Optimizing the Supply Chain Design for Sourcing and Supply of Critical Materials

by

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Abstract

A significant supply disruption occurred in 2019 from a packaging component supply shortage, impacting sites and products globally across the AstraZeneca (AZ) network. Supply to patients continued; however, a team was created to then manage the supply of critical materials. These materials are typically single sourced and used commonly across multiple AZ sites and brands signifying that a disruption could impact patient supply and AZ revenue across multiple brands. This thesis focuses on providing a framework for evaluating risk and vulnerabilities in the sourcing of the critical material supply chain design with a focus on primary packaging. With this methodology, users can identify opportunities for developing a more flexible and resilient supply chain.

After analyzing a subset of Stock-Keeping Units (SKUs). and segmenting them based on complexity and criticality, we applied the Time-to-Survive (TTS) and Time-to-Recover (TTR) framework to identify high risk materials and supply nodes. TTR is the time for a supply chain to recover after a disruption at a particular node. TTS is the time the supply chain can continue operations based on demand and inventory levels. A TTS/TTR tool was created to index and sort the high risk materials supplemented by a process for interpreting the outputs and mitigations. After identifying the areas of risk, we also proposed a method for analyzing the trade-off between dual-sourcing versus holding increased inventory by evaluating the potential return on assets (ROA) ratio.

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Chapter 1

Background and Introduction

"Our manufacturing and supply function has continued to support our growth by delivering every new launch on time and in full, and sustaining strong customer service and product lead-time reductions."

AZ Financial Report 2020, pg. 64

1.1 Project Objectives

This thesis focuses on providing a methodology for evaluating risk and vulnerabilities in the sourcing and supply of critical materials with a focus on primary packaging (foils) within the EU and Asia. Critical materials are defined in this context as a material that can be single-sourced and, if the supply is disrupted, can impact AZ distribution and revenue. To be considered a critical material, the revenue impact must be above a set threshold. With this methodology, users can then identify opportunities for developing a more flexible and resilient supply chain.

1.2 Project Approach

The approach used in this project is shown in Table 1.1 and is divided into three phases. During the data collection phase, key variables such as lead time, demand, and inventory levels for selected SKUs in Europe and Asia. These SKUs represent about 80% of the total foils market for AZ were collected from sites. Time-to-recover (TTR) estimates were discussed with suppliers. After understanding the scope of the supply chain, the Time-to-Survive (TTS) and TTR framework was applied. Chapter 3 provides background on the TTR/TTS framework.

A supply chain scoring model to visualize metrics such as resiliency and cost as the foils portfolio changes will augment the TTS output. Based on the results, optimization strategies like inventory redistribution and trade-offs between dual sourcing versus increased inventory were developed. The baseline mapping model and supply chain scoring is Excel-based and built with input from the parallel ongoing digitization efforts, material standardization, and quality testing projects allowing for future integration.

Although this project is based on real data, the information used in this thesis is redacted and do not reflect actual operations.

1.2.1 Not in Scope

Not covered in this thesis include items such as material harmonization, equipment harmonization, site efficiency metrics, and waste reduction (e.g. pursuant of sustainability goals). However, these topics will be mentioned briefly as part of the analysis in Chapter 5 and future work in Chapter 8.

Phase	Approach	Key Outputs
Data Collection	Baseline mapping of the existing supply chain including supplier raw materials to bulk material (prior to product packing) at AZ internal sites containing metrics such as lead time, time to recover, and inventory at specific nodes in the network.	Create additional visibility within the foils and films portfolio enabling stakeholders to make more data-driven decisions related to the supply chain design.
Data Analysis	Structuring data and creating a pre-processing tool to aggregate data from multiple sources	Understand the complexity in the data, identify data gaps, removal of incomplete data, and identify opportunities within master data project.
Tool Development	Supply chain scoring model for the key pillars such as risk, complexity, resiliency, sustainability, and cost effectiveness showcasing trade-offs between different strategies.	This model forms the basis for business case recommendations by also allowing for sensitivity studies with levers to fluctuate demand.

Table 1.1: Project Approach and Deliverables

1.3 Thesis Overview

This thesis is organized in chapters to guide the reader through an overview of the current upstream supply chain overview for sourcing and supply of select raw materials, market dynamics, and available risk mitigation measures before discussing the proposed supply chain evaluation and risk identification methodology using time-to-survive/time-to-recover framework.

The target audience has some background knowledge in supply chain design and traditional inventory management. For readers that would like details on the implementation of the models, we suggest focusing on Chapter 4. For readers wanting to understand the insights and implications of the model applications, refer to Chapter 5. The content covered in each chapter is briefly described here for convenience.

Chapter 1 provides context to the project objectives, scope, and approach. **Chapter 2** introduces AstraZeneca (AZ) as well as a high-level overview of their sourcing and supply strategy for select materials. This chapter introduces AZ's supply chain for packaging materials as well as areas that impact supply chain design such as market dynamics and improvement projects. These areas are introduced to provide context around why they are important to consider when evaluating risk and resiliency of a supply chain. The chapter ends with an overview of current risk mitigation processes to augment the TTR/TTS framework developed in this thesis.

In **Chapter 3** we review the existing literature on topics pertaining to supply chain redesign frameworks and methods for creating a more resilient and flexible supply chain. Here we delve deeper into the concepts of "Time-to-Survive" and "Time-to-Recover" applied to a biopharma company along with mitigation strategies to minimize supply chain risk. Lastly, we provide a survey of industrial applications of supply chain redesign strategies. This chapter sets the background for the TTR/TTS framework described in Chapter 4.

Chapter 4 discusses the methodology used to analyze the existing supply chain, implement a time-to-survive model, and investigate mitigation options. **Chapter 5** uses this model to provide an overview of the results for selected SKUs. **Chapter 6** demonstrates a case study for interpreting the model and mitigation strategies to reduce identified risks.

In **Chapter 7** we provide recommendations based on the insights garnered from Chapter 5 and Chapter 6. Finally, in **Chapter 8** we offer recommendations for application and extension of this work to other materials as well as suggestions for future opportunities to investigate within the sourcing and supply landscape to continually improve supply chain performance in this changing environment post the COVID-19 pandemic.

Chapter 2

Company Overview

"We push the boundaries of science
to deliver life-changing medicines."

AstraZeneca Financial Report 2020

AstraZeneca (AZ) is a global pharmaceutical company active in over 100 countries with headquarters in the United Kingdom. AZ is the product of a merger between Astra and Zeneca in 1999. As shown in Figure 2-1, AZ works within the entire life-cycle of a medicine from research and development, to manufacturing and supply, and to global commercialization of primary/specialty care medicines [9].

These life changing medicines focus on three main therapy areas:

- Oncology
- Cardiovascular, Renal and Metabolism
- Respiratory Diseases

AZ has a range of capabilities such as small molecules, biologics, and devices. As stated in AZ's financial reports, key areas that are being evaluated within AZ are sustainability strategies enabling reduction in scope 1 and 2 greenhouse emission and increased access to healthcare with over 10 million people "reached through patient assistant programs." Furthermore, with the Operations 2025 plan, the focus will shift

Figure 2-1: The lifecycle of medicine at AstraZeneca [9]

on "scaling [AZ's] capabilities to support the continued growth of [AZ's] portfolio, combined with leveraging the benefits of new manufacturing technology and digital innovation across [AZ's] end-to-end supply chains"[9].

After the start of the COVID-19 pandemic there were several items in the supply chain suggested to be reviewed to understand if improvements could be made including within the future of R&D, digital transformations, and supply chain. Nevertheless, AZ was still ranked as number 13 in the Gartner Supply Chain Top 25 for 2021 with GlaxoSmithKine coming in at number 8 and Novartis at number 11 [15]. Even with the challenges placed by the pandemic, no signficant disruptions to the supply of medicines were incurred [9].

The following sections provide an overview of certain aspects of AZ's supply chain related to the sourcing of foils as well as a brief summary of ongoing market trends that could impact supply chain performance. Finally, we'll close this chapter with an overview of some of the existing risk mitigations processes and how the scope of this thesis supplements these existing processes.

2.1 Current Supply Chain Overview

Within AZ an organization called the Global External Sourcing (GES) governs the sourcing and supply of materials such as APIs (Active Pharmaceutical Ingredients), formulation and device sourcing as well as packaging material and PC&E (Process Chemicals and Excipients). The role of GES is to work with external suppliers, deliver new product supply chains, and optimize existing supply chains.

The following sections provide a high-level overview of the existing supply chain for critical materials with the focus on primary packaging. We further examine how the market impacts the sourcing and supply of these materials as well as how ongoing initiatives can affect supply chain operations. The chapter ends with an overview of the current risk mitigation strategies to provide a foundation to build the TTR/TTS framework that will be discussed in Chapter 4.

2.1.1 Defining Critical Materials

Within the medical device and pharmaceutical industry, many source materials are single-sourced, at times due to regulatory constraints. The Critical Materials Team (CMT) within GES was formed to manage the suppliers that provided critical materials such as PC&E, packaging, and Bio Direct Materials. These materials are critical to manufacture but were typically overlooked in the past as they are low spend. This approach is different from managing API, device, and F&P as these items are equally important, however, already have a high spend strategic supplier relationship focus. This criticality designation is similar to the automobile industry in which certain low spend materials (such as a circuit board) were overlooked; however, had high impact when there was a disruption [42].

The criticality basis was defined on several factors such as how how many AZ sites were being supplied from that site, the importance of the material to AZ, and the financial implications if that material was lost. These materials are considered low spend yet high impact as they are common across multiple sites.

The scope of this project is in Primary Packaging which is further described in the next section, 2.1.2.

2.1.2 Sites and Material Used

This thesis focuses on primary packaging – specifically foils used for items like blister packs. Europe primarily uses blister packs whereas the United States uses bottles; therefore, the focus for this project was the European region as well as Asia to cover 80% of the foil use. Primary packaging is material that provides protection against moisture, oxygen, or light. Since the primary packaging is in contact with the product, this element of the packaging is part of the regulatory submission meaning that if any changes are made whether on the material composition, source of materials, or supplier – the changes may require extensive technical and regulatory work. Secondary and tertiary packaging is also quite highly regulated but not to the same extent.

The process for making the foil can be shown in Figure 2-2. The foils themselves vary in properties ranging from coldform, lidding foils, laminated foils, and aluminum bags. These foils can have different layers depending on the properties that are required. Inventory can be held at various locations in the process and in different forms (e.g. raw material versus finished product). The scope of this project does not evaluate which part of the process is the most economical or flexible.

Figure 2-2: Example of foil making process. In this example there are a few key steps such a rolling the material, applying lacquer or paint depending on the specifications, and then slitting the material to size to ultimately be distributed to the buyer's site.

An example of the supply chain evaluated for this project is shown in 2-3 with a simplified process flow. In this example, the supply for materials 1 and 2 are single-sourced, whereas material 3 has two sources. Details of the supply chain evaluation are found in Chapter 4.

AZ's sourcing strategy has been generally single-sourced; however, there are a

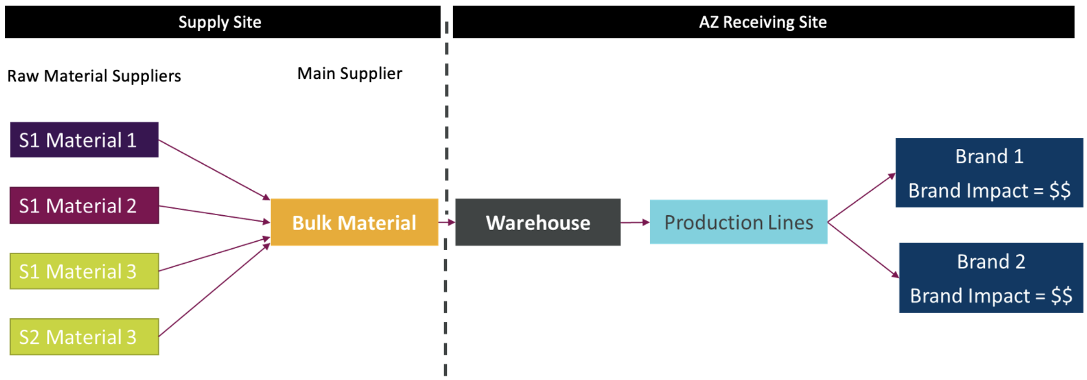


Figure 2-3: Example supply chain distribution from sourcing to production. This network shows how the same material can be sent to multiple AZ sites and brands. A disruption to the creation and transportation of this bulk material can thus impact multiple geographies and markets.

handful of strategic suppliers and dual sourcing. Leverage with existing suppliers can be difficult if based on the amount of volume supplied as AZ has a smaller volume compared to consumer good companies.

Some of the items that impact the complexity of a supply chain include the number of raw material suppliers, the number of supplier sites, type of materials being produced, as well as additional specifications. Each additional specification (such as the foil width, reel weight, shiny versus dull side) has an impact on the upstream supply chain since most products can be created from the same master reel.

The items considered are illustrated in Figure 2-4. This figure was inspired by an article from the Boston Consulting Group [35]. They recently wrote a paper on investigating the number of unique supply chain nodes within select biopharma and medtech companies. A node refers to the items such as the number of suppliers, production methods, manufacturing sites, dosages, markets, customers, etc. They found that within biopharma there can be 7,000 unique nodes; within medtech, 11,000. It's estimated that AstraZeneca has about 1,000 unique nodes for the foils and films supply chain when considering the number of raw material suppliers along with variation in complexity of the final product (e.g. width, artwork, shiny versus dull side, etc).

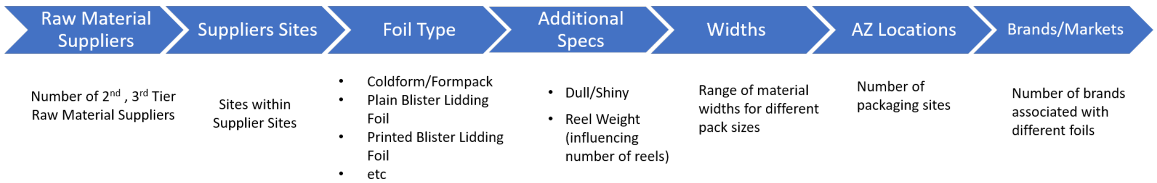


Figure 2-4: Illustration of items impacting supply chain complexity

2.1.3 Market Dynamics

These past few years have been challenging with the onset of the Covid-19 pandemic. Healthcare systems and supply chains have been impacted with changing demands, increases in lead times, and material price increases. Furthermore, within the UK, there is the impact of Brexit on business which resulted in some stock building due to the uncertainty in border arrangements and potential delays [9].

A report from McKinsey in 2020 [7] states that based on the current climate, several items require reevaluation by companies such as creating transparency or visibility in the supply chain, understanding the risks associated with each component, and understanding the inventory that's available to maintain production and flexibility among the sites.

Foils are a commodity where market dynamics primarily affect the tier 2 and/or tier 3 suppliers. Further exacerbating the material challenges is the aluminum shortage. Although China accounts for almost 60% of the global supply, energy crises and supply chain disruptions of magnesium in China are impacting aluminium production [46]. Prices of aluminum are approaching a 13-year high[14]. Analyzing the lead times from suppliers, the average quoted lead time is approximately 7 weeks depending on the product type (e.g. printed versus unprinted lidding foil, coldform, etc). This lead time fluctuates based on the market conditions varying ±4.5 weeks. Recently, these lead times are extended even longer. Some companies are offering or exploring a vertically integrated supply chain such as Bachem[3] and Corden Pharma [2] to mitigate upstream sourcing constraints.

2.2 Ongoing initiatives affecting a supply chain redesign

In addition to market dynamics, there are several ongoing initiatives listed below that have implications on the supply chain design. These activities relate to the sustainability targets and supply chain flexibility with respect to the sourcing and supply of materials. These initiatives are not isolated solely to AZ but across the pharmaceutical industry and span a longer time-horizon (5-10 years) to implement.

1. **Sustainability** – There are ongoing projects to develop more sustainable materials and reduce waste. AZ has produced a sustainability report [1] outlining some of the key targets and initiatives they are undertaking over the next 5-10 years. Novartis has disclosed that they are "aiming to eliminate PVC from all secondary and tertiary packaging by 2025" [28]. Elimination of PVC is critical as PVC has been identified as having toxic emissions when incinerated and potentially implementing polypropylene (PP) blister materials. The material change is advantageous as it allows for a reduction in size of the blister packs reducing material consumption. However, in the case where materials become specialized, there could be sourcing issues as the material may become unique to particular suppliers as a market differentiator.

2. **Waste Reduction and Circular Design** – Waste can be generated on the production lines or with large MOQs (minimum order quantities). In production lines, as more varieties of widths are requested, there's an increased upstream complexity to keep waste production low. For example, when specifying multiple foil widths, suppliers may generate various size mother reels to minimize the amount of waste that is generated from the slitting process. The take-away from these efforts is to understand that each additional lever for variety in SKUs increases not only downstream complexity but upstream complexity as well.

3. **Asset Standardization** – In parallel to material sourcing, another aspect of the supply chain evaluation is equipment design. As equipment reaches its end-

of-life, equipment consolidation and standardization of equipment specifications allow for more flexibility among the different sites.

The items listed above were considered while evaluating the supply chain risk and mitigation for the foils sourcing and supply.

2.3 Current Risk Mitigation Processes

Supply chains can have several risks including man-made disasters, logistics challenges, and market fluctuations for raw materials as seen by the challenges within the aluminum space as discussed in Section 2.1.3. Business continuity plans are developed to mitigate the effects of these disruptions. Furthermore, the supply chains are periodically evaluated for opportunities such as dual or multiple sourcing of suppliers.

There are several processes that are used used in the supply chain such as S&OP (Sales and Operations Planning) meetings, supply chain risk assessments, financial assessments, supplier organizational maturity, etc. to identify risk. As new products are introduced, processes such as SCAIR (Supply Chain Analysis of Interruption Risks - an AZ specific process) are utilized to understand where there may be a risk in the supply chain.

To continually monitor and reduce risk, some of the actions taken include strategically assessing areas where dual sourcing may be needed, increasing "safety stock" to account for increased variability in lead times, and continuously engaging suppliers during S&OP Meetings. Historically for AZ the focus for managing risk has been on high spend materials such as API, device, and F&P; however, the commodity items, like packaging, are those items that have typically been overlooked yet have the highest impact across multiple brands. Therefore, this thesis is aptly timed as there is a need for increased visibility and understanding of what SKUs and associated sites are impacted. Providing a framework for understanding these high risk nodes enables users to define strategies for mitigating the at-risk SKUs, as well as generate the conversation around these SKUs.

Chapter 3

Literature Review

> "Two years into the pandemic, the global supply chain continues to sputter and break down. Each day comes news of choked ports, out-of-place shipping containers, record freight rates, and other problems that cause disruption and defy easy answer."
>
> *World Economic Forum Davos 2022 [5]*

Covid-19 accelerated an unprecedented global supply chain disruption causing many businesses to re-evaluate their supply chains [6]. The supply chain has been disrupted in contrasting ways whether from the supply of Personal Protective Equipment (PPE) such as N95 masks [13] or the unexpected increase in demand for lumber causing prices to increase by 300% [44] as the cost for wooden pallets doubled [4]. However, according to a recent study from McKinsey, these disruptions are to become more frequent and are estimated to occur every 3.7 years with an average 45% loss in one year's EBITDA due to the disruption [27]. Pharmaceutical companies were found to be less impacted (29%) due to the high inventory levels providing a level of protection and priority given to life saving medicines.

However, a looming question is how should a company go about redesigning a supply chain given the level of uncertainty in both the supply and demand side of the supply chain given that "supply chain systems and processes employed by companies are designed for normal operations, not for once-in-a-lifetime disruption and recovery" [39]? Simchi-Levi further emphasized in "Three Scenarios to Guide your Global Supply Chain Recovery" that companies need to do three things to begin to answer the aforementioned question with the first being able to identify and understand the areas of risks in the supply chain not just with the large suppliers or suppliers that are directly upstream but also the sub-suppliers. A report from McKinsey found that "only 2% of companies have visibility into their supply chain beyond the second tier"[7]. The second and third items then follow to include effective resource allocation and investing in mitigation strategies.

Pharmaceutical environments have additional complications during supply chain disruptions due to the regulatory nature. An example posed by Lücker, et al. [26] was regarding a fire or biological contamination: the site has to then undergo regulatory approval post-event which takes time. Because of this time requirement and also the need to maintain high service levels coupled with high product margins, maintaining additional inventory is the typical response. Holding this additional inventory seems reasonable when viewing the problem from a newsvendor model lens of calculating the cost of overage (the cost of having too much inventory) versus the cost of underage (cost of stocking out) [31].

The following sections in this chapter review factors influencing supply chain design, introduce the Time-to-Survive/Time-to-Recover framework, and summarize literature illustrating the opportunities to evaluate the trade-off between dual sourcing and other risk mitigation strategies.

3.1 Supply Chain Design with focus on Pharmaceutical Industries

In the *Key Sources of Operational Inefficiency in the Pharmaceutical Supply Chain*, Paplexi and Bamford [33] noted that "healthcare organizations are facing difficulties in undertaking improvement initiatives...compared with industrial and retail sectors." They elaborated that these difficulties may be related to the high level of service that is required in the healthcare sector where "the possibility of failure is not acceptable."[30]. Paplexi further summarized some of the key issues that affect healthcare performance (refer to Table 2 in their paper) which included items such as:

1. Organizational structure causing fragmentation in operations and applying practices.

2. Regulatory environments affecting adoption of improvement initiatives.

3. "Cultural Inertia" with "difficulties in changing practices, core strengths or culture due to fear of failure or fear of the unknown" or "improvement fatigue due to some elements such as the constant treadmill of government bodies changing."

4. Cost of making changes could be constraining as there can be long development cycles to make changes.

5. Inherent supply chain complexity because of "the impact on patient's health requiring an adequate and accurate supply chain."

Supply chain design features several key characteristics or levers that can be evaluated. This includes capacity redundancy [20], flexibility [36], procurement contracts [34], and risk management practices. This is not an exhaustive list, but exemplifies the fact that there are several elements of a supply chain that can assist companies on attaining a resilient, flexible supply chain. These concepts will be explored further in Chapter 4.

3.1.1 Creating a more resilient, flexible supply chain

When evaluating supply chains, segmenting materials, creating visibility, and understanding forecast variability are a few areas to start investigating. Supply chain segmentation is typically the first step to understanding how to design a supply chain. For example, in 1983, Kraljic [21] developed a purchasing strategy weighing on two factors fitting in a 2x2 matrix:

1. "The strategic importance of purchasing in terms of the value added by product line, the percentage of raw materials in total costs and their impact on profitability..."

2. "The complexity of the supply market gauged by supply scarcity, pace of technology, and/or materials substitution, entry barriers, logistics cost or complexity..."

The Kraljic matrix from his 1983 Harvard Business [21] Review article is excerpted below in Figure 3-1:

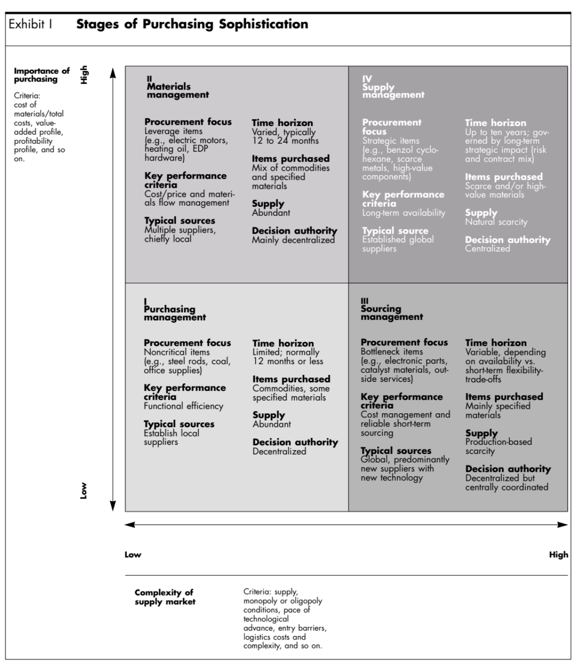


Figure 3-1: Excerpt of the Kraljic Matrix for procurement strategies

Variations of these 2x2 matrices include segmenting items between the level of demand uncertainty and lead time with an overlay of where these items would fit on a push/pull strategy [40]. This figure can be adjusted as referenced below in Figure 3-2 regarding managing different risk categories.

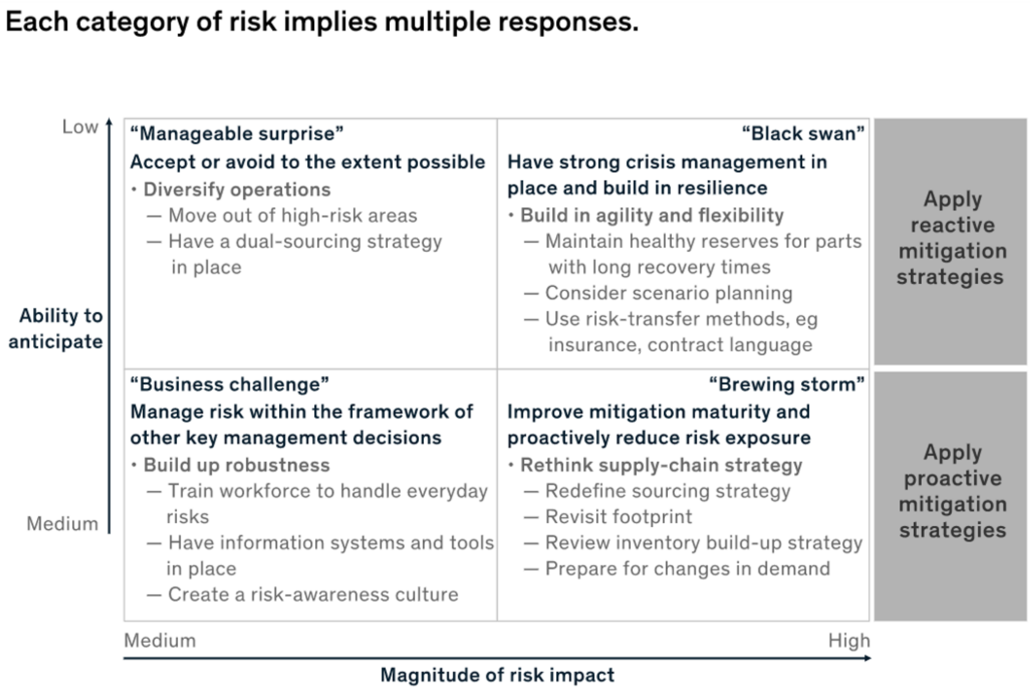


Figure 3-2: Table from McKinsey report on supply chain risk management [7]

Although many papers refer to consumer goods, these approaches can be applied to the pharmaceutical industry to understand the push-pull boundary. As with consumer goods, a push strategy can be applied for areas of low uncertainty/long lead times and a pull strategy for areas of high uncertainty/short lead times [40]. Chapter 4 explores how to segment different goods to decide what management approach to take as well as inventory methodologies to apply.

Besides material segmentation, industries have approached supply chain resiliency and flexibility with sourcing strategies and tools to enable risk identification. Toyota has developed a flexible supply chain by enabling each site to have the capability of producing all types of products. They have sourced suppliers locally to enable just-in-time delivery [32]. Cisco, a telecommunications and networking company, has developed a "resiliency scorecard that includes four categories – manufacturing resiliency, supplier resiliency, component resiliency, and test equipment resiliency" [40] to maintain visibility.

To further supplement supply chain visibility, understanding forecasting accuracy and demand variability can help dictate whether to apply a push or pull strategy. An article in Nature from 2013 [10] noted the inherent difficulty in pharmaceutical forecasting given "the uncertainty of drug development, the unpredictable actions of competitors" and regulatory/clinical aspects. Cha et al. found that "more than 60% of the consensus forecasts...were either over or under by more than 40% of the actual peak revenues" and this pattern continued even years after the release of the drug (albeit at a slight increase in forecast accuracy). Although this thesis does not cover forecasting accuracy, demand forecast is a key variable in the TTR/TTS model described in detail in Chapter 4 and can influence results.

In practice an automotive company attempted to invest in better forecasting methods; however, they found that these forecasts didn't affect the inventory levels at the sites. What they found was that "at the heart of the inventory crisis was not poor forecast accuracy but rather poor choice of where the inventory is stored or positioned in the supply chain. Repositioning stock led to a 30% reduction in inventory levels while maintaining the same level of service and response time" [40] which leads to sections 3.1.2 and 3.2 discussing visibility in inventory.

3.1.2 Risk Assessments and Mitigation Frameworks

Many companies have existing risk assessments and mitigation frameworks as exemplified in Chapter 2; however, "only a small fraction of them actively and effectively manage risk" [40]. These risk assessments can occur at varying points in drug development, for example, when introducing a new product to a site, or adding a new piece of equipment, signing with a new supplier. Within AZ, risk assessment and management is also an activity that happens continually in commerical supply as well. Nevertheless, many companies focus their time and energy on areas of "obvious high risk" where "total spend and performance impact are both high" or the supply is single-sourced. Many of these risk assessment approaches focus on the resulting product versus the material that goes into making the product. According to Lücker, et al. [26] many companies try to increase inventory to manage these supply chain disruptions; however, this inventory should not be confused with operational safety stock (e.g. stock to handle demand variability).

These traditional risk assessments may not identify low-spend items (for example, in the automotive industry, this could be an O-ring which is a low material cost), however, if supply is disrupted production will stop [42]) or the raw materials that go into a key component for production (for example, in the pharmaceutical industry this could be the aluminum that goes into the blister packs, vials, or bottle caps). The medical device and pharmaceutical industry have an added layer of complexity as materials are typically single-sourced. This is where re-defining how a supply chain is evaluated becomes a necessary endeavor. In Section 3.2 we introduce the Time-to-Survive and Time-to-Recover overview as an alternative way of viewing a supply chain from a risk, resiliency, and flexibility perspective.

3.2 Time-to-Survive and Time-to-Recover

To mitigate some of the challenges posed in Section 3.1.2, the time-to-survive/time-to-recover framework is posed to be applied in the sourcing and supply of raw materials in the pharmaceutical supply chain. As suggested in Golany's thesis for a telecom company [17], one of the "challenges not addressed well by classical (probability and impact) risk models is the ability to handle rare events which are unlikely to happen, but have a potentially drastic impact." The model used in this paper is described further in a paper by Simchi-Levi [43]. One of the first applications of using TTR and TTS was with the Ford motor company as summarized in a review article also by Simchi-Levi [42]. The benefit of this approach is three-fold:

1. Increase supply chain visibility and hidden risk areas.

2. Provide a more quantitative approach to making inventory and sourcing decisions.

3. Create discussion points within the organization and with suppliers.

The model has two key terms: time-to-survive and time-to-recover. Time-to-Recover (TTR) is the time it would take a node in the supply chain to recover after a disruption. A disruption could occur at any point in the supply chain and include an event such as a logistics issue, a fire at a warehouse, or raw material constraints. Time-to-Survive (TTS) is the amount of time the site can continue production before stocking out. TTR and TTS can be applied not just for identifying areas of risk but also areas where excess inventory was developed over time that would ultimately have minimal impact on the supply chain during a disruption as quoted below:

> "When the TTS is just a few days, these are critical suppliers and a careful review of their TTR is necessary. By contrast, there were other suppliers with a very long TTS (greater than 50 weeks). This is an opportunity to cut costs since, in many cases, a long TTS is achieved by building a lot of strategic inventory. Cutting inventory by 50%, for example, would have very little impact on its ability to respond to a disruption" [41]

.

3.3 Trade-offs from Single versus Multi-Sourcing

After identifying materials or nodes at risk, the next step is determining what strategy to pursue. The pharmaceutical and medical device industry has a history of applying single sourcing strategies where single sourcing is defined here as having all material come from a single supplier site. It is important to note that this definition only applies at the first tier of the supply chain. Delving deeper into the many tiers of the supply chain, there are usually cases where the supplier may be double or triple sourced for certain materials. Alternatively, there may also be cases where a company thinks they are dual sourced; however, somewhere in the upstream supply chain, two different suppliers are using the same source for a material. Therefore, if that node in the supply chain were to be disrupted, there would be minimal protection from dual sourcing as both suppliers use the same source. Therefore, before doing any analysis, having a relationship with suppliers where dialogue can occur to discuss weak nodes is critical; otherwise, the investment in dual sourcing may not minimize the risk identified as anticipated.

A few of the advantages and disadvantages to single versus multiple sourcing are quoted below:

> "With single sourcing there are several benefits such as production cost reductions due to economies of scale and learning effects, lower inventories and better quality due to just-in-time and continuous improvement initiatives, stronger relationships, and reduced administrative costs....The flip side to single sourcing is that it dramatically increases disruption risks. Multiple sourcing can help reduce a firm's exposure to various types of risk, e.g. shortages, strikes, natural disasters, technological uncertainty and can help maintain competitiveness between suppliers" − Namdar, Jafar, et al. [29]

.

This results in the question of how to decide whether to pursue single, dual sourcing, or another option such as spot purchasing. Several papers have recently been published to evaluate this strategic opportunity. Namdar, Jafar et al. created a model "incorporating the effects of collaboration using supplier recovery rate and of visibility using warning against disruption." Costantino, et al. [12] emphasized the need for an evaluative approach to choosing souring options proposing the "Real Options approach." This model considers sourcing options in both stable and risky environments creating a probability that a supplier would default along with the costs associated with including a new supplier. Li & Li [23] experimented with dual sourcing from a minimization of loss-aversion to find the optimal orders from two suppliers.

Li et al. [22] evaluated deciding between dual sourcing or single sourcing with an emergency option. In this scenario, "the buying firm procures products from a single supplier, and simultaneously purchases an option of buying up to a certain quantity...who guarantees the availability of the product." So when there is a disruption event, the site has the opportunity to execute the option or not at the agreed upon option price. Additionally, Wang et al. [45] explored modeling the differences between dual sourcing or internal process improvements. The results from these papers varied depending on several factors such as supplier relationships, products, costs, level of risk acceptance, etc; therefore, no general concepts are provided.

This paper follows the methodology used in Huang et al. [19] using Return-on-Assets as a measurement to assist in sourcing strategy decisions.

Chapter 4

Methodology

> "Information is the oil of the 21st century, and analytics is the combustion engine."
>
> *Peter Sondergaard, Senior VP, Gartner Research*

4.1 Data Collection and Challenges Discussion

Before delving into the project details, there are some data collection challenges that are actively being worked on but were not available for this project. For example, there are diverse data management systems such as ERP and APO. Most of the raw material codes are not included in APO; therefore, existing inventory management tools cannot be utilized fully for the critical materials team. Currently data is extracted manually from each of the individual sites. Additionally, the raw material connection to the final product was not readily available for the scope of this project.

Furthermore, within the supply chain visibility landscape, global real-time visibility of the supply chain does not exist and therefore can be difficult to understand market impacts on production. Nevertheless, this thesis lays the groundwork for future system integration.

The data collection was manually aggregated by various groups in AZ. This model is contingent upon having continuous and reliable data to update with. A model refresh should be completed as suggested below in Table 4.1[1] in the intermediate term when the data is not connected to the main systems and need manual intervention.

Initiating Event	Refresh Timing
All Inputs	Minimum Annual Refresh
Market Intelligence Reports	Quarterly
Lead Times	Monthly
S&OP Cycle with Supplier	Monthly
Demand or Inventory Changes	Monthly
Time-to-Recover	Minimum Annual Refresh

Table 4.1: Example of TTR/TTS model refresh timing depending on the initiating event

4.2 Defining Supply Chain Values and Metrics

The first step in understanding AZ's supply chain was mapping the base case and defining what are key features we would want to characterize. Therefore, before beginning the evaluation we selected key values, or pillars, that can be associated with a measurable value against change to the current design. Figure 4-1 shows an example of values that were used to define the foils and film supply chain. Definitions and metrics defined in this paper are listed below Figure 4-1. The focus for this thesis is on Flexibility, Resiliency, and Risk Tolerance.

[1] The refresh timing for Time-to-Recover can be set on a similar cadence as the refresh updates for business continuity plans

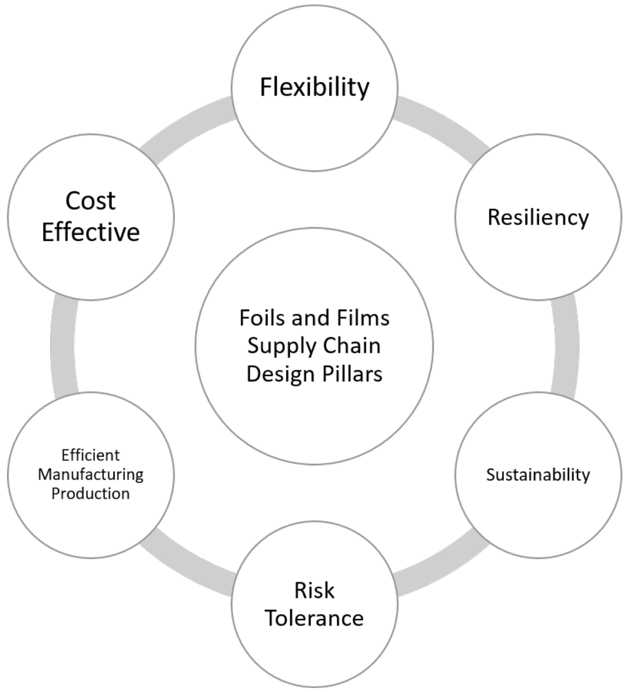


Figure 4-1: Supply Chain Redesign Values Pillar

Pillar	Definition	Metric
Flexibility	The ability to respond to events or production changes	time-to-respond
Resiliency	The ability to return to the former operation with minimal to no interruption in production [37]	(time-to-recover) [11]
Sustainability	responsibly manage material from cradle-to-grave	product sustainability index
Risk Tolerance	Accepted level of risk (e.g. for example, difference between dual and single sourcing)	Risk Score via time-to-recover
Efficient Manufacturing Production	minimize impact on production lines	overall equipment effectiveness
Cost Effective	minimize investment while maintaining or increasing manufacturing productivity	(equipment investments, inventory costs, etc)

Table 4.2: Example of TTR/TTS model refresh timing depending on the initiating event

4.3 Understanding Existing Foils and Films Supply Chain

The scope of work included evaluating two supplier sites within foils and films for a total number of 407 SKUs comprising of 28 brands. The regions evaluated were in the European and Asian regions. Six types of foils were included in the analysis. The films were excluded from the scope.

4.3.1 Nine-Box Segmentation Model of Materials

AZ has its own methodology for segmenting the final product materials; however, this thesis takes the segmentation approach from the materials lens. Initially the materials were segmented following the principles described in Godell's paper on *Enabling supply chain segmentation through demand profiling* [16]. These segmentation principles were based on sales impact, volume, and demand variability to generate Figure 4-2.

The materials were each separated by site. All data was gathered for the year 2020-2021. The following data was used to assess the material segment: demand forecasts, sales data, and demand variability. The segmentation for demand and sales were based on the following grouping segments: 85%, 10% (e.g. 85-95%), and 5% (e.g. 95-100%). Using these three factors, a nine-box segmentation was developed as described below.

Demand data was acquired from each site by understanding their forecasts. One item to note is that this forecast data does not represent the actual orders. The ordering data from the procurement teams at each site was not available. In the future, using the actual purchasing data will provide a more accurate risk profile. The demand for each SKU represented the volume production at each site. Demand was listed from highest to lowest where the materials were then categorized as high demand (volume) material is classified as 1, medium volume as 2, and low volume as 3 based on the aforementioned grouping segments. This same process described above was used for sales forecast to describe the value (i.e. sales impact) of the segmentation process with letters in place of numbers.

For demand variability, the coefficient of variation, $CV = \frac{\sigma}{\mu}$ where σ is the standard deviation of demand and μ is the average demand was calculated for each SKU on an annual basis. Items with a coefficient of variation less than 1 were considered low, between 1-1.4 were considered medium, and greater than 1.4 high. Figure 4-2 offers a proposed segmentation approach for use with the foils SKUs. These segments will become more pertinent when prioritizing materials identified at risk as discussed in Section 4.4.

<table>
<tr><th rowspan="2">Value + Demand</th><th colspan="3">Coefficient of Variation</th></tr>
<tr><th>Low</th><th>Medium</th><th>High</th></tr>
<tr><td>A1</td><td rowspan="6">Use Forecast

Continuous Review Order Policy

Minimize Safety Stock</td><td rowspan="6">Use Forecast

Continuous Review Order Policy

Optimize Inventory based on cost

Evaluate lead times to compensate for infrequent demands</td><td rowspan="6">Continuous Review Order Policy

Optimize Safety Stock based on Service Level

Evaluate lead times to compensate for infrequent demands</td></tr>
<tr><td>A2</td></tr>
<tr><td>A3</td></tr>
<tr><td>B1</td></tr>
<tr><td>B2</td></tr>
<tr><td>B3</td></tr>
<tr><td>C1</td><td colspan="3">Use Economic Order Quantity; keep safety stock</td></tr>
<tr><td>C2</td><td colspan="3" rowspan="2">Use Economic Order Quantity
Periodic Review Order Policy
Minimize Inventory</td></tr>
<tr><td>C3</td></tr>
</table>

Figure 4-2: Example of nine box segmentation output. A, B, C = High Value, Medium Value, Low Value, respectively. 1, 2, 3 = High Volume, Medium Volume, Low Volume, respectively. The nine-box segmentation format and suggested actions used the principles from Godell's paper on supply chain segmentation [16].

4.4 Time-To-Survive Model Development

Time-to-Survive (TTS) and Time-to-Recover (TTR) were chosen as metrics to help analyze the risk in a supply chain metric and provide more visibility. This approach allows for an augmented view on the existing supply chain map as shown in Table 4.3 to respond to shifts in supply and demand. Simulations can be run to prioritize the inventory allocation if there is a market disruption. The following section describes the additional data collection required.

Attribute	Existing Approach	Augmented Approach
Upstream Visibility	Static supply chain mapping of upstream AZ suppliers	Begin conversations with suppliers about quantifying BCP and TTR
Data Sourcing	Manually Extracting Data	Tool integration with databases to minimize manual data processing
Insight Generation	manual data extraction combined with evaluations differing depending on who is doing the analysis	Develop set of principles to use in conjunction with TTS/TTR model

Table 4.3: Creating a more visible supply chain with TTS/TTR

4.4.1 Data Collection

Figure 4-3 shows an overview of the inputs and outputs from the TTS/TTR model. In the following sections we will review the inputs and model development. Chapter 5 will review the outputs.

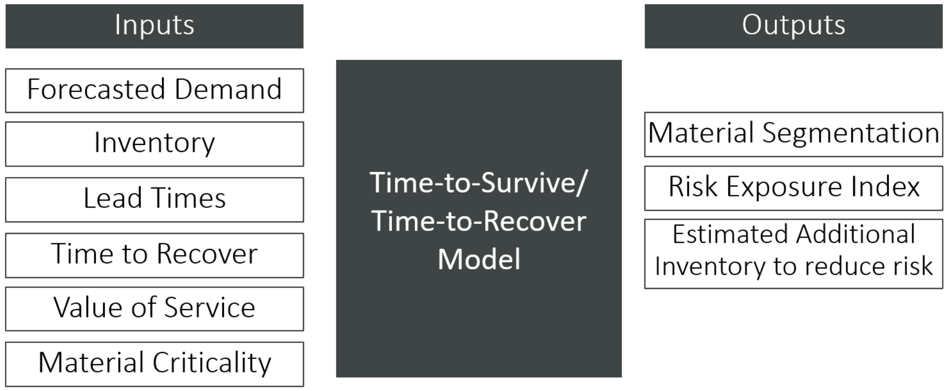


Figure 4-3: Overview of inputs and outputs from the TTS/TTR model. Chapter 4 discusses the inputs. Chapter 5 discusses the outputs.

TTR working with Suppliers

As part of business continuity planning, suppliers can provide a risk matrix to indicate the probability and impact of the event occurring as shown in Figure 4-4. However, these matrices do not necessarily indicate how long a supplier would need to respond to an event. This is where the engagement with the supplier is needed to understand the Time-To-Recover from a quantitative perspective.

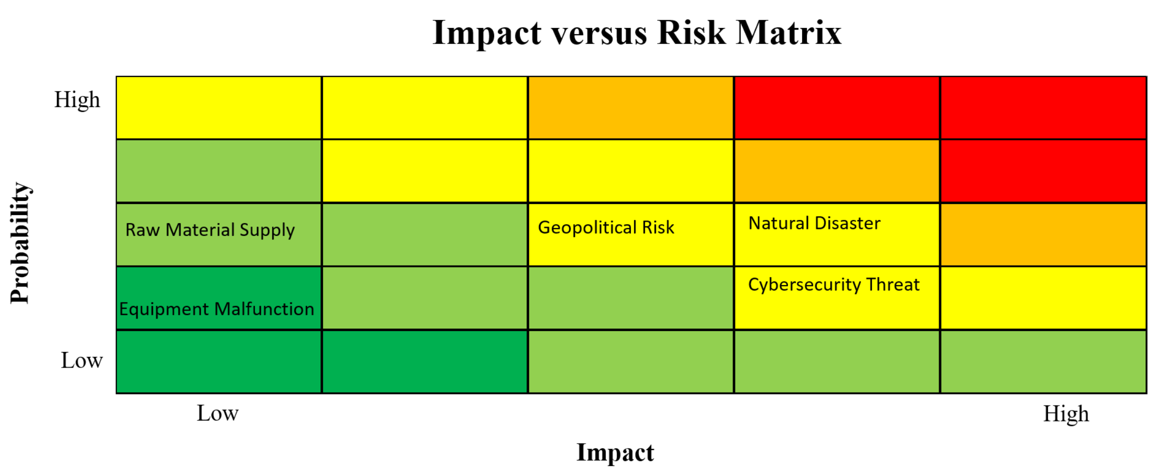


Figure 4-4: Example Supplier Risk Matrix showing the probability of an event occurring and the associated impact. The risk matrices are inputs into business continuity plans.

In a Harvard Business Review (HBR) article, Simchi-Levi, Schmidt, and Wei [42] created a proposed questionnaire to understand the impact from node disruptions. An adapted version of this framework is shown below to facilitate dialogue and information exchange.

- Tier 1 and beyond supplier locations and volumes
- Supplier Risk Assessments such as sourcing strategies (e.g. single versus dual or more), alternate locations, and performance
- Time to Recover or the amount of time it would take for the site to be restored following a disruption

However, note that the level of detail provided depends on the relationship and availability of information. Furthermore, the responses to questions depend on how the questions are phrased; for example, if asking a supplier for the amount of inventory they have of a certain material, the response is actually not helpful because you do not know their demand from other customers. However, it would be useful if there is a level of inventory that is "book-marked" for certain operations for a specific site.

The TTR was bucketed into three segments: minimum, maximum, and average for each node in the supply chain. The minimum TTR is the shortest time to recovery (e.g. a machine failure), maximum is the longest time to recover (for example, sourcing of raw materials), and average is the average of the minimum and maximum recovery time. The user can ultimately select what TTR they would like to use. However, using the minimum and maximum recovery time provides the risk identification bookends or boundaries. Using this approach allows for the company to also evaluate if there are any outstanding TTR issues that would suggest a need for process improvement. For example, if the TTR during normal market conditions is greater than 6 months due to a machine failure, then a discussion could be warranted to discuss the reliability of the machine and methods to reduce that TTR. Figure 4-5 shows an example of a simple network.

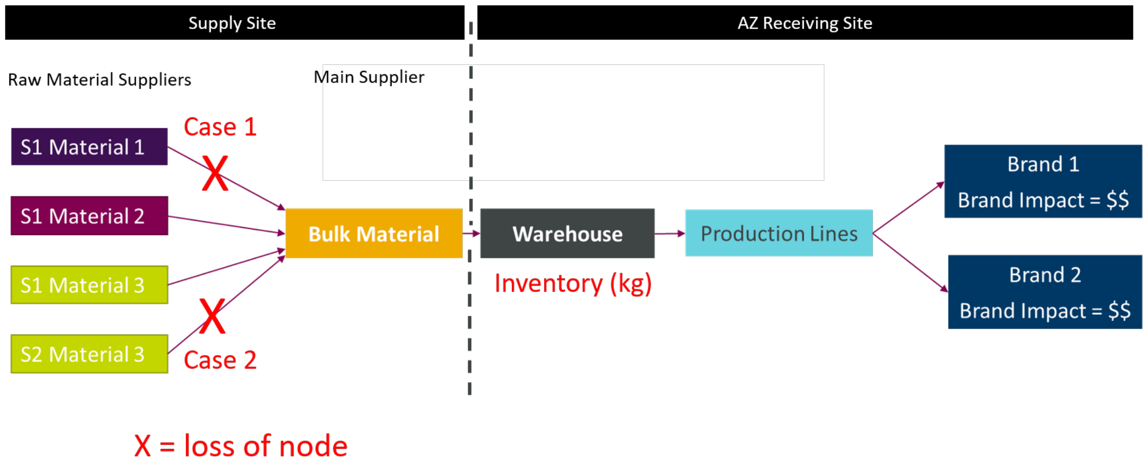


Figure 4-5: Example of simple supplier sourcing of three materials. In this network, there are the raw material suppliers for each material that is used to create the bulk material to ship to an AZ site.

Alternate sourcing does affect the TTR values. Figure 4-5 shows two cases: one where the supply of a material is single-sourced (case 1), the other in which there are two suppliers for a material (case 2). It is not realistic to assume that a TTR could be 0 just because there is an additional supplier as in case 2; therefore, there is still time accounted for bringing the second supplier up to speed. This transition period can be avoided if there exists two active sources that are interchangeable. Not covered in this thesis, however, was the capacity available at the additional supplier sites. For example, in some cases there could be three suppliers of a single material in which two out of three suppliers are used to supply said material. If one supplier was disrupted, the third supplier would be called to start; however, this third supplier may not be able to achieve the full capacity needed to fulfill the desired demand (e.g. perhaps they are only able to achieve 30% of the requested demand and the remaining supplier can satisfy 50%, so only 80% of the requested demand is fulfilled when the original supplier is disrupted).

An abbreviated version of the TTR input sheet is shown below in Table 4.4 as an example. This Excel-based template was provided to suppliers to document the Time-to-Recover. The document was based on the upstream supply chain mapping that was already provided by AZ.

Raw Material	# of Upstream Suppliers	Time to Recover(weeks)	Main Supply Site
Overlacquer	1	10-11	Site 1
Ink	1	1-3	Site 1
Lacquer	1	8-11	Site 1
Aluminum	2	10-17	Site 1
Polyamide Film	3	8-14	Site 1

Table 4.4: Example of table filled out by suppliers to understand the estimated TTR. The number of upstream suppliers refer to the suppliers that are qualified to supply that material.

Inventory (minimum versus average)

Figure 4-6 shows an example of the inventory for a material over the span of about one year. Since the inventory levels vary throughout the year and there could be periods of minimum inventory for months at a time before replenishment, the minimum inventory levels, as shown by the dotted line in Figure 4-6 were used. This is a conservative estimate since a disruption can occur at any time. Additionally, these values would need to be cross-checked at the site to validate these levels.

Demand Considerations

Demand was based on the forecasted demand and not actual purchase orders. An example of the demand is shown in Figure 4-7. The demand used was the average monthly demand over 2020-2021. The standard deviation of the SKUs for the nine-box segmentation was based on an aggregated SKU. This was due to the inability to connect the SKUs to the finished pack during the course of this analysis. This connection would be accomplished by going through the bill of materials for each of the finished packs to identify which raw material is associated with what finished pack(s). This data gap will be closed with ongoing data management projects at AZ.

The result of this gap is that the variability in raw material may be reduced given the aggregation of the forecasts.

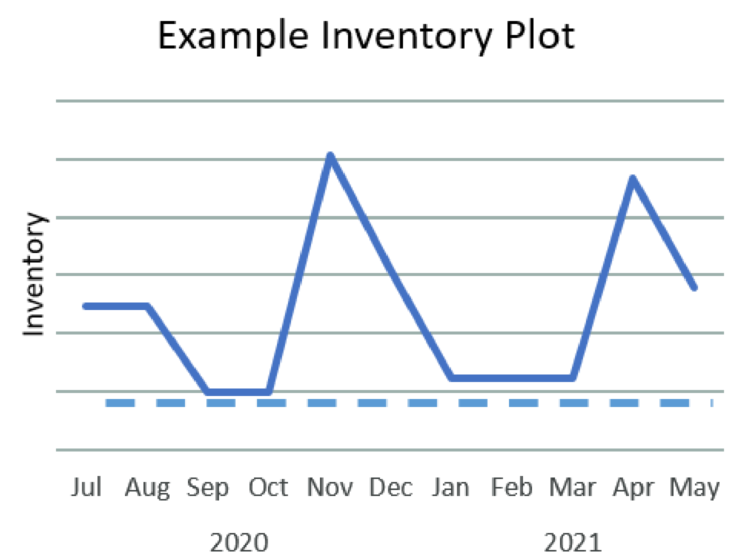


Figure 4-6: An example of inventory levels for a foils SKU. Note that not all inventory level plots were represented as standard as this figure. The dashed line represents that minimum inventory level.

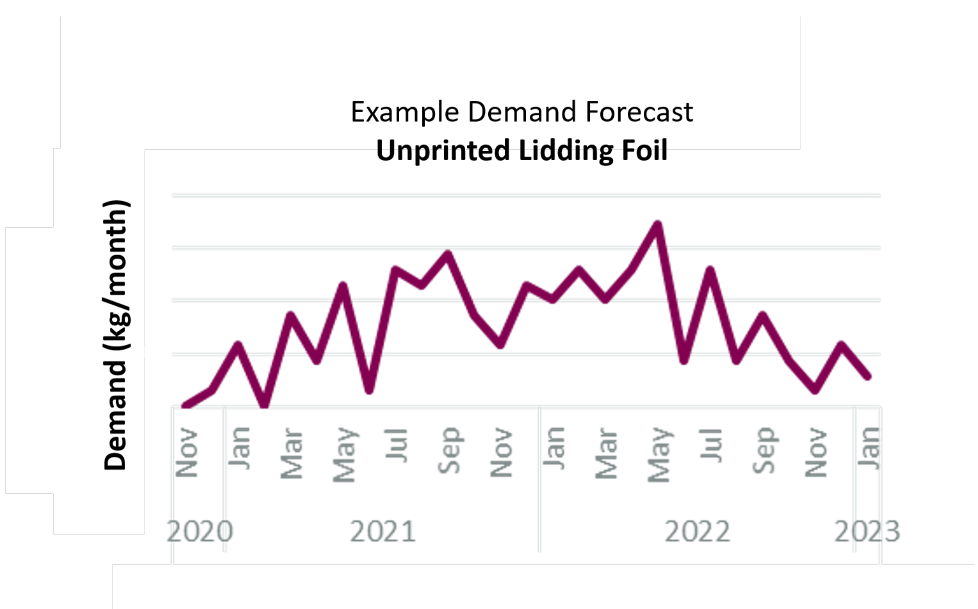


Figure 4-7: An example of forecasted demand for an unprinted lidding foil

Lead Times

Lead times for the initial model were based on standard contractual lead times. Lead times, however, can fluctuate depending on market conditions and continuous review of lead times can help create a more accurate model. Lead times were defined as the time for the finished product (where finished product in this case is the base material for AZ to use in their packaging) to reach AZ after being ordered.

Lead times also include a factor for quality checks (e.g. the amount of time it takes for the material to pass through quality once at the site). Lead times were monitored with the supplier through normal work processes and part of the OTIF (on-time, in-full) calculations. For the purposes of this experiment, we did not include the variability and it is an additional feature the user can include.

A distribution of the standard lead times for an aggregated view of the finished products is shown in Figure 4-8. The differences in lead time are due to a couple of factors: the type of material and the location of the site in relationship to the supplier. For suppliers located close to the production site, they can operate with more of a just-in-time approach (allowing for material to be shipped to the site by the end of the day).

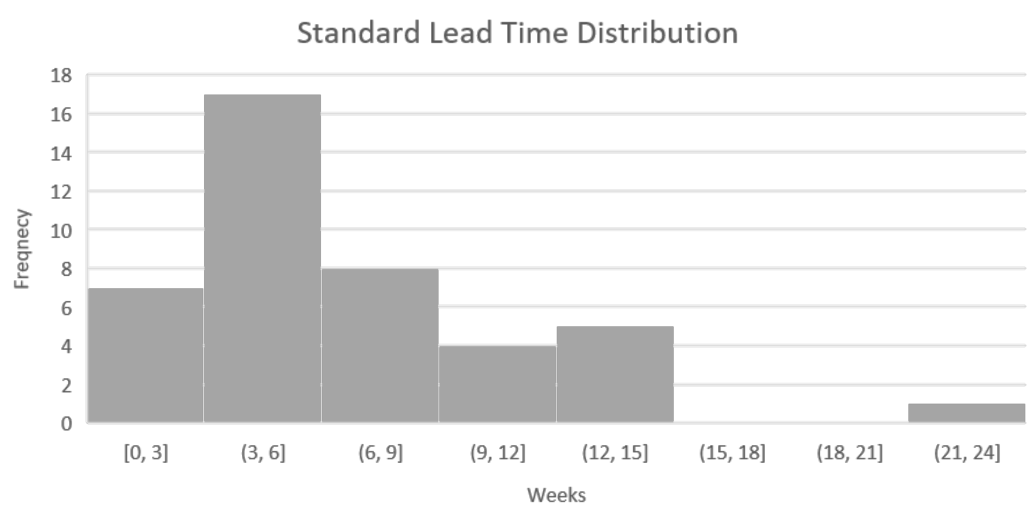


Figure 4-8: Shows the standard lead times for selected finished products. This is an aggregated view of different finished products.

Finally, two additional elements to finalize the interpretation of time-to-recover and assessing impact of risks are: quantifying the value of service and material criticality.

Quantifying the Value of Service

The value of service is the financial impact that can incur as a result of the loss of service from a disruption in the supply chain. In this case, the financial impact is the loss of sales for the finished pack which can have varying degrees of impact. For example, if a material is considered cross-brand (e.g. this is a material that could be used for multiple finished packs), then the impact could be higher depending on production levels and schedule. If a product is not available and there is a competitor available, there can be customer churn reducing market share. In addition to the quantitative aspects, there are also impacts to the company brand where not having products available could reflect poorly on the company image.

In summary the value of service can be characterized as direct loss of sale and brand value (public perception of the product). Here the value of service is estimated solely as the estimated revenue that would be lost as a result of a material disruption.

Quantifying Material Criticality

Material criticality evaluates the impact to the patients should the material become unavailable for a period of time. This definition of material criticality is different from AZ standard definitions of patient criticality. This criticality is divided into three components:

1. Therapy area associated with the finished pack. For AZ the therapy areas are based on the following:

    (a) Oncology

    (b) Respiratory and Immunology

    (c) Cardiovascular, Renal, and Metabolism

(d) Neuroscience

(e) Gastrointestinal

(f) Cross-Brand

2. Impact to Patient if the patient could not access the therapeutic for a period of time. For example, is it deleterious to the patient's health if he/she misses a dose or does a competitor brand exist.

3. Patent life-cycle

Based on the characteristics referenced above, the materials were categorized as either low, medium, or high impact. This is an additional piece of information to help users identify high risk areas to focus on generating mitigating strategies.

4.4.2 Model Design

After aggregating the forecasted demand and minimum inventory, the time-to-survive (TTS) for each material was calculated as with inventory in units such as (kg) and demand in (kg/month)[2].

$$TimeToSurvive = \frac{MinimumInventory}{Demand}$$

With the time-to-survive calculated for each material and estimated times to recover, the risk exposure was calculated as follows:

$$RiskExposure = FinancialImpact * (TTS - TTR)$$

where financial impact was in dollars lost per week, TTR (time-to-recover) and TTS (time-to-survive) were both measured in weeks. The difference between TTR and TTS is called the exposure time. Items were flagged as potential risks if the TTS was less than the TTR. Items were flagged as potential opportunities for inventory reduction if TTS was greater than TTR by 3 months or more.

[2]Material can also be measured in cubic meters

The risk exposure index (REI) was normalized against the highest risk exposure item allowing the user to view a relative risk of each material/node. This normalization of the REI allows for users to see quickly where the highest risk materials are relative to others as well as what node in the supply chain creates that level of risk.

To augment the TTS/TTR model, guidance on the additional stock needed to cover the risk period was added. Additional policy stock inventory required to mitigate risk was calculated as shown below and is not inclusive of the current safety stock levels. The safety stock equation used is an adjustment to the benchmark equation [38]:

$$SS = k * \sigma_L$$

where k is the safety factor determined by the desired service level, which in this case was 99.9%. and σ_L is the standard deviation of lead time.

The additional inventory needed to close the risk gap and handle the variablility in demand from time-to-recover is based on a modification to the SS equation as

$$SS = k * \sigma_{RecoveryTime}$$

The following equation is based on Huang's paper [19] for calculating $\sigma_{RecoveryTime}$ when only demand variability is known:

$$\sigma_{RecoveryTime} = \sigma_{leadtime} * \frac{\sqrt{TTR(months)}}{\sqrt{LeadTime(months)}}$$

As the focus for this thesis is on additional policy stock (stock allocated for supply disruptions), cycle stock (stock to be used during a period), safety stock (stock to mitigate against demand variability) and pipeline stock (stock in transit to AZ facilities) are excluded from this analysis.

4.5 Dual Sourcing versus Increased Inventory

One lever to creating supply chain flexibility as well as reducing risk is by dual-sourcing. Dual-sourcing is defined as having a second manufacturing site that abides by the regulatory market requirements [25]. This second manufacturing site should also be a different supplier. However, consideration should be made on what the definition of dual sourcing means for a company and for a site. Dual sourcing could be "complete" meaning that the site has the ability to use two different materials for all the production lines in question. Additional definitions are provided below:

1. **Active Dual Source** – used in production and can absorb full volume. This is the highest level of risk mitigation.
2. **Passive Dual Source** – fully qualified so can run on the line but not actively used to avoid.
3. **Registered Dual Source** – registered but not ran on the line. This means the sources can be switched faster; however, feasibility work is not finalized.
4. **Sole Supplier, multi-site** – one supplier but two manufacturing sites.

However, dual sourcing can also mean that some production lines have the ability to run a certain material, but other lines do not. In this case, a site may think that they have mitigated their risk for dual sourcing; however, in reality, they have not mitigated the risk completely because only a certain line can run that material. If that line is down for maintenance or has had an issue, dual sourcing will not help if the secondary material cannot be run on another line.

Data Collection

In addition to the demand and inventory data collected as referenced in the above sections, an analysis was conducted to estimate the cost of dual-sourcing versus increasing inventory. Additional information required for assessing the trade-off between dual-sourcing versus adjusting inventory allocation were estimates of costs incurred for dual-sourcing as well as estimates of costs for holding additional inventory.

Model Development

The approach to evaluating the trade-off between dual-sourcing and increasing inventory is adapted from a Master's thesis by Huang and Liu [19] who explored this concept in the medical device industry. They used the value of the Return on Assets (ROA) to determine whether to dual source or increase inventory. The ROA is impacted net income and total assets. Table 4.5 shows a qualitative impact on net income and assets from dual sourcing compared to increasing inventory in Table 4.6.

When viewing Table 4.5, there are five columns. The first column describes the two variables that impact the ROA: net income and the asset side of the balance sheet (referred to as solely assets). In this case, we want to look at what happens to these two variables when choosing to dual source a material. The remaining four columns show variables that can affect either net income or total assets. These variables are cash, inventory, administrative expenses, and operating expenses. This table can be viewed as an abbreviated balance sheet to understand what happens to each variable depending upon what action is taken. An example of how cash is used for dual sourcing expenses can be found below Table 4.5.

Impact on Net Income and Assets from Dual Sourcing

Effect	**Cash**	**Inventory**	**Admin. Expenses**	**Op. Expenses**
Net Income	Decreases	n.a.	Decreases	Decreases
Assets	Decreases	Depends	n.a.	negligible

Table 4.5: Impact on net income and assets on cash, inventory, administrative expenses (admin. expenses) and operating expenses (op. expenses) from dual sourcing. In this case, cash decreases net income and assets as it is used for creating new contracts. Some of the cash may be used to buy inventory which will decrease cash on the asset side of the balance sheet but increase inventory during the period in which the second source is being selected and validated. Administrative expenses decrease net income as more hours are needed to manage the new source. Operating expenses decrease net income as packing lines are now needed to perform trials on new materials potentially reducing operations output.

To further expound on Table 4.5, for the cases of dual sourcing, cash is used for dual sourcing expenses which can include the following items:

- Procurement Hours to create and negotiate a new contract
- Engineering Hours for quality control, testing, new materials, etc
- Trials for testing new materials which also needs to account for down periods in which the production lines/machines are not being used to produce final products for sale
- Potential new tooling costs for use of newly sourced material
- Specialists hours for disciplines that may need to work part-time on the dual sourcing efforts
- Additional inventory to account for mitigating the period between when a site is completely dual-sourced and when the risk exposure is still evident

The impact on inventory depends as there can be an interim period in which inventory is used as a short-term mitigation while the dual-sourcing project is being implemented. This in turn can affect the operating expenses with holding more inventory as well as the potential to need a new supplier manager, support from an organization or site management for incorporating a new source to a site. Inventory only allows for additional time to mitigate the supply disruption; however, if a single source supplier completely fails, another source would need to be found.

Impact on Net Income and Assets from Increasing Inventory

Effect	**Cash**	**Inventory**	**Admin. Expenses**	**Op. Expenses**
Net Income	n.a.	n.a.	n.a.	Decreases
Assets	Decreases	Increases	Negligible	n.a.

Table 4.6: Impact on net income and assets on cash, inventory, administrative expenses (admin. expenses) and operating expenses (op. expenses) from increasing inventory. More information on how to interpret this table can be found in the following paragraph.

As with the dual sourcing referenced in Table 4.5, the increased level of inventory has different effects on net income and assets that are assumed as follows. From a cash perspective, the net income is unaffected (hence not applicable or n.a. in the table) since buying inventory doesn't affect the cash flow on the income statement. However, on the asset side of the balance sheet, when purchasing inventory, cash decreases while inventory increases. With respect to inventory, there is a shelf life associated with the material; so if demand drops suddenly, there is a possibility that the inventory cannot be used anywhere. There is a period of time where the material becomes obsolete and would need to be written off affecting the P & L (Profit and Loss) sheet. Additional inventory in this scenario would not require additional resources as the existing supplier network would be used therefore the administrative expenses are negligible; however, operating costs would increase due to increased inventory holding in the warehouses.

This model extends on the TTR/TTS model. After estimating inventory costs and dual sourcing costs, the concept of return on assets (ROA) was used to evaluate the differences between the two options as suggested by Wang and Liu [18]. The return on assets formula is found below where net income and total assets can be found using the financial information provided in a company's annual reports.

$$ReturnOnAssets(ROA) = \frac{NetIncome}{TotalAssets}$$

There are several assumptions in this analysis including that cash is not borrowed. If cash is borrowed, there will be an additional interest rate added back to the ROA calculations. Additionally, it is assumed that dual sourcing does not incur any additional costs related to convenience (e.g. incurring higher costs for swing capacity). Finally, taxes were not assumed in this calculation.

Chapter 5

Results and Discussion

> "A proactive approach, combined with a vibrant risk-management culture, will be a game changer for companies, helping them avoid and manage the future disruptions in their supply chains."
>
> *McKinsey [7]*

5.1 Base Case Supply Chain Complexity

Before exploring the application of the TTR/TTS framework, a base case evaluation of the foils supply chain was conducted. The purpose was to understand the existing complexity and opportunities to gain increased flexibility within the supply chain. Flexibility here is associated with the ability to share materials among different sites to add an additional layer of business continuity. The foil specifications (i.e. widths, color, reel weights, etc.) are different depending on the site and machine by design to give individual sites unique flexibility. Potential for future specifications to be of similar widths can minimize the complexity at the site and supplier level. The overall project strategy will depend on several projects for standardizing materials/assets and process development to share materials over the coming years as described in

Chapter 2. Global packing asset and specification alignment among the sites allow for simplification of the overall supply chain.

5.2 TTR Results

A distribution of the time-to-recover for an aggregated view of the finished products is shown below in Figures 5-1 and 5-2. As with the lead time figure (Figure 4-7) shown in Chapter 4, the variations in time are due to a few factors: the type of material, the location of the site in relationship to the supplier, and market dynamics. Market dynamics include geopolitical arrangements (e.g. impact on taxation, limiting export of materials, etc.). As with lead times for finished products, *sub-suppliers* located close to the supplier's main production site can operate with more of a just-in-time approach (allowing for material to be shipped to the site by the end of the day).

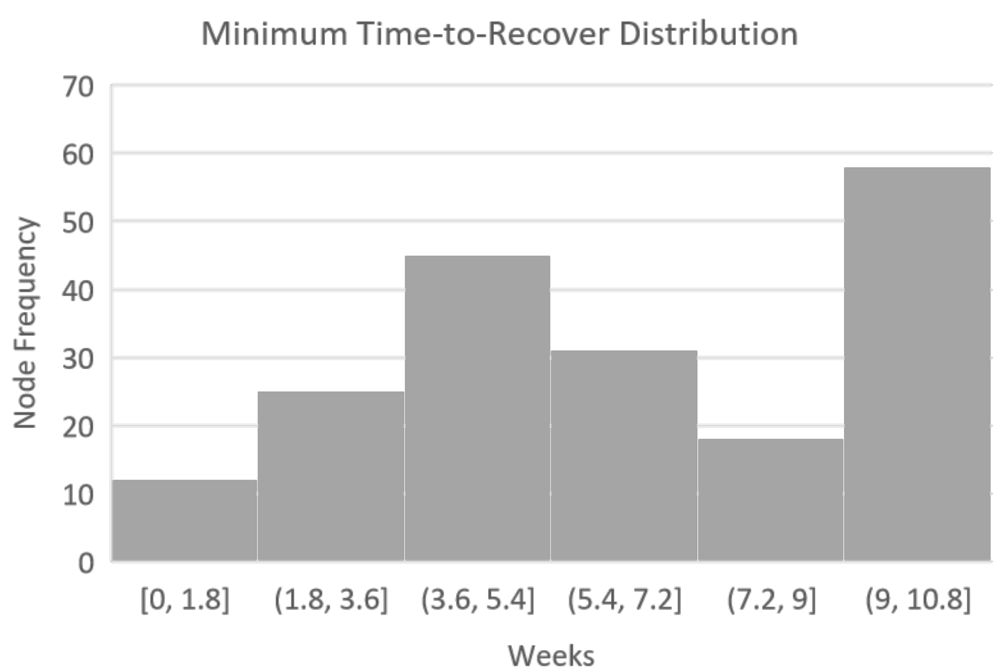


Figure 5-1: Shows the distribution of time-to-recover times for selected materials over a minimum TTR. This is an aggregated view of different materials over different locations.

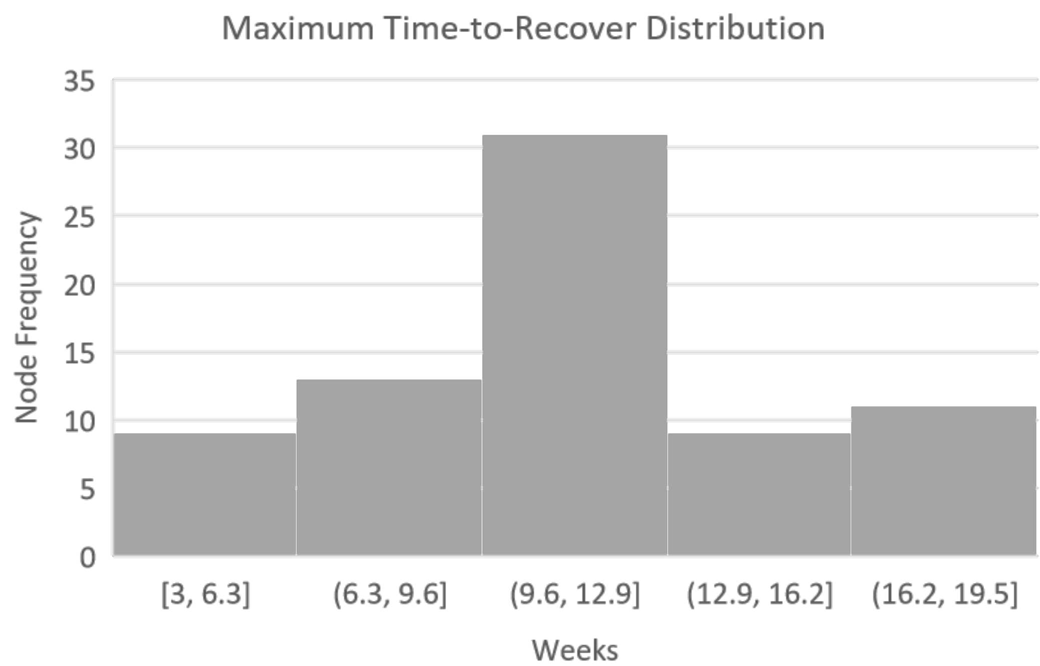


Figure 5-2: Shows the distribution of time-to-recover times for selected materials over a maximum TTR. This is an aggregated view of different materials over different locations.

TTR	# Flagged as Risk	# Flagged % of SKUs	% of Revenue
Min TTR	39	10%	13%
Average TTR	90	22%	30%
Max TTR	133	33%	45%

Table 5.1: Distribution of SKUs identified as being in a potential risk category and the % of financial impact.

Table 5.1 shows a summary of the materials flagged for risk based on the minimum, average, and maximum TTR. This table also shows the relative magnitude of impact based on sales revenue (reference column "% of Revenue"). The % of Revenue column helps the users understand the overall impact to the supply chain should they experience such a disruption in the supply chain. In this initial evaluation, 407 SKUs were evaluated for select material around the globe. The source data from this table can be found in the Appendix.

By using the minimum, maximum, and average time-to-recover, the user at a glance can understand if there are any outstanding issues on the TTR. For example, if a TTR is greater than, for example six months, this could be an indicator to the company that there should be a discussion with the supplier as to why the TTR is that high. By undergoing this exercise, suppliers can also identify areas within their own production operations that can be improved.

Table 5.2 provides an example output from the TTR/TTS. An overview of how to use this table is in Section 5.2.1. Figure 5-3 (top) shows the distribution of the types of foils in which the TTR is greater than the TTS per each TTR scenario (e.g. min, average, max). Based on the current demand profile, the printed lidding foils appear to have the highest vulnerability. The printed lidding foils are materials that have branded artwork and can be used for only a specific brand. Plain lidding foils can be use across multiple brands in which the artwork can be printed on-demand. Therefore, one mitigation to this vulnerability is to explore shifting from printed lidding foils to plain lidding foils and then printing the artwork at internal AZ sites.

This model also allows the identification of areas where inventory may exceed the maximum time-to-recover. For example, of the 407 SKUs, 56% had a time-to-survive greater than 6 months. In this case, if the time-to-recover is significantly less than the time-to-survive, there may be opportunities going forward to reduce inventory holding and thus open up cash flow for other activities.

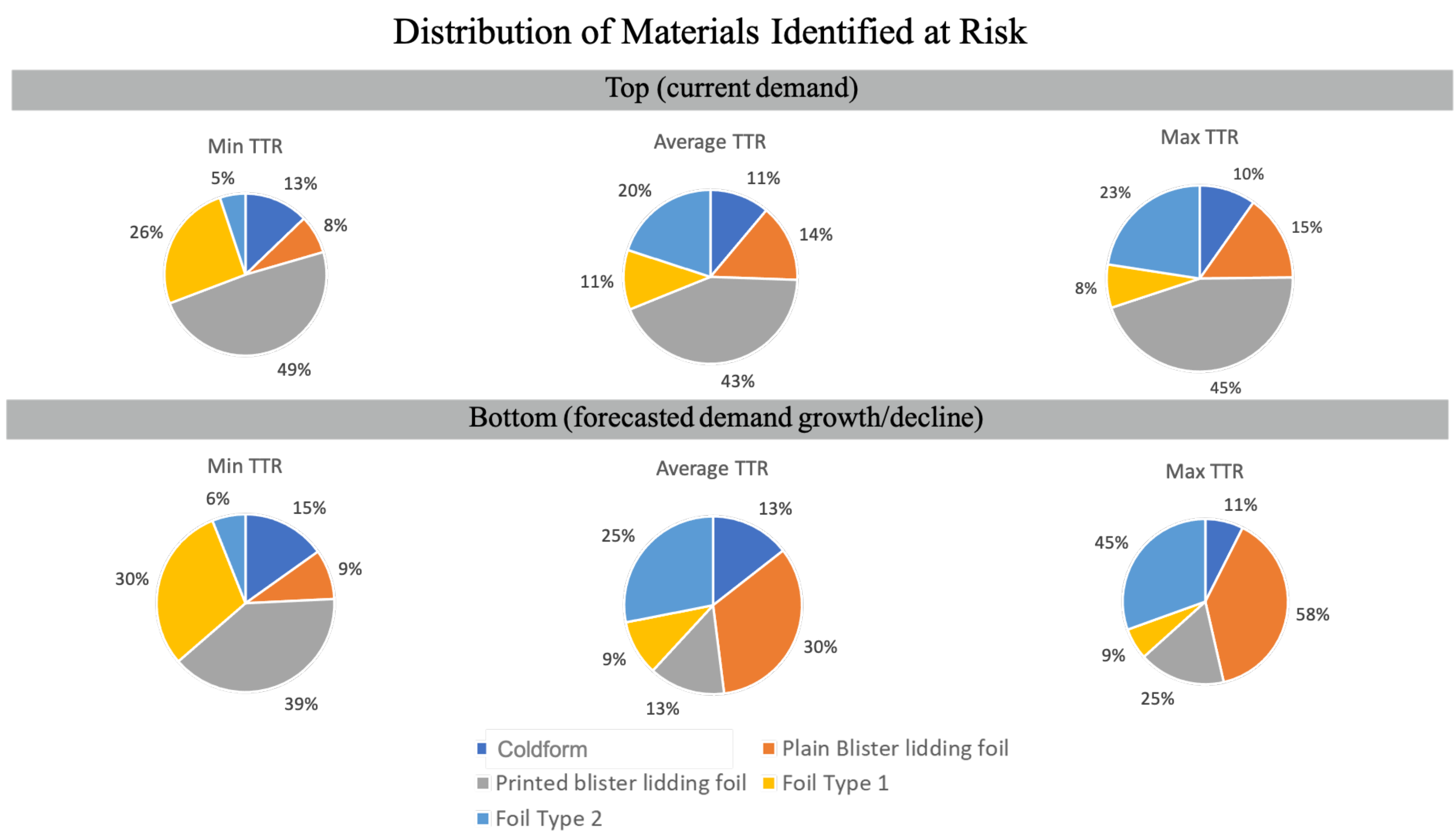


Figure 5-3: Shows the distribution of the types of foils in which the TTR is greater than the TTS. The top section is based on the current snapshot of demand. Based on this current demand profile, the printed lidding foils for a particular brand appear to have the highest vulnerability. The bottom section shows the foils identified at risk with the projected demand growth or decline. The type of material more at risk changes from printed lidding foil to plain lidding foil.

Code	Descr.	Seg.t	Brand	Criticality	REI	Delta Inv.(kg)	Min. Inv. (kg)	Delta Inv. (k$)	TTS(months)
123	Foil 1	A2-Medium	Brand 1	1	1	1000	300	779	0.08
456	Foil 2	A3-Medium	Brand 2	1	0.77	250	150	20	0.1
101	Foil 3	B3-High	Brand 4	2	0.3	345	200	0.8	0.25
112	Foil 4	C3-High	Brand 5	3	0.1	750	100	1	0.5
Continued	...	...	...	...	...	...	...	...	...

Table 5.2: Output table from the TTR/TTS model for evaluating raw material sourcing with an average TTR. The definitions of the columns are shown below.

- **Material Segment** – includes nine-box segmentation (proposal for material segmentation) and AZ Brand Segment. **Value** A-high value, B- medium value, C- low value.

  Volume 1-high volume, 2-medium volume, 3- low volume.

  Variability low, medium, or high

- **Material Criticality** - Criticality can be assessed via characteristics like how many customers are affected by the loss of this product and what are the ramifications for that loss.

  1 – High criticality, 2 – Medium Criticality, 3 – Low Criticality

- **Risk Exposure Index (REI)** - Measures the financial loss that could be incurred if you stock out of a specific material. The calculation is based on the following:

  Exposure = Financial Impact * (TTS – TTR), where

  TTS = Time-to-Survive and TTR = Time-to-Recover and financial impact is aggregated at brand + strength level.

  The index is found by normalizing the items with to the highest exposure SKU.

- **Estimated Inventory Changes** - Estimated amount of inventory that would be required to allow for TTS – TTR to be positive and no longer be considered a risk.

5.2.1 Overview of Model Implementation Process

This section provides a method for interpreting the results from the TTR/TTS table. Figure 5-4 is an example of a process flow diagram. This process has two parallel paths – the first path is to evaluate what materials have not been flagged as at risk and materials where more inventory may be allocated than required based on the time-to-survive. Holding more inventory has risk associated with it in the pharmaceutical landscape besides the financial ramifications. These risks include the material being held past its expiration date or regulatory changes affecting the artwork on the foils.

After evaluating what materials may have more inventory than required, the user can start evaluating the materials that have been identified as at risk. In a decentralized environment where the data systems may not be integrated and in an environment where the TTR/TTS model is managed by a global organization versus by individual sites, there are additional quality control steps required. The first step of the process is evaluating what segment the material is in as described in Chapter 4. If the material is a slow mover, a different management technique is suggested versus if the material is a fast mover. These additional steps require working with individual sites to confirm understanding of the material's segmentation in relation to that site.

The next part of this process involves understanding the supplier risk. Supplier risk can be quantified using variables such as OTIF (on-time, in-full); however, it is also a function of the quality of relationships between the sites and the suppliers.

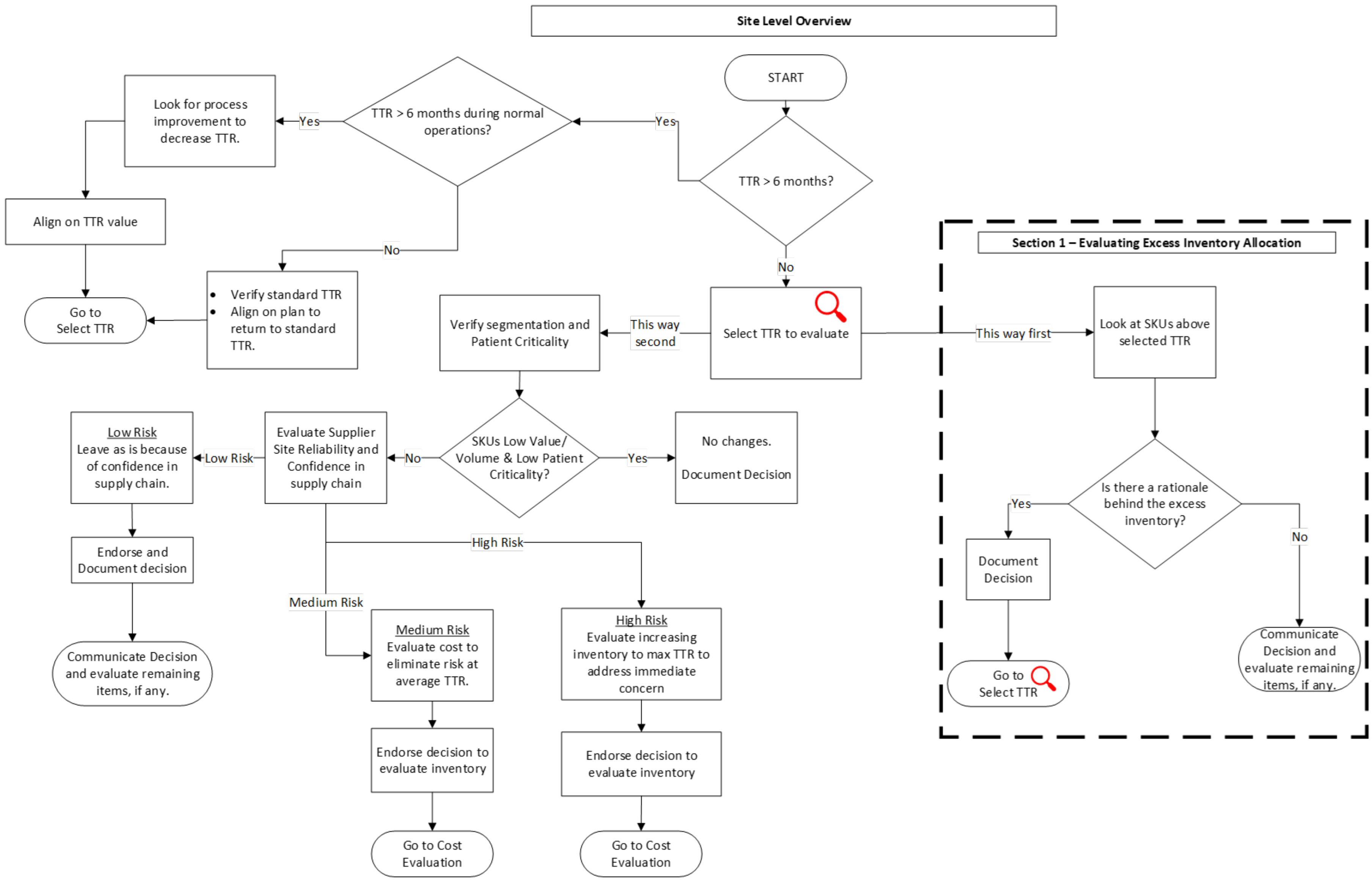


Figure 5-4: Process Implementation Diagram for both evaluating high risk and excess inventory

After determining that the materials in question are high or medium risk and actionable, the next steps are to consider accepting the risk and monitor, increase inventory to buffer against a disruption event, or begin dual sourcing efforts (described further in Chapter 6) . Figure 5-5 begins the discussion on cost impacts to the sites. The risk exposure index is used as a means of prioritizing the materials and then determining whether to pursue alternative options or change the policy stock inventory.

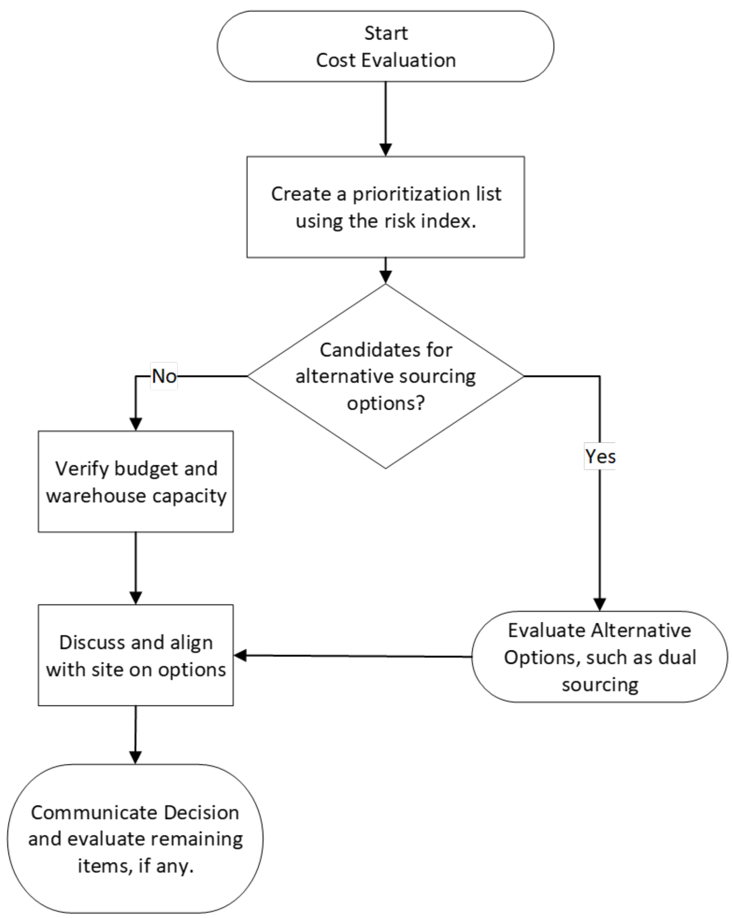


Figure 5-5: Part II of the process implementation diagram to evaluate cost opportunities

Additional considerations include discussions with the sites on items such as additional warehouse capacity and simultaneously understanding constraints on the existing budget. If there is not additional warehouse capacity available, opportunities such as adding a 3rd party warehouse or re-positioning inventory at a supplier site can be discussed. In addition many operating sites may be under a budget for the year and if purchasing additional inventory is under the responsibility of site procurement, there is a prioritization that needs to be created for risk mitigation projects. Prioritizing the purchase of additional inventory or even pursuing dual-sourcing projects needs management direction and support.

5.2.2 Supply Chain Resiliency with Changes in Demand over the next 5 years

The different materials were then subjected to a sensitivity study to understand how does the supply chain change over the next few years. The products were characterized as either having Declining, Low, Medium, or High Growth Potential. The following percentage changes in demand were used to simulate how the demand forecast would change over the next 10 years.

- Decline: -50%
- Low Growth: +1%
- Medium Growth: +10%
- High Growth: +20%

TTR	Flagged as Risk	Number Flagged % of SKUs	% of Cost
Min TTR	33	8%	13%
Average TTR	69	17%	29%
Max TTR	118	29%	47%

Table 5.3: Distribution of SKUs with updated forecasted demand identified as being in a potential risk category and the % of financial impact. As with Table 5.1, this table shows the relative magnitude of impact based on sales revenue (reference column "% of Revenue"). The % of Revenue column helps the users understand the overall impact to the supply chain should they experience such a disruption in the supply chain.

Table 5.3 is suggesting that using the TTR/TTS model in isolation for just the current year or the next year may not describe the entire supply chain landscape. Using the demand lever can elaborate the supply chain risk based on anticipated growth or decline further allowing the user to make data driven decisions in deciding what material to mitigate. If a material is going to decline in use over the years, pursuing dual-sourcing options may not be the most strategic decision versus inventory adjustments to close the risk gap for an average TTR. In this scenario, the total number of materials flagged as at risk is less (220 versus 262); however, the cost impact remains relatively the same (comparing % of cost from Table 5.1 and Table 5.3). This is due to the high growth brands compensating for the lower growth or declining brands. Investing in mitigating the declining or slow growth materials versus the high growth performers puts the supply chain at additional risk because inventory is being held for the non-optimal material. The distribution of the types of material (Figure 5-3) also changes with a shift toward plain blister lidding foil becoming the vulnerability point.

In the next chapter, we will go through a case study at one of the sites and work through the process flow. We will end with determining a trade-off between dual sourcing and increasing inventory for a segment of materials.

Chapter 6

Case Study: Evaluating TTR and suggested actions

> “The rewards for building a resilient organization are substantial. The ’hardened’ enterprise will be able to not only withstand all manner of disruption but also increase its competitiveness."
>
> *Yossi Sheffi, 2005.*

6.1 Case study: applying the TTR/TTS framework using dashboards

Below is an example of using this time-to-survive/time-to-recover framework to assess high risk areas and strategize mitigations. Through this case study, we’ll look at how using dashboards combined with the TTR/TTS framework can facilitate risk analysis and opportunity for re-positioning inventory. We will start with a global view and work towards the specific site we want to evaluate further using the process flow described in Chapter 5. Based on these identified risks, we will look at the trade-off between dual-sourcing and increasing inventory as described in Chapter 4.

Please note that the information below is based on redacted data and does not reflect actual operations in any capacity. The following is meant only as an example of how this tool can be used in operation.

6.2 Dashboard Use

To obtain an overview of the operations, dashboards were created using Power BI. Power BI is a business intelligence software from Microsoft that allows users to collect and visualize data. Any business intelligence software can be used. Figure 6-1 can be used to quickly identify what area we would like to look at first. For this analysis, we'll look at the map and find the highest risk area based on the size of the circle which represents relative risk. For this scenario, we'll start with the region marked by the star (Europe). The size of the circle represents the relative risk area.

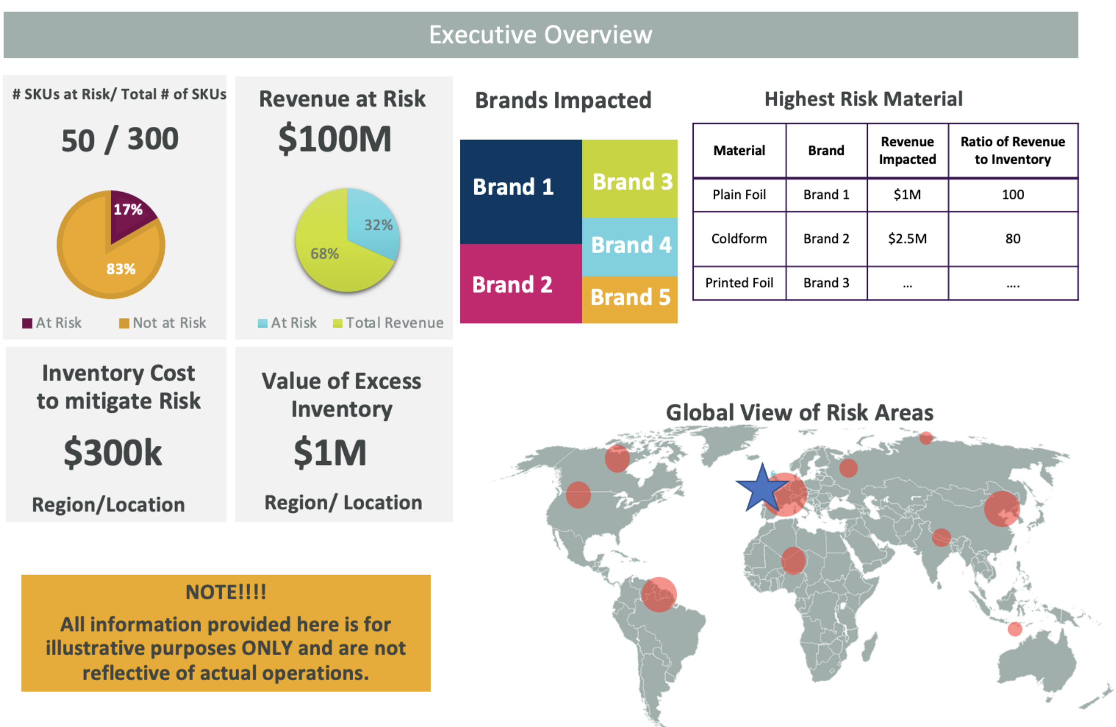


Figure 6-1: Executive overview of a supply chain mapping using TTR/TTS framework providing a global perspective. The size of the circles on the map represent the magnitude of the risk.

Once we arrive at the regional view, as shown in Figure 6-2, we can once again hone in on which site to evaluate first. Once the site is selected, Figure 6-3 provides a site level overview providing a granular view on the vulnerable materials.

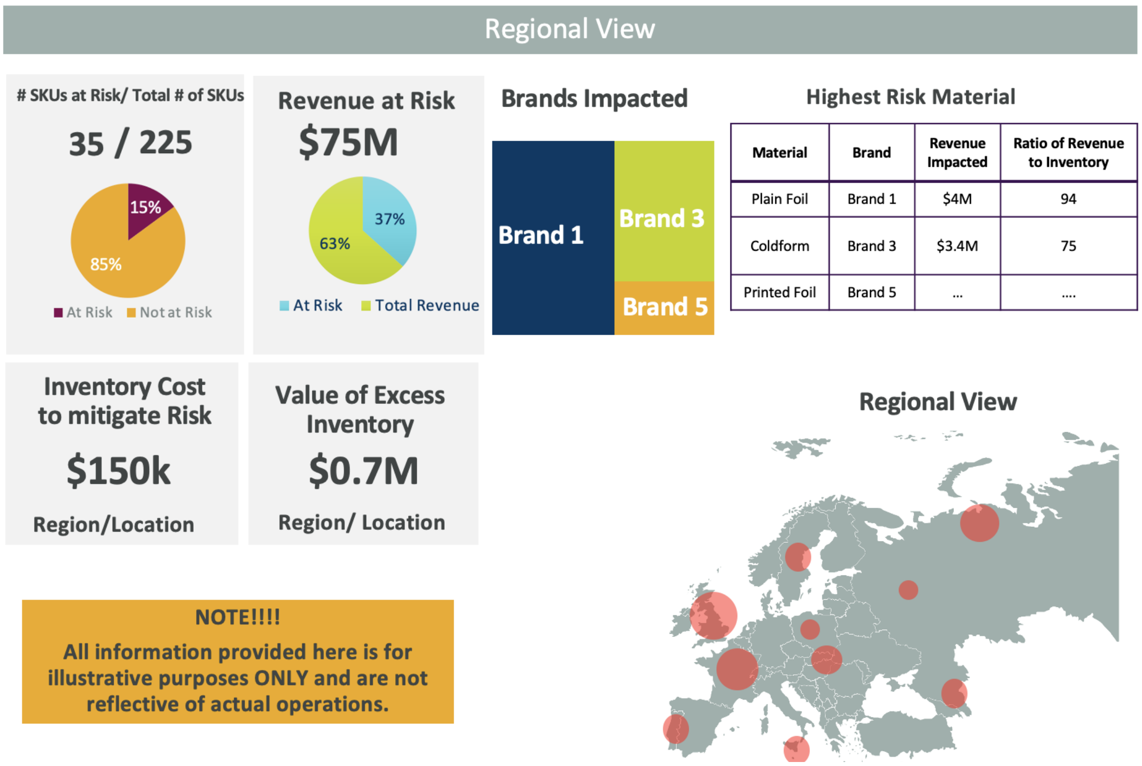
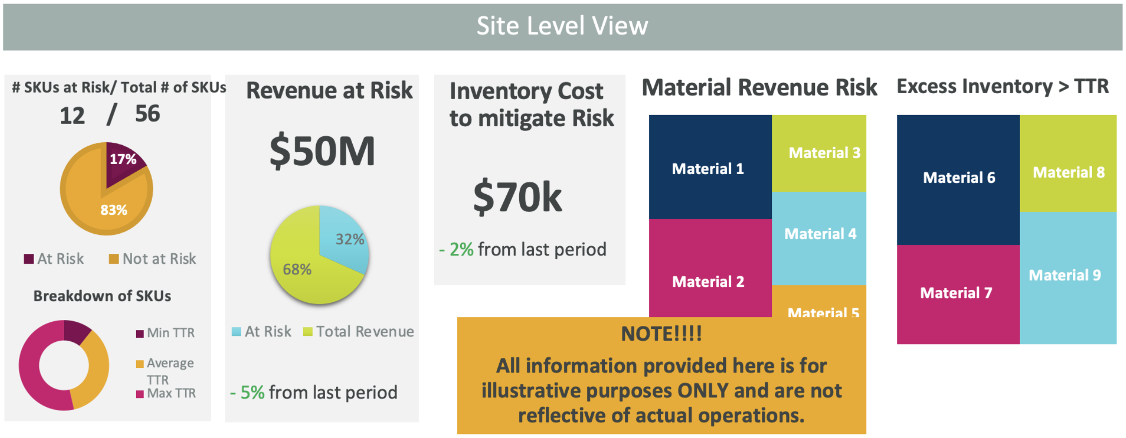


Figure 6-2: Regional overview of a supply chain mapping using TTR/TTS. This is not representative of actual operations

At the site level view, we can see that the distribution of materials at risk is as follows: a total of 56 materials were evaluated at this site (upper left corner of the dashboard). For this case study, we'll look at the number of materials at risk for a disruption that causes 2 months of average TTR (or 12 materials).



Material Code	Material Description	Segment (1)	Brand	Patient Criticality (2)	Risk Exposure Index (3)	Delta Inventory to eliminate risk (kg) (4)	Current Min. Inventory (kg)	Delta Inventory Cost ($)	TTS (months)
123	Printed	A2-Medium	Brand 1	1	1.000	12,782	193	$ 779,711	0.08
456	Printed	A3-Medium	Brand 2	1	0.770	2,339	217	$ 142,665	0.49
789	Printed	A2-Medium	Brand 3	1	0.582	6,490	992	$ 395,912	0.83
101	Plain	A3-Medium	Brand 4	1	0.472	1,283	263	$ 70,592	0.89
111	Coldform	A1-Medium	Brand 5	1	0.451	54,230	14,170	$ 3,757,048	0.93
213	Coldform	B3-High	Brand 6	3	0.302	2,430	129	$ 168,339	0.35
141	Plain	A3-Medium	Brand 7	1	0.160	136	41	$ 8,319	1.13
516	Plain	C3-High	Brand 8	3	0.036	8	1	$ 505	0.88
171	Plain	C2-Medium	Brand 9	3	0.029	10,869	3,287	$ 753,030	1.05
819	Plain	C3-Medium	Brand 10	3	0.025	134	45	$ 8,153	1.22
202	Coldform	C3-Medium	Brand 11	3	0.013	247	126	$ 15,056	1.50
212	Plain	C3-Medium	Brand 12	3	0.013	183	90	$ 11,145	1.51

Figure 6-3: Site level view of packing materials. The table output columns are defined in Chapter 5.

Figure 6-4 provides a zoomed-in view of the materials flagged at risk from Figure 6-3. Of the remaining SKUs that were not labeled at risk, 15 were found to have a TTS greater than the maximum TTR ($\sim$ 6 months in this scenario). These materials have a potential for future inventory reduction after discussion with the site owners. Referring back to Figure 6-4, the material segments and priority were verified with the site. Given the low impact, low REI (Risk Exposure Index as defined in Chapter 4), and low supplier risk, materials in segment 1 were classified to take no action and leave as is. However, the materials in segment 2 were classified for further evaluation. In this case, we'll look at the trade-off between dual sourcing versus increasing inventory.

Material Code	Material Description	Segment (1)	Brand	Patient Criticality (2)	Risk Exposure Index (3)	Delta Inventory to eliminate risk (kg) (4)	Current Min. Inventory (kg)	Delta Inventory Cost ($)	TTS (months)
123	Printed	A2-Medium	Brand 1	1	1.000	12,782	193	$ 779,711	0.08
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171	Plain	C2-Medium	Brand 9	3	0.029	10,869	3,287	$ 753,030	1.05
819	Plain	C3-Medium	Brand 10	3	0.025	134	45	$ 8,153	1.22
202	Coldform	C3-Medium	Brand 11	3	0.013	247	126	$ 15,056	1.50
212	Plain	C3-Medium	Brand 12	3	0.013	183	90	$ 11,145	1.51

Figure 6-4: TTR/TTS output from selected site showing the vulnerable materials. Based on the process flow interpretation discussed in Chapter 5, these materials can be split into two segments: Segment 1 are materials that need further evaluation. Segment 2 are materials that have no action and the risk will be accepted. Not shown in this table are the anticipated growth/decline in demand of the associated materials.

6.3 Trade-off Dual Sourcing versus other mitigations

Dual sourcing is a strategic mitigation lever. One item to consider while dual sourcing is the need for additional inventory to close the risk gap while the dual sourcing efforts are underway. For this case, we are assuming that it takes 24 months to fully implement a dual source and therefore need inventory coverage during that time.

The total estimated dual sourcing cost is $1,501,500 as shown in Table 6.1. In addition, all costs have a margin included to reflect unknowns. If dual sourcing is driving the costs, it's possible to evaluate what is driving the costs and then try to find areas to reduce them to make dual sourcing cost competitive with increasing inventory.

Dual Sourcing Costs	Hours	Rate ($/hour)	Total Cost
Procurement Hours	22	250	5,500
Engineering Hours	-	-	440,000
Trials	-	-	616,000
New Tooling	-	-	-
QA/QC/Others	-	-	220,000
Regulatory Specialists	2,200	100	220,000
		Total Cost of Dual Sourcing	$1,501,500

Table 6.1: Example of expenses from dual sourcing. Note that these values are simulated. QA/QC are for quality control.

The costs associated with increasing inventory are both the costs for buying the inventory plus the operating costs holding the inventory as shown in Figure 6-5. To capture the multiple options for changing policy stock inventory, we evaluate the costs for increasing inventory to close the gap between the TTS and min TTR, average TTR, max TTR, and 12 months. The assumption here is that the purchasing of inventory is a one-time cost with an associated holding cost over 5 years. Cash is used to buy the inventory; therefore, overall assets remain unchanged on the balance sheet.

Summary Table	Time to Implement minimum (months)	Additional Stock Cost ($) with margin for unknown costs	Annual Operating Costs ($)	Total Cost ($)
Min TTR	3	238,335	155,590	393,925
Max TTR	3	2,050,538	1,338,639	3,389,176
Average TTR	3	1,172,444	765,399	1,937,843
12-month inventory	6	2,780,385	1,815,100	4,595,485
Base Case	0	-	-	-

Figure 6-5: Summary of additional inventory costs as well as operating costs from holding the additional inventory. The costs above reflect the additional stock needed to close the gap between the time-to-survive and time-to-recover. The gap periods are listed in the first column.

Table 6.2 shows the results of the ROA analysis by looking at the impacts of the net income and net assets. The ROA of each category was compared against the base case (e.g. the existing supply chain). The change in net income and assets are consistent with the qualitative discussion in Chapter 4. The greater the differential, the greater the financial impact. In this case, dual sourcing does not appear to be the best option but rather at least mitigating up to the average TTR to decrease the gap between the average TTR and TTS.

Scenario	Base	Min TTR	Dual Source	12-Months	Av. TTR	Max TTR
Delta ROA (%)	0	-0.49	-8.08	-5.47	-2.42	-4.23

Table 6.2: Change in Return on Assets compared to the base case scenario. Base case scenario is no action – neither increasing inventory nor pursuing dual sourcing. The scenarios listed here include dual sourcing, minimum, average, and maximum TTR as well as 12-month TTR. 12-month TTR was included since many of the materials have a 12-month inventory by default to maintain high service levels. The smaller the change, the less impact there is to the Return on Assets.

Alternatively, if dual sourcing costs were reduced to $770k as shown by the star in Figure 6-6, dual sourcing or increasing inventory to the average TTR would have the same impact on the ROA. Figure 6-6 shows the reduction in dual sourcing costs that would be required to be cost competitive with increasing inventory for risk mitigation. However, in the cases of a total failure in supply chain (for example, a single source supplier with a single warehouse that is caught on fire), dual sourcing can provide a greater mitigation as the amount of inventory to hold could extend beyond a year in this scenario to ensure operation during recovery. It is a management decision to understand the level of risk that is accepted.

Looking beyond the financial implications for dual sourcing, there are some general challenges within AZ to implement a dual source. For example, the sites may not prioritize implementing a dual sourcing project due to competing activities. Furthermore, there are impacts to the site OEE (overall equipment effectiveness) when testing a new material source which may create a reluctance to implement a dual sourcing project.

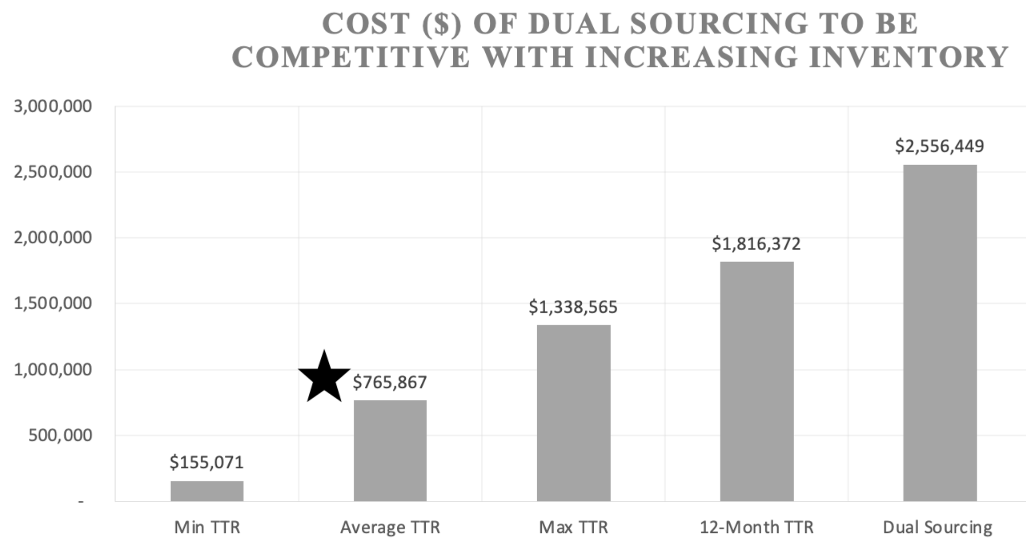

Figure 6-6: The star indicates what the cost of dual sourcing should be to mitigate risks up to the average TTR. In this scenario, dual sourcing or increasing inventory would have a similar impact on the ROA.

Chapter 7

Recommendations for Management

> "Supply chains are interdependent ecosystems. Thousands of small suppliers feed mid-sized suppliers, which, in turn, feed large global corporations."
>
> *Peter Sondergaard, Senior VP, Gartner Research*

Supply chain risk occurs when a shock to the system exposes a vulnerability in the supply chain. Understanding the vulnerabilities, whether they are structural, operational, material, etc., is key to choosing where to proactively invest and thereby minimize the exposure from the supply chain shock. Given the current climate of the supply chain and the consequences of recency bias[1], it is recommended to act now to develop the processes and systems in place to identify those areas of vulnerability. Key to this change will be digitalization of the supply chain.

The TTR/TTS framework illustrated in Chapter 4 can be applied to existing sites as well as become embedded as part of a new product introduction work process. The mitigation measures evaluated in Chapter 5 and 6 are not limited to policy stock

[1]Recency bias is where there is more emphasis and memory placed on events currently taking place versus those in the past. As the supply chains begin to recover, less importance may be placed on risk mitigation frameworks. https://www.sciencedirect.com/topics/psychology/recency-effect

development or dual-sourcing therefore this chapter discusses additional mitigation options. However, before delving into those additional mitigation measures, we will begin with highlighting the importance of supplier relationships for realizing some of the benefits of the TTR/TTS framework.

7.1 Supplier Relationships

Supply chain visibility for both the supplier and the organization is critical to being able to work together through supply chain disruptions. To achieve this layer of visibility requires collaboration as well as continually developing and nurturing existing relationships. These relationships will be critical for not only maintaining a resilient and flexible supply chain but also for creating innovative solutions. For an example of supplier relationships applied in an organization, we turn to Toyota.

Aoki and Lennefors [8] cited a new perspective on an "improved" version of Toyota's *keiretsu* concept or "close-knit networks of vendors that continuously learn, improve, and prosper along with their parent companies" [24]. This new version breaks from the traditional approach allowing Toyota to create "supplier relationships that are more open, global, and cost-conscious than they ever were, yet it has deepened the trust, collaboration, and educational support that were the hallmarks of *keiretsu* in their earlier form" [8].

Although there is an initial investment in developing long-term relationships, supplier relationships and contributions were attributed to Toyota's resilience from the 2009-2010 period in which Toyota recalled vehicles around the globe but was able to increase overall quality and safety of the vehicles following reevaluation of their own standards as well as working with the suppliers to "strengthen their quality management...".

To create these long-term relationships, Liker and Choi wrote an article entitled *Building Deep Supplier Relationship* in the Harvard Business Review [24] comparing Toyota's partnership model with Honda and found that their approaches were quite similar and could be summarized as a hierarchy. A replication of this hierarchy is shown below in Figure 7-1:

Figure 7-1: Developing supplier relationships hierarchy adapted from Liker and Choi [24]

AZ is practicing some of these approaches with their suppliers. For example, by working with the suppliers to create supply chain maps, AZ is learning about their supplier and perhaps allowing the supplier to learn even more about their own supply chain as well (e.g. if the supplier has a decentralized organization, creating the supply chain maps is a way to connect disparate pieces). Additionally, by continually having S&OP meetings, both parties have the ability to share performance and share information about upcoming market dynamics that may impact the supply chain.

7.2 Planning, Balancing, Mitigating

Outside of supplier relationships, implementation of risk mitigations as well as alignment on acceptable levels of risk, particularly in environments where issues may not exist today, is under the discretion of management collaborating with the sites. If the TTR/TTS framework is adopted going forward, TTR can be a line item discussed during specific S&OP meetings to continue developing transparency and visibility on the supply chain.

The following sections showcase additional options to explore to enhance supply chain resiliency and flexibility; however, before progressing to the next section, there are a few initiatives that AZ is undertaking enabling exploration of the risk mitigation options as well as better results from the TTR/TTS tool.

First an ongoing "Master Data" project where data from each site's ERP system is being aggregated into a single system. This project harmonizes the material codes by standardizing the way material is stored (e.g. using the same naming convention) to enable accessibility by users. Additionally, this project will allow for ease of identification between raw materials and finished products without needing to look up the bill of materials each time.

Second, there is an ongoing initiative to explore upstream market intelligence tools. These tools will enable early identification of risks in the supply chain allowing for users of the TTR/TTS framework to zoom in on the nodes in question to proactively mitigate a supply chain disruption.

7.2.1 Demand Forecast Accuracy

As discussed in Chapter 3, after creating a clear view of where the inventory is located, another option is to scrutinize the forecast accuracy among the sites over the course of the past year to assess performance. The first step is beginning with a self-assessment to understand the status of where the company is in terms of forecasting accuracy. With an understanding of this base case scenario, further investigation can explain the potential sources of discrepancy (e.g. emergence of a competitor, shift in regulatory environment and/or market changes).

7.2.2 Inventory Re-positioning and Sharing

As discussed in Chapter 4, using the TTR/TTS framework also enables identifying materials where the TTR is less than the TTS. This may be indicative that there is room to reallocate inventory as discussed in the inventory re-positioning case referenced in Chapter 2. It is integral to include procurement in these discussions related to segmentation, risk indices, and mitigation plans.

Inventory sharing between the sites can also allow for increased business continuity and flexibility. Evaluations need to include which sites need the added flexibility and standardized methods for sharing material if there is not one already existing (e.g. how to document material movement between sites). Tax implications, material responsibility (i.e. once it is out of the supplier's scope, if anything happens to the material, does the responsibility rely on the site), and quality control would need a defined process. Standardized quality control allows for material to be quality checked one time and then shared among the sites.

Another inventory option is storing and earmarking inventory at a supplier site. From a dual sourcing perspective, further work with a single supplier can be done to evaluate how many upstream qualified suppliers and additional sites would be needed to further enhance the resiliency of the network.

Chapter 8

Conclusions and Future Work

"Some of Japan's most dominant companies owe their success not only to technology and process expertise but also to an often overlooked factor:...supplier relationships."

Aoiki and Lennefors [8]

This thesis provided a framework for applying the TTS/TTR model to the sourcing and supply of packaging materials in a pharmaceutical supply chain. The scope included developing the model framework, the process for interpretation, the application using Business Intelligence tools, and closing with an approach to quantify the trade-off between dual sourcing and increasing inventory. To reiterate, the scope for this thesis is limited to only the sourcing and supply for select foils; therefore, no further evaluations were evaluated on other parts of the supply chain (such as distribution logistics) or procurement methods. However, the foils are the most complex category based on SKU proliferation partially driven by printed artworks; therefore, the TTR/TTS tool complexity can be lowered as it is expanded to other materials. For example, the bottles category has an order of magnitude lower number of SKUs relative to foils.

Future work can include three areas: exploring further supply chain digitalization/harmonization, investigating upstream market intelligence applications, and developing further trade-off models for risk/resilience scoring. To achieve the benefits of this TTR/TTS framework, employing a model that connects with existing ERP systems will allow the organization to enhance real-time visibility on the supply chain and areas of risk. Investigating applications that deliver upstream market intelligence could provide a more proactive approach to managing supply chain vulnerabilities. Additionally, further work can be done on expanding a more quantitative measure of identifying whether to pursue single or dual sourcing strategies as there are more refined approaches as described in Chapter 3.

However, one item to reiterate is that, regardless of the data availability and work processes, maintaining collaborative relationships with suppliers is critical for managing supply chain vulnerabilities as discussed in Chapter 7.

Appendix A

Tables

Material Code	**Material Maping**	**Location**	**Nine-Box Segment**	**Patient Crticality**	**REI**	**Delta Inventory (kg)**	**Delta Inventory Cost ($k)**	**TTS (months)**
355	Printed blister lidding foil	**Site 1**	A2-medium	1	1	2671.07	488.81	0.075953
202	Plain Blister lidding foil	**Site 2**	A2-medium	1	0.447185	1160.98	3427.55	0.404856
985	Plain Blister lidding foil	**Site 4**	A1-medium	1	0.425032	1492.26	335.86	0.079103
869	Printed blister lidding foil	**Site 1**	A3-medium	1	0.385068	466.47	85.36	0.490446
977	Coldform	**Site 4**	A1-medium	1	0.327438	3555.23	884.40	0.085647
148	Printed blister lidding foil	**Site 2**	A1-medium	1	0.195103	5013.11	22013.33	0.019937
920	Plain Blister lidding foil	**Site 5**	A2-low	1	0.08761	142.58	3.14	2.137344
705	Coldform	**Site 1**	C3-high	3	0.077219	496.41	103.17	0.349283
345	Printed blister lidding foil	**Site 5**	B3-high	3	0.05461	64.28	2.29	0.108
727	Printed blister lidding foil	**Site 3**	C3-high	2	0.036886	92.08	97.60	18.36
502	Printed blister lidding foil	**Site 3**	C1-high	2	0.029229	169.86	180.05	8.568
410	Printed blister lidding foil	**Site 5**	B3-medium	3	0.012081	49.97	2.01	0.109
549	Printed blister lidding foil	**Site 5**	B3-high	3	0.010537	18.72	0.86	0.416988
202	Printed blister lidding foil	**Site 5**	B2-medium	3	0.008508	117.41	4.08	0.481114
829	Foil Type 1	**Site 4**	C3-high	1	0.000823	7.86	8.54	0.664615
786	Printed blister lidding foil	**Site 5**	C3-high	1	0.000669	119.39	10.76	0.398361
703	Printed blister lidding foil	**Site 5**	C3-high	1	0.000337	2.91	0.13	0.572727

Figure A-1: Example Minimum TTR materials identified at risk. This is not representative of actual operations.

Material Code	Material Description	Location	Nine-Box Segment	Patient Criticality	REI	Delta Inventory (kg)	Delta Inventory Cost ($k)	TTS (months)
567	Printed Blister Lidding Foil	Site 1	A2-medium	1	1.000	13620	830826	0.1
240	Plain Blister Lidding Foil	Site 5	A1-medium	1	0.893	6579	6473981	0.40
800	Printed Blister Lidding Foil	Site 1	A3-medium	1	0.798	2504	152733	0.5
372	Plain Blister Lidding Foil	Site 1	B3-high	1	0.668	9	522	1.3
877	Printed Blister Lidding Foil	Site 1	A2-medium	1	0.633	6974	425388	0.8
364	Plain Blister Lidding Foil	Site 1	B3-medium	1	0.527	39	2388	1.44
805	Plain Blister Lidding Foil	Site 4	A1-medium	1	0.505	8263	619893	0.08
899	Coldform	Site 4	A1-medium	1	0.391	19688	1632554	0.09
812	Plain Blister Lidding Foil	Site 5	A1-medium	1	0.218	27477	40218462	0.02
287	Plain Blister Lidding Foil	Site 1	A3-medium	1	0.187	148	9005	1.1
605	Plain Blister Lidding Foil	Site 1	B3-medium	1	0.153	1384	76103	0.9
918	Coldform	Site 1	B1-medium	1	0.147	58647	4063045	0.9
655	Coldform	Site 1	C3-high	3	0.113	2595	179773	0.3
332	Plain Blister Lidding Foil	Site 2	A2-low	1	0.098	624	4580	2.14
509	Plain Blister Lidding Foil	Site 5	A1-medium	1	0.093	11634	23921853	1.97
324	Plain Blister Lidding Foil	Site 5	A1-medium	1	0.070	2959	2988081	2.11
914	Printed Blister Lidding Foil	Site 1	A3-high	3	0.054	411	25044	1.9
893	Coldform	Site 1	C2-medium	3	0.038	11784	816368	1.1
908	Coldform	Site 2	A3-high	1	0.035	1200	6835	1.46
656	Plain Blister Lidding Foil	Site 4	A2-medium	1	0.025	990	2971	2.38
151	Plain Blister Lidding Foil	Site 1	C3-medium	3	0.022	271	16525	1.5
507	Plain Blister Lidding Foil	Site 1	C3-medium	3	0.022	200	12219	1.5
199	Plain Blister Lidding Foil	Site 1	C3-medium	3	0.018	462	28168	1.6
853	Printed Blister Lidding Foil	Site 2	B3-high	3	0.013	87	1328	0.42
434	Printed Blister Lidding Foil	Site 2	B2-medium	3	0.013	576	6682	0.48
462	Plain Blister Lidding Foil	Site 1	C3-medium	3	0.012	146	8876	1.2
602	Printed Blister Lidding Foil	Site 4	C3-high	1	0.011	43	4480	1.51
458	Printed Blister Lidding Foil	Site 3	A1-high	3	0.009	1117	263909	2.62
858	Plain Blister Lidding Foil	Site 1	C3-medium	1	0.008	1723	94778	1.6
759	Foil 1	Site 4	C3-medium	1	0.007	61	30323	1.81
486	Foil 1	Site 4	C3-medium	1	0.006	57	18792	1.15
944	Foil 1	Site 4	C3-high	1	0.006	46	16791	0.66
818	Printed Blister Lidding Foil	Site 2	B2-low	3	0.005	776	9086	1.46
778	Plain Blister Lidding Foil	Site 1	C3-medium	3	0.004	470	28658	2.0
268	Foil 1	Site 4	C3-high	2	0.004	48	5593	1.23
932	Foil 1	Site 4	C3-medium	2	0.004	85	23297	1.49
320	Foil 1	Site 4	C3-medium	1	0.004	48	14092	1.33
945	Foil 1	Site 4	C3-high	2	0.003	75	42560	1.45
327	Foil 1	Site 4	C3-medium	2	0.003	142	32779	1.60
616	Foil 1	Site 4	C3-high	2	0.003	22	7289	1.65
851	Printed Blister Lidding Foil	Site 1	C3-high	2	0.003	335	20449	1.6
474	Coldform	Site 1	C3-medium	2	0.002	1116	77288	1.36
556	Printed Blister Lidding Foil	Site 2	C3-high	1	0.002	13	997	1.08
577	Foil 1	Site 4	C3-high	2	0.002	24	9115	1.77
471	Foil 1	Site 4	C3-high	1	0.002	20	7563	2.08
455	Foil 1	Site 4	C3-high	1	0.001	17	6539	2.08
611	Foil 1	Site 2	C3-high	2	0.001	33	666	1.15
164	Foil 1	Site 4	C3-medium	1	0.001	20	2731	2.23
396	Printed Blister Lidding Foil	Site 2	C3-high	1	0.001	542	16279	0.40
235	Printed Blister Lidding Foil	Site 2	C3-high	1	0.001	14	203	0.57
192	Foil 1	Site 4	C3-medium	1	0.001	30	15817	2.33
185	Printed Blister Lidding Foil	Site 2	C3-medium	1	0.001	58	897	0.88

Figure A-2: Example of materials identified at risk for an average TTR. This is not representative of actual operations.

Material Code	Material Description	Location	Nine-Box Segment	Patient Criticality	REI	Delta Inventory Cost ($k)	Delta Inventory (kg)	TTS (months)
799	Plain Blister lidding foil	Site 1	B3-high	1	1.0000	763	13	1.252
672	Plain Blister lidding foil	Site 1	B3-medium	1	0.9387	3756	62	1.436
112	Printed blister lidding foil	Site 1	A2-medium	1	0.8878	1179842	19342	0.076
872	Printed blister lidding foil	Site 1	A3-medium	1	0.7996	221480	3631	0.490
874	Printed blister lidding foil	Site 1	A2-medium	1	0.7280	626654	10273	0.827
883	Plain Blister lidding foil	Site 5	A2-medium	1	0.7142	5948285	6044	0.405
836	Plain Blister lidding foil	Site 3	A1-medium	1	0.3788	570880	7609	0.079
420	Plain Blister lidding foil	Site 1	B3-high	1	0.3411	4057	67	3.227
740	Coldform	Site 3	A1-medium	1	0.2943	1739384	20977	0.086
648	Printed blister lidding foil	Site 1	A3-high	3	0.2620	38954	639	1.916
903	Printed blister lidding foil	Site 1	A3-medium	1	0.2559	13771	226	1.135
653	Plain Blister lidding foil	Site 1	B3-medium	1	0.1804	113618	2066	0.885
706	Coldform	Site 1	B1-medium	1	0.1781	6152646	88808	0.928
992	Coldform	Site 5	B1-medium	1	0.1753	16801924	8171	1.974
637	Printed blister lidding foil	Site 1	A3-medium	1	0.1706	8604	141	2.976
673	Plain Blister lidding foil	Site 3	A2-medium	1	0.1699	2584	861	2.380
613	Printed blister lidding foil	Site 5	A2-medium	1	0.1651	2085334	2065	2.106
904	Plain Blister lidding foil	Site 1	B3-medium	1	0.1646	5270	86	3.756
573	Printed blister lidding foil	Site 5	B3-medium	1	0.1621	30267035	20678	0.020
211	Printed blister lidding foil	Site 1	A3-high	3	0.1578	64023	1050	2.196
319	Printed blister lidding foil	Site 1	B3-medium	2	0.1315	8560	140	2.296
844	Printed blister lidding foil	Site 1	A3-medium	3	0.1182	3127	51	2.712
671	Coldform	Site 1	C3-high	3	0.1078	257939	3723	0.349
749	Printed blister lidding foil	Site 5	C3-high	1	0.1061	1154466	896	2.743
356	Coldform	Site 2	A3-high	1	0.1035	6357	1116	1.464
545	Plain Blister lidding foil	Site 2	A2-low	1	0.0732	3013	410	2.137
173	Coldform	Site 2	A1-low	1	0.0632	11301	1610	3.313
571	Coldform	Site 1	C2-medium	3	0.0491	1248845	18026	1.052
589	Printed blister lidding foil	Site 2	A3-medium	1	0.0479	786	31	2.174
900	Plain Blister lidding foil	Site 1	C3-medium	3	0.0422	26553	435	1.503
560	Plain Blister lidding foil	Site 1	C3-medium	3	0.0421	19554	321	1.508
538	Plain Blister lidding foil	Site 3	A1-medium	1	0.0414	4448	1483	3.794
410	Plain Blister lidding foil	Site 1	C3-medium	3	0.0406	45723	750	1.608
404	Plain Blister lidding foil	Site 1	C3-medium	3	0.0351	48361	793	2.002
598	Printed blister lidding foil	Site 2	B3-high	3	0.0264	6381	538	0.108
536	Printed blister lidding foil	Site 1	A3-high	3	0.0252	94800	1554	2.672
901	Plain Blister lidding foil	Site 2	A1-low	1	0.0228	-1020	-139	3.593
101	Printed blister lidding foil	Site 1	B3-medium	1	0.0183	18468	220	3.381
155	Plain Blister lidding foil	Site 1	C3-medium	1	0.0169	154016	2800	1.563
535	Plain Blister lidding foil	Site 1	C3-medium	3	0.0168	13690	224	1.213
516	Printed blister lidding foil	Site 2	B2-low	3	0.0140	25593	2186	1.461
853	Plain Blister lidding foil	Site 1	C3-medium	3	0.0140	6864	113	3.337
380	Printed blister lidding foil	Site 1	B1-medium	1	0.0139	53254	208025	2.342
639	Printed blister lidding foil	Site 3	C3-high	1	0.0130	4844	46	1.507
296	Printed blister lidding foil	Site 2	B3-high	3	0.0117	2572	168	0.417
247	Printed blister lidding foil	Site 4	A1-high	3	0.0116	219150	928	2.623
693	Printed blister lidding foil	Site 2	B2-medium	3	0.0114	13585	1172	0.481
950	Foil 1	Site 3	C3-medium	1	0.0105	29721	59	1.814
995	Plain Blister lidding foil	Site 1	C3-medium	3	0.0095	85925	1562	2.273
123	Coldform	Site 1	C2-medium	3	0.0087	388653	5610	2.445
127	Coldform	Site 1	C3-medium	3	0.0081	247767	3576	2.562
344	Printed blister lidding foil	Site 2	B3-medium	1	0.0071	4419	50	2.750
764	Plain Blister lidding foil	Site 3	A1-medium	1	0.0068	-3606	-1202	4.175
897	Printed blister lidding foil	Site 1	C3-high	2	0.0061	30865	506	1.588
316	Printed blister lidding foil	Site 2	B3-medium	3	0.0058	5476	409	0.110
397	Foil 1	Site 3	C3-medium	1	0.0058	18460	56	1.146
939	Printed blister lidding foil	Site 2	C3-high	2	0.0053	1391	69	1.153
458	Foil 1	Site 3	C3-high	1	0.0050	16528	46	0.665
845	Foil 1	Site 3	C3-medium	2	0.0046	22867	83	1.493
736	Foil 1	Site 3	C3-medium	2	0.0044	32134	139	1.599
382	Foil 1	Site 3	C3-high	2	0.0043	5502	47	1.228
729	Foil 1	Site 3	C3-high	2	0.0043	7161	22	1.646
937	Foil 1	Site 3	C3-high	1	0.0041	7422	20	2.080
506	Foil 1	Site 3	C3-medium	1	0.0040	13838	47	1.335
559	Foil 1	Site 3	C3-high	2	0.0040	41833	73	1.449
534	Coldform	Site 1	C3-medium	2	0.0038	121096	1748	1.364
297	Foil 1	Site 3	C3-medium	1	0.0031	15473	29	2.334
953	Foil 1	Site 3	C3-high	2	0.0030	122	354	2.437
196	Foil 1	Site 3	C3-high	1	0.0030	6413	17	2.080
705	Foil 1	Site 3	C3-high	2	0.0029	19512	33	2.481
906	Foil 1	Site 3	C3-medium	1	0.0028	2674	19	2.227
341	Foil 1	Site 3	C3-high	2	0.0027	8956	24	1.768
970	Printed blister lidding foil	Site 2	C3-medium	3	0.0027	3755	303	1.586
309	Printed blister lidding foil	Site 2	C3-high	1	0.0026	1946	26	1.080
812	Foil 1	Site 3	C3-high	1	0.0017	444	13	2.353
712	Foil 1	Site 3	C3-high	1	0.0017	1140	31	3.050
703	Foil 1	Site 3	C3-high	2	0.0015	5400	15	2.903
603	Foil 1	Site 3	C2-high	2	0.0014	201	579	2.959
188	Printed blister lidding foil	Site 2	A1-low	1	0.0011	30718	2755	2.951
987	Foil 1	Site 3	C3-medium	1	0.0010	441	12	2.543
489	Foil 1	Site 3	C3-high	2	0.0009	6555	11	3.686
946	Foil 1	Site 3	C3-high	1	0.0009	7619	20	2.800
518	Printed blister lidding foil	Site 2	C3-high	1	0.0009	1486	76	1.056
507	Foil 1	Site 3	C3-high	1	0.0008	595	16	3.661
508	Printed blister lidding foil	Site 2	C3-high	1	0.0007	30936	1029	0.398
277	Foil 1	Site 3	C3-high	2	0.0007	3285	9	3.629
349	Printed blister lidding foil	Site 2	C3-high	1	0.0007	396	26	0.573
150	Printed blister lidding foil	Site 2	C3-high	1	0.0007	1	15	1.800
466	Printed blister lidding foil	Site 2	C3-medium	1	0.0007	1854	121	0.882
366	Foil 1	Site 3	C3-high	1	0.0006	6	18	3.935
484	Printed blister lidding foil	Site 2	C3-medium	1	0.0005	586	27	2.255
243	Printed blister lidding foil	Site 2	C3-high	1	0.0005	19762	484	1.016
138	Printed blister lidding foil	Site 2	C3-high	1	0.0005	5078	321	2.348
611	Foil 1	Site 3	C3-high	2	0.0005	4008	11	3.789
743	Foil 1	Site 3	C3-high	1	0.0005	5398	16	3.892
385	Printed blister lidding foil	Site 2	C3-high	1	0.0004	665	36	2.634
728	Printed blister lidding foil	Site 2	C3-high	1	0.0004	550	36	1.647
562	Printed blister lidding foil	Site 2	C3-medium	1	0.0003	2925	226	1.525
105	Printed blister lidding foil	Site 2	C3-medium	1	0.0002	1217	62	2.253
430	Foil 1	Site 3	C3-high	1	0.0002	2561	7	4.114
846	Printed blister lidding foil	Site 2	C3-medium	2	0.0001	6697	532	0.949
216	Printed blister lidding foil	Site 2	C3-medium	1	0.0001	1166	115	2.600
195	Printed blister lidding foil	Site 2	C3-medium	2	0.0001	2796	219	2.535
734	Printed blister lidding foil	Site 2	C3-medium	2	0.0001	2590	164	0.998
450	Printed blister lidding foil	Site 2	C3-high	1	0.0001	437	17	1.400
124	Printed blister lidding foil	Site 2	C3-medium	2	0.0000	3297	234	1.731
580	Printed blister lidding foil	Site 2	C3-medium	1	0.0000	823	32	3.945
509	Printed blister lidding foil	Site 2	C3-high	2	0.0000	1270	58	2.790
955	Printed blister lidding foil	Site 1	B3-medium	2	-0.0003	27180	399	1.935

Figure A-3: Example of materials identified at risk for a maximum TTR. This is not representative of actual operations.

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