional description of this procedure.

3.3.1 Step 1: Gather Team

The team is an essential part in this FMEA process. The company needs to assemble cross-discipline members that will be affected by the outsourcing decision. This includes supply chain analysts, design engineers for the product, assembly line engineers, budgeters, and people who understand the company's global positioning strategy (usually upper management). The team is not limited to these people. It would also be beneficial to have members from the company's suppliers on the team. These people would help the team understand the relationship the company has with its current

suppliers. However, having members of the supplier being analyzed is not beneficial, as they would probably create a conflict of interests. Having customer representatives on the team is also helpful; they can provide the downstream insight on how they would be affected if these risks were to occur.

3.3.2 Step 2: Identify Issues

The next step in the process is to identify issues that are associated with outsourcing. These issues are similar to the ones discussed in the introduction of this thesis. In identifying these issues, both controllable and uncontrollable events are looked at. Each issue is listed in the first column of Prioritization Table. Figure 9 shows this table with the first column highlighted. It is the first tool of the Outsourcing Risk FMEA. This table will help organize the thoughts of the team and keep them on track with the analysis.

PRIORIZATION TABLE		
Issues (Controllable, Uncontrollable)	Risk (based on issues)	Caus
Quality	(1) part does not meet specifications	inacc faulty wron wron of de
	(2) machine tools out of date	suppl have new t
	(3) supplier does not have experience	
Natural Disaster	(1) Hurricane destroys plant	

Figure 9. Prioritization Table with Highlighted Issues Column

Controllable issues, as discussed in Section 1.1.3, are any issues that can be mitigated easily. They include issues in the following 4 categories, but are not limited to them: cost, quality (technology, experience, reputation), delivery (capacity, reliability) and collaboration (communication, culture, information transfer).

Uncontrollable issues, also discussed in Section 1.1.3, are those that the company cannot foresee and cannot regulate. They do not have specific categories that they fall under, but include such things as natural disasters, acts of terrorism, exchange rate fluctuations, etc.

When identifying issues, it is important to keep in mind the supplier that is being analyzed. The issues identified should be consistent with what to expect. Some issues, such as quality failure, need to be universally addressed. However issues like natural disasters do not need to be considered if the supplier is in a mild climate.

3.3.3 Step 3: Identify Risks

The next step is to then identify specific risks associated with these issues. Each issue may have a different number of risks associated with it. For example, with the quality issue, an acceptable risk may be "part does not meet specifications." However, the risks of "machine tools are obsolete" and "plant does not have experience in producing this part" may also fall under the quality issue. For this supplier, there is more than one risk for the quality issue.

Another important point is that the risk associated with the issues must be relevant to the supplier. For example the risk of "hurricane destroying the plant" is not a relevant risk to the natural disaster issue if the plant is located in a desert area. These risks are placed in the next column of the Prioritization Table, highlighted in figure 10.

PRIORIZATION TABLE		
Issues (Controllable, Uncontrollable)	Risk (based on issues)	Cause
Quality	(1) part does not meet specifications	inaccu faulty c wrong wrong of desi
	(2) machine tools out of date	supplie have re new to
	(3) supplier does not have experience	
Natural Disaster	(1) Hurricane destroys plant	

Figure 10. Prioritization Table with Highlighted Risk Column

3.3.4 Step 4: Identify Causes of Risks

The next step is to identify the causes of the risks that were just brainstormed. There may be multiple causes for each risk. They are placed in the third column of the Prioritization Table, highlighted in figure 11. The purpose of identifying the causes is to get the group thinking about what they already know and understand about the risks. The causes will also help the team come up with ways to mitigate the risks in the later section of the analysis. As an example, "product not up to specifications" could be caused by inaccurate tooling, where "inaccurate tooling" would be placed in the causes of risk column as well as any other potential cause.

PRIORIZATION TABLE			
Issues (Controllable, Uncontrollable)	Risk (based on issues)	Causes of Risks	Effects o
Quality	(1) part does not meet specifications	inaccurate tooling, faulty controls, wrong design sent, wrong interpretation of design	parts do correctly assembl get rid of produce producti more cor

Figure 11. Prioritization Table with the Causes of Risk Column Highlighted

3.3.5 Step 5: Identify Effects if Risk Occurs

In the fourth column, the effects of the risks are listed. This column is highlighted in figure 12. By identifying these risks, the team is more prepared to make decisions regarding the criteria of FMEA. They can reference these effects in their discussion of Severity, Occurrence and Detection. An example of a risk for "product does not meet specifications" could be parts do not fit correctly into larger assembly. "Parts do not fit correctly into larger assembly" would be written in the effects column.

PRIORIZATION TABLE				
Issues (Controllable, Uncontrollable)	Risk (based on issues)	Causes of Risks	Effects of Risk	Seve (S)
Quality	(1) part does not meet specifications	inaccurate tooling, faulty controls, wrong design sent, wrong interpretation of design	parts do not fit correctly into larger assembly, need to get rid of already produced parts, production stalls more complex	

Figure 12. Prioritization Table with Effects of Risk Column Highlighted

3.3.6 Step 6: Severity Rating (S)

In the next column, the team rates the severity of the effects of the risk. This column is highlighted in figure 13, with this particular risk's score.

PRIORIZATION TABLE					
Issues (Controllable, Uncontrollable)	Risk (based on issues)	Causes of Risks	Effects of Risk	Severity (S)	Occ (O)
Quality	(1) part does not meet specifications	inaccurate tooling, faulty controls, wrong design sent, wrong interpretation of design	parts do not fit correctly into larger assembly, need to get rid of already produced parts, production stalls	9	
			more complex		

Figure 13. Prioritization Table with Severity Column Highlighted

The Severity rating is ranked on a scale from 1-10. The meaning of each point scale is shown in figure 14. The numbers that are not specifically defined fall between those that are defined; they are up to the team's discretion. For example, "part does not meet specifications" may have a severity rating of 9 because the part produced will not sync with the assembled product, so all of the produced parts must be discarded.

Rating	Meaning
1	company is not affected
2	
3	company minimally affected, repaired easily
4	
5	company affected, but repairable
6	
7	
8	company largely affected, repairable, but difficult
9	
10	company is affected beyond repair

Figure 14. Severity Rating for Outsourcing Risk FMEA

3.3.7 Step 7: Occurrence Rating (O)

In the sixth column of the Prioritization Table, the team evaluates the likelihood of the risk occurring. This column is highlighted in figure 15, with this particular risk's score.

PRIORIZATION TABLE

Issues (Controllable, Uncontrollable)	Risk (based on issues)	Causes of Risks	Effects of Risk	Severity (S)	Occurrence (O)	De (D)
Quality	(1) part does not meet specifications	inaccurate tooling, faulty controls, wrong design sent, wrong interpretation of design	parts do not fit correctly into larger assembly, need to get rid of already produced parts, production stalls	9	2	
			more complex			

Figure 15. Prioritization Table with Occurrence Column Highlighted

The Occurrence rating is ranked on a scale from 1-10. The meaning of each point scale is shown in figure 16. The numbers that are not specifically defined fall between those that are defined; they are up to the team's discretion. For example "part does not meet specifications" may have an occurrence rating of 2, because it is relatively unlikely that the plant would produce all parts not within specifications. Some parts may be incorrectly produced, but every part is unlikely to not be within specifications.

Rating	Meaning
1	occurs very minimally (Probability < 0.10)
2	0.10 < Probability < 0.17
3	occurs a little amount (0.17 < Probability< 0.25)
4	0.25 < Probability < 0.32
5	occurs a substantial amount (0.32 < Probability < 0.40)
6	0.40 < Probability < 0.45
7	0.45 < Probability < 0.50
8	occurs rather frequently (0.5 < Probability < 0.55)
9	0.55 < Probability < 0.62
10	occurs very frequently (Probability > 0.7)

Figure 16. Occurrence Rating Outsourcing Risk FMEA

3.3.8 Step 8: Detection Rating (D)

The next column is where the team brainstorms the Detection rating. This column is highlighted in figure 17 with this particular risk's score.

PRIORIZATION TABLE

Issues (Controllable, Uncontrollable)	Risk (based on issues)	Causes of Risks	Effects of Risk	Severity (S)	Occurrence (O)	Detection (D)	RF
Quality	(1) part does not meet specifications	inaccurate tooling, faulty controls, wrong design sent, wrong interpretation of design	parts do not fit correctly into larger assembly, need to get rid of already produced parts, production stalls more complex	9	2	9	

Figure 17. Prioritization Table with Detection Column Highlighted

This rating departs from traditional FMEA. The Detection rating refers to the company's ability to properly identify the risks they are discussing. The panel must reflect on their own level of understanding of the risk being analyzed and whether they have the information to understand it fully. In order to be completely certain, the company must already have the information necessary to make an informed decision about the risks involved. The criterion is ranked on a 1-10 scale, defined in figure 18. The numbers that are not specifically defined fall between those that are defined; they are up to the team's discretion. For example, "part does not meet specifications" may have a detection rating of 9 because the team would not have the knowledge to know if the supplier they are looking at would cause error in the production of every part. There is probably some error the team can assume will occur, but there is virtually no way of knowing if the supplier will ruin all the parts.

Rating	Meaning
1	certain understanding, already have available information
2	
3	fair understanding, do not have information, fairly easy to obtain
4	
5	mediocre understanding, do not have information, obtainable, but slightly difficult
6	
7	
8	unclear understanding, do not have information, will be rather difficult to obtain
9	
10	no understanding, do not have information, not available

Figure 18. Detection Rating for Outsourcing Risk FMEA

3.3.9 Step 9: Calculate Risk Priority Number (RPN)

The last column of the Prioritization Table lets the team calculate the RPN, shown in figure 19, with this particular risk's RPN. Equation (1) is how to calculate the RPN, where S is the Severity rating, O is the Occurrence rating, and D is the Detection rating.

$$RPN = S \text{ x } O \text{ x } D \qquad (1)$$

This formula yields RPN values from 1-1000.

PRIORIZATION TABLE

Issues (Controllable, Uncontrollable)	Risk (based on issues)	Causes of Risks	Effects of Risk	Severity (S)	Occurrence (O)	Detection (D)	RPN
Quality	(1) part does not meet specifications	inaccurate tooling, faulty controls, wrong design sent, wrong interpretation of design	parts do not fit correctly into larger assembly, need to get rid of already produced parts, production stalls more complex	9	2	9	162

Figure 19. Prioritization Table with RPN Column Highlighted

3.3.10 Step 10: Prioritize

The next step in the Outsourcing Risk FMEA is to move to the risks to the Mitigation Table. In the first column of the table, the team will list the risks in order of

highest RPN to lowest RPN. The column is highlighted in figure 20. This allows to the team to look at the highest priority risks first.

MITIGATION TABLE

Prioritized List	Plan of Acti (without considerinç resources)
(162) part does not meet specifications	send emplc help plant ç track
	find anothe to receive p from
(100) hurricane destroys plant	
(80) supplier does not have experience	
(63) machine tools out of date	

Figure 20. Mitigation Table with Prioritized List Column Highlighted

3.3.11 Step 11: Plan of Action

In the next column of the Mitigation Table, the team will brainstorm all possible ways to eliminate each risk. The column is highlighted in figure 21. The resources of the company are not taken into account so that no idea is discounted and that the best possible ideas are put forward. To continue the example, for the "part does not meet specifications risk" a possible plan of action would be to send a representative from the company to the supplier to provide support for the supplier in order to meet the specifications. Another plan of action would be to disable the outsourcing relationship.

MITIGATION TABLE

Prioritized List	Plan of Action (without considering resources)	Feasibi Action
(162) part does not meet specifications	send employee to help plant get on track	very fea afford tc employe site, it w to find e willing tc
	find another plant to receive parts from	not feas relation already establis extreme find ano late stag
(100) hurricane		

Figure 21. Mitigation Table with Plan of Action Column Highlighted

3.3.12 Step 12: Analyze Feasibility

In the final column of the Mitigation Table, the team will discuss the feasibility of each plan of action. Now, the team can take into account the company's resources, and whether the company can allocate those resources to this cause. In this column, highlighted in figure 22, the team would write out whether they think each plan of action is feasible and how. As a conclusion to our example, sending a company representative to the supplier would be pretty feasible. It would just force the company to reallocate some of their personnel. However, disabling their relationship with the company would not be very feasible as they would have to scramble to find another supplier.

MITIGATION TABLE

Prioritized List	Plan of Action (without considering resources)	Feasibility of Plan of Action
(162) part does not meet specifications	send employee to help plant get on track	very feasible, could afford to staff one employee at supplier site, it would be hard to find employee willing to go
	find another plant to receive parts from	not feasible, relationship has already been established, would be extremely difficult to find another plant at a late stage
(100) hurricane		

Figure 22. Mitigation Table with Feasibility of Plan Action Highlighted

3.3.13 Step 13: Review Analysis

The last step in the process is to review the feasible actions. If there are enough feasible actions to mitigate the risks, then this supplier should be further considered for an outsourcing relationship. However, if the team finds that there are too many risks that are not able to be mitigated, then the supplier either needs to provide more information, or it can be taken off the list of consideration.

3.4 How to Use Results of Analysis

At the end of this process, the team should expect to have a deeper understanding of the risks they are taking when outsourcing to the supplier in question. They will also know which risks they will be able to mitigate and which risks require additional resources. The team will have a good indication of whether this supplier will be able to perform to their requirements. The important aspect of the results is that they do *not* make the decision for the team. They are merely used a discussion tool. There are many other factors other than risks that need to be taken into account when making the decision to outsource, including financials, strategy, and operations. In coordination with Victor's process, the team can use this analysis to complete the qualitative discussion of risk.

4 CASE STUDY: BOEING 737 VERTICAL FIN

This chapter applies the Outsourcing Risk FMEA to a Case Study about Boeing's decision to outsource their 737 vertical fin. The case is a demonstration of how to use this technique in practice. Because it is performed by me and not a team of individuals, it is not a full scale example. Section 4.1 gives the background of the case as explained by Mroczkowski's thesis. Section 4.2 presents the issues that Mroczkowski analyzes in his thesis. Section 4.3 lays out the rationale behind the rankings for the risks associated with the issues in section 4.2. Section 4.4 discusses what the feasibility section means in terms of this analysis. Section 4.5 analyzes how effective the case study was and areas for improvements.

4.1 Background of Case[4]

The vertical fin component of the Boeing 737 commercial airplane is used as the vertical stabilizer for the aircraft. In the 737, the fin is made of an aluminum structure using techniques dating back to the WWII era. In 1988-89, Boeing awarded Xi'an Aircraft Company (XAC) a contract to produce these vertical fins in China. XAC proved to be a reliable manufacturer, delivering their 1000th vertical fin to Boeing in 2004. On October 28, 2003, Boeing announced that Korea Aerospace Industries (KAI) would also be producing vertical fins. This decision was born out of a $313M deal with Korea to bring production to their country and the sale of 40 F-15 aircrafts.

This case study focuses on recreating BCA's 2003 decision to outsource to KAI. It will outline the risks associated with the issues that Mroczkowski has analyzed as part of his Integrated Decision Support Model. The study is an example of how Boeing could use Outsourcing Risk FMEA in conjunction with the Integrated Decision Support Model to help make their outsourcing decision.

4.2 Issues in Case[5]

Mroczkowski presents several issues in the case. They are described below for reference. These issues will be used in the third step of the Outsourcing Risk FMEA for this case.

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[4] This section was paraphrased from Victor Mroczkowski's thesis, for which this thesis is a complement. See References.

[5] See above.

Technology Clockspeed. This refers to how fast the technology of producing a new part can change.

Product/Process Architecture. This refers to how modular, complex and flexible the design of the product is. The more modular, less complex, and more flexible (in terms of the design being able to support change) the design is, the easier it will be to modify if necessary.

Supply Base Characteristics. This refers to different attributes of the supplier that may be taken into consideration. This includes the supplier's capability, their power in industry, and the downstream relationships they have with their own suppliers.

Enterprise Characteristics. These are the characteristics of the company looking to outsource. The company must consider their own knowledge of the part being outsourced, and their competitive position.

Customer Value. These are issues the customer is concerned with, including their preference for a domestic versus foreign goods, and the economic value of outsourcing for the customer.

Exogenous Forces. These are forces that the company cannot control easily. They include foreign market access and political forces.

Demand Forecast Accuracy. This refers to how precise the company is at predicting the demand for their product.

Velocity. This refers to how fast the product can be produced.

Quality. This refers to the suppliers ability to meet company specifications and standards.

Delivery. This is the supplier's ability to deliver their product on time.

Capacity. This takes the resources of the supplier into account, and their ability to product the amount needed.

Production Cost per Unit. This asks the question of whether there is a lower cost associated with production for outsourcing the particular product.

Transportation/Logistics Cost. This refers to the additional cost acquired by having to ship the manufactured product to the assembly plant.

Investment Cost. This refers to how much the company needs to invest in order to get the supplier on track with their process and provide support.

Supplier Management Cost. This refers to the cost of managing the supplier on a daily basis. Personnel will probably have to be redirected to deal solely with a new supplier.

Tax Impact. This refers to the tax of the county where the product is made, as well as tax impacts on any shipping.

Supply/Dependency Risk. This refers to any risks associated with the supply side (e.g. labor disputes, knowledge and capacity dependence, inventory holding, supplier bankruptcy, etc.).

Enterprise System Breakdown. This refers to any risks that would affect the company, including intellectual property breaches.

Uncontrollable Risks. This refers to any risk the company does not have the ability to detect and/or control.

4.3 Risks Associated with Issues and the Logic for their Severity, Occurrence and Detection Rating

The completed Outsourcing Risk FMEA worksheets for this case are available in Appendix D. The following sections discuss the justification for the risks' ratings.

4.3.1 Better Fabrication Technology Emerges

Severity (9). It would be very hard initially for the company to stack up to the competition.

Occurrence (1). The technology for making aluminum fins has been modified consistently over the years and is now well established. A new innovation is not likely to occur.

Detection (2). BCA would have ample resources to find out about emerging technology, if they are not innovating themselves.

4.3.2 KAI Does Not Produce Correct Parts RPN = 100

Severity (10). If the wrong parts are produced, BCA would have to rely on their reserves, which will eventually run out if not replaced.

Occurrence (2). While this may occur in small doses, large production of incorrect parts in unlikely to occur. BCA would be on top of fixing the problem immediately.

Detection (5). BCA would be able to analyze KAI's ability to produce the correct part, but they would not be able to forecast extenuating circumstances.

4.3.3 KAI Unable to Handle Complexity

Severity (8). This problem could be mitigated by BCA. However, it would be severe if KAI was unable to handle the complexity of the fin.

Occurrence (2). The fin is not as complex because there are less precise tolerances.

Detection (2). BCA should have done good analysis of KAI's ability to handle a complex part.

4.3.4 KAI Does Not Have the Capabilities to Produce

Severity (10). This would result in BCA not being able to continue their assembly of the product.

Occurrence (1). This is tied with detection. BCA would not source to a company that they knew did not have the capabilities.

Detection (1). BCA would have accurate data to determine if KAI had capabilities before making their decision to use them.

4.3.5 KAI's Downstream Supply Base Fails

Severity (7). This would be relatively severe in that KAI would have to scramble to find other suppliers.

Occurrence (4). KAI's suppliers do have a small chance of failing in some way. This could be as severe as bankruptcy, or less serious as in failing to deliver goods on time.

Detection (9). BCA would have a hard time trying to find valid information on all of KAI's own supply base.

4.3.6 Competitive Pricing for Product Makes Manufacturing Unaffordable

Severity (6). This would be severe initially in that it would drastically affect the production budget, but the fin could be redesigned.

Occurrence (1). The aluminum fin has been very established in how it is made and designed; therefore competition would not be breaking too many barriers. Also, there is not much competition in the design of this part.

Detection (3). BCA would have a good idea of new innovations in the area, but some details may be top secret.

4.3.7 Customers Do Not Want Outsourced Parts

Severity (5). This is slightly severe in that the customer may reject the final product if they know that the fin was outsourced.

Occurrence (4). Customers may not trust the reliability of an outsourced fin, so they may be more inclined to reject it.

Detection (2). BCA has a good handle on what their customers want.

4.3.8 Korea Shuts Production Down

Severity (10). This would fully stop production of the fin.

Occurrence (1). Korea has incentives to keep the plant open for jobs and the economy, as well as the contractual deal with BCA.

Detection (1). BCA does have connections with Korean government due to their recent contract.

4.3.9 KAI Cannot Meet Demand for Product

Severity (7). This would slow production and the customers would not be happy about not having their demands met.

Occurrence (2). BCA would evaluate KAI's potential before choosing them. Short of extenuating circumstances, KAI should be able to meet the demand.

Detection (4). This is part of the research done about the company. Boeing would have knowledge about KAI's production rates, but not about uncontrollable circumstances that might effect production.

4.3.10 KAI Production Time Increases

Severity (3). BCA has a large amount of backup fins to use until the production time can be brought down again.

Occurrence (7). Some variability in production time is to be expected from KAI.

Detection (4). BCA has some idea of KAI's ability to produce, but again, they cannot account for all circumstances.

4.3.11 Batch of Parts Does Not Meet Design Specifications

Severity (4). Because it is only a batch of parts, the entire assembly would not be affected. It is only affected until the defect was fixed.

Occurrence (8). Small errors do occur frequently in production.

Detection (2). BCA would be expecting these errors to occur.

4.3.12 KAI Fails to Deliver On Time

Severity (5). BCA can move into their backup fins until KAI is back on track.

Occurrence (6). There will definitely be instances where KAI fails to deliver, but not terribly frequently.

Detection (3). BCA would be able to have some sort of delivery statistics on KAI.

4.3.13 KAI Does Not Have the Resources to Produce

Severity (8). Production would cease, however BCA could help them acquire the necessary resources.

Occurrence (1). Again, tied with detection, BCA would not outsource to a company that did not have enough resources.

Detection (1). BCA would analyze these resources beforehand.

4.3.14 Costs Increase Quickly

This risk applies to the production cost, logistics cost, investment cost, and supplier management cost issues.

Severity (4). This is not as severe because BCA could redo their budget from other areas of the program.

Occurrence (8). Variability in costs is to be expected.

Detection (2). BCA's budget is continually being updated.

4.3.15 New Tariff Raised on Imported Goods

Severity (3). Again, this is not as severe because BCA could redo their budget.

Occurrence (5). Economic recession causes the US to raise money through many different avenues, this being one of them.

Detection (1). Boeing has employees to keep current on the financial policies that will affect their company.

4.3.16 KAI Deliberately Underperforms

Severity (4). This could hurt BCA in the long run of continual underperformance. However, if it is just enough to go undetected, it is probably not as severe.

Occurrence (3). KAI does not have much incentive to cheat a good relationship with Boeing.

Detection (8). It is hard for BCA to detect whether a firm is morally conscience in this respect before entering into a relationship with them.

4.3.17 KAI Goes Bankrupt

Severity (10). This would ruin BCA's production. They would go into their backup stock, but would have to scramble to find a new supplier. A scrambled decision would most likely be a bad one.

Occurrence (2). There is a very small chance that KAI will not be able to manage their assets well.

Detection (10). BCA has no way of knowing whether KAI would go bankrupt before entering into contract.

4.3.18 Intellectual Property is Stolen

Severity (8). Losing these designs would be very harmful to BCA's Research and Development.

Occurrence (1). It is unlikely that KAI would sell out BCA's design, because of their contract.

Detection (10). BCA would have no way of judging KAI's morals on this issue before entering into contract.

4.3.19 Oil Prices Increase

Severity (4). This would effect BCA's budget, but not in a drastic way.

Occurrence (10). Oil prices have been continually increasing.

Detection (1). BCA would have employees who would need to find information about the increase in oil prices, especially with their primary products being transportation devices.

4.4 Discussion of Feasibility

After prioritizing the risks based on RPN, the next step was to come up with plans of action for these risks without looking into what resources BCA would have. Some of the risks were very similar and therefore had similar plans of action. Next, the feasibility of the plan was contemplated, taking BCA's available resources into consideration. With a large company such as Boeing, resources are very abundant, and therefore, the plan of action is feasible in almost every case.

However, the most common plan of action was to find another supplier in the event of some of these risks. BCA does outsource their products to other suppliers. In this case, the vertical fin was produced by both XAC and KAI. In the event of these risks preventing either of the two suppliers from producing up to the level needed, BCA can call upon one to ramp up production while the other is having difficulties. This is more motivation for BCA to outsource to KAI, as they would provide a safety net for XAC and vice versa.

After reviewing the feasibility, KAI looks to be a good potential supplier. By recommendation of this analysis, KAI should be considered further by the decision committee.

4.5 Reflection on Case Study

This case study does provide some benefit to the clarification of using FMEA as a way to analyze outsourcing risks. This example analysis provides Boeing with a template for how this analysis could be applied. It also complements Mroczkowski's thesis, as all of the issues were taken from the issues he considered in his case study. By using this analysis with the Integrated Decision Support Model, Boeing will have a more complete understanding of tools to use in their decision process.

The major drawback is that the case study only provides an example. It does not prove the concept, because it was just my thoughts on what Boeing could be thinking in a decision. The ideal situation would be for a group of Boeing employees to go through this analysis. The employees would have to currently be making an outsourcing decision, and would therefore be in need of a tool to help them sort their discussions. After going through the analysis, they would be able to provide feedback, which I would then incorporate into subsequent updates on the analysis. This would provide Boeing with a better tool for their decisions.

5 CONCLUSION

The chapter provides the conclusions drawn from this thesis. Section 5.1 gives a description of a test plan for this analysis in the future. Section 5.2 outlines the benefits this analysis will have for Boeing, as well as how it could be incorporated with the Integrated Decision Support Model. Section 5.3 reflects on what I have learned during this process. Finally, Section 5.4 provides a brief summary of the thesis.

5.1 Future Plans

The conclusion of the case study left an open area for the further improvement of this idea. For future study, an experiment on the effectiveness of the Outsourcing Risk FMEA would be beneficial. This would include using a control group from any company (preferably Boeing, but this is not a requirement) who would be making an outsourcing decision. They would complete the analysis as described in this thesis with a proctor who is familiar with the analysis. After completing the analysis, the proctor would prompt the group to give feedback about the effectiveness of Outsourcing Risk FMEA. This feedback would be specific to which parts of the FMEA need more improvements. The suggested improvements would then be used to update the FMEA. A supplementary experiment with the updated Outsourcing Risk FMEA would be necessary until the group finds the FMEA very useful in their decision making process.

5.2 Benefits to Boeing

This tool can be used to help Boeing make their outsourcing decisions. It provides Boeing with a systematic way to determine risky supplier relationships. It forces the team in charge of the outsourcing decision to consider more issues in their evaluations of suppliers. It motivates them to research the supplier, as the analysis would not be completed without research. Most importantly, this tool provides a standard way that Boeing can evaluate the risks associated with outsourcing across all disciplines. Standardization is one way a large company, such as Boeing, can operate more efficiently and effectively.

This analysis provides Boeing with a tool to complement the Integrated Decision Support Model. In this model, Boeing employees evaluate the issues described in section 4.2 on a numerical scale from -5 to 5. In the results of Outsourcing Risk FMEA, the team is provided

with a prioritized list of risks. The prioritized list will help the team in determining the score for each risk on the Integrated Decision Support Model's -5 to 5 scale. Higher priority risks receive higher scores, as they affect the company more drastically.

5.3 Reflection on Learning

5.3.1 FMEA and Outsourcing

I learned a great deal about Failure Mode and Effect Analysis. This knowledge will not only help me in future engineering analyses I will be performing, but I also now have a tool that I know how to apply in decision making situations. I have a much deeper understanding of the issues a business needs to consider when making outsourcing decisions. My current career goal is to go into engineering management. Therefore at some point in my career, I will most likely be placed on a team that would need to be making these decisions. Having a stronger comprehension of the factors that need to be considered would aid this decision process, and also aid the management of it. Along with an insight of analysis that can be performed to structure the decision, these concepts would help my group and I be successful.

5.3.2 Accomplishment

A more poignant takeaway from this thesis is a sense of accomplishment in creating a new analysis for a company. Being able to take an engineering analysis and apply it to a business setting combines both of my interests. Because of that, this process was enjoyable. Being able to design an analysis that would provide benefit to Boeing, as well as many other companies, gives me pride in knowing that I have helped aided them in making these difficult decisions.

5.4 Summary

This thesis explored the development of applying Failure Mode and Effect Analysis (FMEA) to outsourcing decisions, specifically in the risk sector. The beginning of the thesis gives an overview of what a company does when deciding to outsource. Because there is little standardization in consideration of risks, an opportunity to develop a structured method presented itself. The thesis then explored the concept of Failure Mode and Effect Analysis. It

looked at its current applications, and its potential for being used to analyze risks in outsourcing decisions. After deciding that FMEA was a good method for these decisions, a new application, called Outsourcing Risk FMEA, was developed. The thesis outlines the development process and the details of the Outsourcing Risk FMEA procedure. A case study was conducted where Outsourcing Risk FMEA was applied to Boeing Commercial Airlines' 2003 decision to outsource their 737 vertical fin to Korea Aerospace Initiatives. The result of the case study provided Boeing with an example that they could use as a template for further analysis. The drawback to the study was that there was no feedback generated from Boeing. A future experimental setup to obtain feedback from Boeing was discussed. This analysis provides a structured, standard method for companies to contemplate risks in their outsourcing decisions.

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APPENDIX A: SAMPLE RISKS AND QUESTIONS ASKED IN DEVELOPMENT OF ANALYSIS

Possible Risk: political turmoil
Questions to ask:

- How will this effect production?
- Will we have access to the firm to give direction/fix problems/answer questions?
- Will we have access to product delivery?
- How do we maintain communication?
- What will happen to proprietary information?

Possible Risk: quality of outsourced product not up to scale
Questions to ask:

- How will this affect our final product?
- Is collaboration possible to bring other firm up to standards?
- Should we move to another firm?
- How often will this occur?
- How was this able to be prevented?

Possible Risk: transportation time too long
Questions to ask:

- How will this affect our final product?
- Will this extend the final product delivery?
- Is there a more reliable transportation method available?
- How often will this occur?
- Are we able to account for this earlier?

Themes from questions:
**degree of consequences
*likelihood of finding a solution
*likelihood of occurring
*information availability– from problem to company and company to outsource firm (to fix)
*ability to predict

APPENDIX B: TEMPLATES FOR PRIORIZATION AND MITIGATION TABLES

Team Members: _____

Name of Part to be Outsourced: _____

Name of Considered Supplier: _____

PRIORIZATION TABLE

Issues (Controllable, Uncontrollable)	Risk (based on issues)	Causes of Risks	Effects of Risk	Severity (S)	Occurrence (O)	Detection (D)	RPN

Team Members: _____

Name of Part to be Outsourced: _____

Name of Considered Supplier: _____

MITIGATION TABLE

Prioritized List	Plan of Action (without considering resources)	Feasibility of Plan of Action

APPENDIX C: INSTRUCTIONS FOR USING OUTSOURCING RISK FMEA

Outsourcing Risk FMEA Instructions

1. Gather group of people who will be essential in outsourcing decisions.

2. List a series of controllable and uncontrollable issues to consider while making outsourcing decisions. (start using Prioritization Table)
    a. Controllable issues should include, but are not limited to, issues within the following 4 categories: cost, quality (technology, experience, reputation), delivery (capacity, reliability) and collaboration (communication, culture, information transfer).
    b. Uncontrollable issues include any event that will affect the company and they cannot control (ex. natural disasters, terrorism, exchange rate fluctuation). These issues do not have specific categories.
    c. In deciding these issues, it is important to keep in mind the scope of the decision being made. Make sure the issues being discussed are relevant to the area being looked at.

3. List specific risks associated with the written issues.
    a. Make sure that risks are case-specific to the decision. (ex. "hurricane destroys plant" is not a relevant uncontrollable natural disaster risk for a desert area.)
    b. ex. "plant produces parts that are not within specifications" is a specific risk for the controllable quality issue

4. For each risk, list the possible causes of the situation occurring.
    a. ex. "plant produces parts that are not within specifications" could be caused by inaccurate tooling.

5. For each risk, identify and list the possible effects of the situation occurring.
    a. ex. "plant produces parts that are not within specifications" will probably cause those parts to be assembled incorrectly in the larger product.

6. Identify the Severity (S) rating.
    a. This rating refers to the severity of the effects from the event on the company.

Rating	**Meaning**
1	company is not affected
2	
3	company minimally affected, repaired easily
4	
5	company affected, but repairable
6	
7	
8	company largely affected, repairable, but difficult
9	
10	company is affected beyond repair

Other numbers are scaled in between, as deemed fit by the discussion panel.

7. Identify the Occurrence (O) rating.
    a. This rating refers to the how often the event will be taking place.

Rating	Meaning
1	occurs very minimally (Probability < 0.10)
2	0.10 < Probability < 0.17
3	occurs a little amount (0.17 < Probability< 0.25)
4	0.25 < Probability < 0.32
5	occurs a substantial amount (0.32 < Probability < 0.40)
6	0.40 < Probability < 0.45
7	0.45 < Probability < 0.50
8	occurs rather frequently (0.5 < Probability < 0.55)
9	0.55 < Probability < 0.62
10	occurs very frequently (Probability > 0.7)

And the other numbers are scaled in between as deemed fit by the discussion panel.

8. Identify the Detection (D) rating.
    a. This rating departs from traditional FMEA. The detection rating refers to the company's ability to properly identify the risks they are discussing. The panel must reflect on their own level of understanding of the risk being talked about and whether they have the information to understand it fully. In order to be completely certain, the company must already have the information necessary to make an informed decision about the risks involved. The ratings are as follows:

Rating	Meaning
1	certain understanding, already have available information
2	
3	fair understanding, do not have information, fairly easy to obtain
4	
5	mediocre understanding, do not have information, obtainable, but slightly difficult
6	
7	
8	unclear understanding, do not have information, will be rather difficult to obtain
9	
10	no understanding, do not have information, not available

Other numbers are scaled in between the described ones.

9. Calculate the Risk Priority Number (RPN).
    a. RPN = S x O x D

b. The RPN will assign values to the risks from 1-1000.

10. Prioritize the risks and move the list of prioritized risks to the Mitigation Table.
    a. The risks with the highest RPN are the most critical in considering when making the final decision. They go to the top of the list, which are rewritten on the new Table.

11. Discuss and list possible plan of actions. (on Mitigation Table)
    a. The team will discuss the risks associated with the sourcing decision, using the FMEA output as a guide for the discussion. The most crucial risks will be discussed first and for the longest time available.
    b. For each risk, the team will come up with a plan of action that would reduce or eliminate the risk in question. *DO NOT take into account the resources the company has.

12. Discuss feasibility of plan of action.
    a. The team will discuss each plan of action now keeping in mind the company's resources. It will determine whether the company has the means of mitigating the risk in question.

13. Review the analysis.
    a. At the end of the session, the company will review the feasibility of mitigating the risks discussed. This will hopefully lead to a better sourcing decision.

**This tool does not provide any type decision. It only prioritizes the risks that need to be considered.

APPENDIX D: COMPLETED PRIORITIZATION AND MITIGATION TABLES FOR BOEING 737 VERTICAL FIN CASE STUDY

**Tables begin on next page due to landscape format.

Team Members: N/A Example Study

Name of Part to be Outsourced: Boeing 737 Vertical Fin

Name of Considered Supplier: Korea Aerospace Industries

PRIORIZATION TABLE

Issues (Controllable, Uncontrollable)	Risks (based on issues)	Causes of Risk	Effects of Risk	Severity (S)	Occurrence (O)	Detection (D)	RPN
Techology Clockspeed	Better Fabrication Technology Emerges	competing companies have better R&D	competitors are able to steal market	9	1	2	18
Product/Process Architecture	1.KAI does not Produce Correct Parts	manufacturing errors, has wrong design specifications	part is unable to be used until KAI is able to produce correct parts	10	2	5	100
	2. KAI Unable to Handle Complexity	does not have experience with this type of product, machines are old/outdated	part is unable to be manufactured until KAI can handle the complexity	8	2	2	32
Supply Base Characteristics	1. KAI Does Not Have the Capabilities to Produce	similar to above, machines outdated, plant space is limited	part unable to be manufactured until KAI fixes capabilities	10	1	1	10

Team Members: N/A Example Study

Name of Part to be Outsourced: Boeing 737 Vertical Fin

Name of Considered Supplier: Korea Aerospace Industries

PRIORIZATION TABLE

Issues (Controllable, Uncontrollable)	Risks (based on issues)	Causes of Risk	Effects of Risk	Severity (S)	Occurrence (O)	Detection (D)	RPN
	2. KAI's Downstream Supply Base Fails	downstream suppliers fail due to any number of controllable or uncontrollable forces,	KAI does not receive supplies it needs, so cannot produce part that BCA needs	7	4	9	252
Enterprise Characteristics	Competitive Pricing for Product Makes Manufacturing Unaffordable	competition is abundant and drives cost down	manufacturing then becomes too expensive with KAI	6	1	3	18
Customer Value	Customers Do Not Want Outsourced Parts	customers believe outsourced parts have less quality and reliability	demand for product decreases, lose customer loyalty	5	4	2	40
Exogeneous Forces	Korea Shuts Production Down	political factors (overthrow, etc.)	part unable to be manufactured until situation is cleared	10	1	1	10

Team Members: N/A Example Study

Name of Part to be Outsourced: Boeing 737 Vertical Fin

Name of Considered Supplier: Korea Aerospace Industries

PRIORIZATION TABLE

Issues (Controllable, Uncontrollable)	Risks (based on issues)	Causes of Risk	Effects of Risk	Severity (S)	Occurrence (O)	Detection (D)	RPN
Demand Forecast Accuracy	KAI Cannot Meet Demand for Product	production capabilites are slow, old/unreliable machines	BCA will continually be behind on meeting customer demand	7	2	4	56
Velocity	KAI Production Time Increases	like above, production capabilities are slow, old/unreliable machines	BCA will be behind in their aircraft production until KAI production is back on schedule	3	7	4	84
Quality	Batch of Parts Does Not Meet Design	manufacturing errors	batch is discarded, go into reserve fins if necessary	4	8	2	64
Delivery	KAI Fails to Deliver On Time	production time increased	deplete backup fins, plane production slowed	5	6	3	90

Team Members: N/A Example Study

Name of Part to be Outsourced: Boeing 737 Vertical Fin

Name of Considered Supplier: Korea Aerospace Industries

PRIORIZATION TABLE

Issues (Controllable, Uncontrollable)	Risks (based on issues)	Causes of Risk	Effects of Risk	Severity (S)	Occurrence (O)	Detection (D)	RPN
Capacity	KAI Does Not Have the Resources to Produce	old machines, poor design, people are not available	part unable to be manufactured until resources are procured	8	1	1	8
Production Cost per Unit							
Transportation/Logistics Cost							
Investment Cost							
Supplier Management Cost	Costs Increase Quickly	number of external factors, not necessarily just one, failures discussed above are costly to fix	budget is not accurate unless it can be fixed quickly	4	8	2	64
Tax Impact	New Tariff Raised on Imported Goods	political factors	budget is not accurate, but can be fixed relatively quickly	3	5	1	15

Team Members: N/A Example Study

Name of Part to be Outsourced: Boeing 737 Vertical Fin

Name of Considered Supplier: Korea Aerospace Industries

PRIORIZATION TABLE

Issues (Controllable, Uncontrollable)	Risks (based on issues)	Causes of Risk	Effects of Risk	Severity (S)	Occurrence (O)	Detection (D)	RPN
Supply/Dependency Risk	1. KAI Deliberately Underperforms	moral factors, incentives to cheat (money, peer pressure, etc.)	BCA might not realize initially, slowly effects total production time	4	3	7	84
	2. KAI Goes Bankrupt	unable to manage money, KAI's suppliers fail	BCA needs to scramble to find new supplier	10	2	10	200
Enterprise System Breakdown	Intellectual Property is Stolen	outside group offers KAI money for BCA's design	BCA's design is compromised, competitive advantage is taken away	10	1	10	100
Uncontrollable Risks	Oil Prices Increase	external factors (war, global economy, etc.)	budget is not accurate, effects shipping costs	4	10	2	80

Team Members: N/A Example Study
Name of Part to be Outsourced: Boeing 737 Vertical Fin
Name of Considered Supplier: Korea Aerospace Industries
Page 1 of 2

MITIGATION TABLE

Prioritized List	Plan of Action (without considering resources)	Feasibility of Plan of Action
(252) KAI's Downstream Supply Base Fails	send employees to KAI to help, control further downstream	yes, no
(200) KAI Goes Bankrupt	find other suppliers	yes, but harder
(100) KAI does not Produce Correct Parts	provide support to KAI to get back on track, find other supplier	yes, yes but hard
(100) Intellectual Property is Stolen	lawsuit, try to regain IP	yes, probably no
(90) KAI Fails to Deliver On Time	go to back up supplies, provide support to KAI to get back on track	yes, yes
(84) KAI Production Time Increases	provide support to KAI to develop faster production plan	yes
(84)KAI Deliberately Underperforms	enforce penalties, find other suppliers	yes, yes but hard
(80) Oil Prices Increase	rebudget from other areas	yes
(64) Costs Increase Quickly	rebudget from other areas	yes
(64) Batch of Parts Does Not Meet Design	go to back up supplies, provide support to KAI to get back on track	yes, yes
(56) KAI Cannot Meet Demand for Product	send employees to diagnose problem, work with KAI to develop faster production time, find new supplier	yes, yes but hard
(40) Customers Do Not Want Outsourced Parts	use more domestic parts in other areas, make people more aware of quality	yes but may not be willing, yes
(32) KAI Unable to Handle Complexity	send employees to provide support with manufacturing, find other supplier	yes, yes but hard
(18) Better Fabrication Technology Emerges	develop new technology in house	yes but difficult
(18)Competitive Pricing for Product Makes Manufacturing Unaffordable	redesign manufacturing	yes but should fall on KAI

Team Members: N/A Example Study

Name of Part to be Outsourced: Boeing 737 Vertical Fin

Name of Considered Supplier: Korea Aerospace Industries

MITIGATION TABLE

Prioritized List	Plan of Action (without considering resources)	Feasibility of Plan of Action
(15) New Tariff Raised on Imported Goods	rebudget from other areas	yes
(10) KAI Does Not Have the Capabilities to Produce	find other suppliers	yes but hard
(10) Korea Shuts Production Down	work with country's government to a point, then find other suppliers	yes but hard (both)
(8) KAI Does Not Have the Resources to Produce	help KAI procure resources (money, connections, etc.), find other supplier	yes but probably unwilling, yes but hard