Improving Inventory and Distribution in an Aerospace Parts and Service Organization

by

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Bachelor of Science in Industrial Engineering, Kettering University (2004)

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Abstract

Hamilton Sundstrand has made several changes to their supply chain in recent years, including increased offshore and outsourced production, new service offerings and relocation of facilities, to meet shifting business needs to remain a top competitor in the aerospace systems industry. This thesis reviews the distribution network of their aftermarket parts and service business to ensure that Hamilton Sundstrand meets customer needs through efficient supply chain design and aligning business strategy with inventory planning.

A review of the current state is employed to locate gaps in strategic design, operating efficiencies and customer service levels. Improvement opportunities identified in the current state analysis are addressed with proposed alternatives to adjust the distribution network to meet current and future needs while minimizing cost and maintaining or raising service levels. The combined proposals of relocating distribution center volumes, reducing on hand inventory at co-located sites and closing a forward stocking location are estimated to result in over one million dollars in annual cost savings.

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1. Introduction

Companies across most durable goods industries have seen a revenue growth opportunity in extending their involvement in the product lifecycle beyond initial purchase through replacement parts, repair services and other recurring revenue sources. The higher profitability of services and replacement parts compared to initial production is appealing, as is the ability to secure a long term relationship with the customer. The aerospace industry is especially engaged in providing long term support as their product lines can see use for many years, sometimes in excess of 20 years. Along these lines, many aircraft parts and systems suppliers have built a strong business in aftermarket parts and service. Hamilton Sundstrand, a major aerospace parts and systems supplier, has established itself as a leader in long term customer service. They have been able to sustain excellent service to meet customer demand and, as a result, enabled long term customer relationships.

Providing the high service levels demanded by their customers brings with it significant operating costs. The Customer Service division, which oversees the aftermarket business for Hamilton Sundstrand, meets customer demand for parts and service through a far reaching distribution network. Fulfilling the needs of many customers worldwide with a broad product catalog, long production lead times and quick order turnaround often means carrying substantial inventories. The policies they set to govern inventory management and distribution logistics can significantly impact their costs and level of service. Deciding where to place inventory, how much inventory to keep and how to fulfill orders are all critical to balancing meeting customer expectations and keeping costs in check.

This thesis is the result of a six-month internship project within the Customer Service division of Hamilton Sundstrand tasked with identifying opportunities to better address the
inventory and distribution challenges of the aftermarket business and recommending alternatives to improve cost and customer service performance. The approach used includes a combination of supply chain strategy, single item inventory optimization, network flow, and multi-echelon inventory analysis. These techniques are popularly used in reducing total supply chain costs and resulted in significant savings in this analysis of Hamilton Sundstrand’s aftermarket network.

1.1. Hamilton Sundstrand

Hamilton Sundstrand is a subsidiary of the United Technologies Corporation (UTC). UTC (NYSE: UTX) “provides high technology products and services to the building systems and aerospace industries worldwide” (UTC 10K Filing, 2009). UTC has managed significant growth organically and through acquisitions throughout its history. In their 2009 10K filing UTC identifies itself as having six business segments in two main categories:

- Commercial Businesses:
  - **Otis** - elevators, escalators, moving walkways and service.
  - **Carrier** - heating, ventilating, air conditioning (HVAC) and refrigeration systems, controls, services and energy efficient products for residential, commercial, industrial and transportation applications.
  - **UTC Fire & Security** - fire and special hazard detection and suppression systems and firefighting equipment, security, monitoring and rapid response systems and service and security personnel services.

- Aerospace Businesses:
  - **Pratt & Whitney** - commercial, military, business jet and general aviation aircraft engines, parts and services, industrial gas turbines, geothermal power systems and space propulsion.
o **Hamilton Sundstrand** - aerospace products and aftermarket services, including power generation, management and distribution systems, flight systems, engine control systems, environmental control systems, fire protection and detection systems, auxiliary power units, propeller systems and industrial products, including air compressors, metering pumps and fluid handling equipment.

o **Sikorsky** - military and commercial helicopters, aftermarket helicopter and aircraft parts and services.

In addition to these business segments UTC operates a group called UTC Power that works on developing and commercializing fuel cell technologies. UTC also operates a central research and development group (Research Center) near the corporate headquarters in Hartford, CT.

![UTC 2009 Revenues by Business Segment](image)

**Figure 1 - UTC 2009 Revenues**

UTC businesses had collective revenues of $52.9B in 2009 with 53.9% coming from the commercial businesses and 46.1% from the aerospace group. Sixty percent of revenues were attributed to business outside of the United States. UTC's 2009 revenues placed them as #37 on the Fortune 500 ranking for the largest American companies for the second straight year (Fortune Magazine, 2010). Internationally they rank #130, slipping slightly from #123 the previous year (Fortune Magazine, 2010). As of December 31, 2009, UTC employed 206,700 personnel worldwide, with approximately 65% of the workforce located internationally.
Hamilton Sundstrand represents 10.4% of the total UTC revenue for 2009 and contributes a significant portion (24.5%) of the aerospace group. Hamilton Sundstrand is among the world's largest suppliers of technologically advanced aerospace and industrial products. Hamilton Sundstrand designs and manufactures aerospace systems for commercial, regional, corporate and military aircraft, and is a major supplier for international space programs (Hamilton Sundstrand Communications, 2010). The company has parts and systems on nearly every in-service aircraft and has been selected as a key supplier for many new developments, including the Boeing 787 Dreamliner that will soon enter service. Hamilton Sundstrand has over 600 parts in nine different systems on the Dreamliner, with lifetime project revenues estimated to surpass $15B. The company is also the prime contractor for NASA’s space suit and life support systems for their international space programs.

Hamilton Sundstrand is the result of a June 10th, 1999 merger of the Sundstrand Corporation with its Hamilton Standard business. Both Hamilton Standard and Sundstrand have a long and prominent history in the aerospace industry. Hamilton Standard got its start in 1929 through the merger of Hamilton Aero Manufacturing and Standard Steel Propellers under ownership of UTC’s predecessor, the United Aircraft and Transport Corporation. Hamilton Standard had propellers and other parts on such historic aircraft as Charles Lindbergh’s The Spirit of St. Louis and Amelia Earhart’s Electra 10E. Sundstrand Corporation had an earlier start in 1905 as a tooling and milling company, gaining its name in 1926 from the founding brothers and innovated in mechanical and electrical aerospace components throughout its history. After the 1999 merger, Hamilton Sundstrand used its Windsor Locks, CT location as the world headquarters. As of 2010, Hamilton Sundstrand includes 16,400 employees located at 150 facilities in 20 countries around the world (Hamilton Sundstrand Communications, 2010).
1.2. Customer Service Division

The Hamilton Sundstrand Customer Service (HSCS) division is primarily charged with providing spare parts, repair services, training and technical support for the product lines that Hamilton Sundstrand develops. The HSCS enterprise reaches from vendor sourcing all the way through to sales to external customers (e.g., airlines).

Figure 2 - Hamilton Sundstrand Customer Service Locations

The Customer Service group supports customers through a worldwide network of facilities, with major distribution centers in the domestic United States, repair facilities in each of the International Air Transport Association (IATA) regions, and On Site Support (OSS) locations at numerous customer locations. Figure 2 shows a map of the major Customer Service locations including distribution centers (DC), repair facilities (RC) and several OSS locations. In addition to the distribution and service infrastructure, a state-of-the-art Customer Response Center was added in 2010 to provide customers with a single point of contact for issue resolution.

The main customer offerings of the Customer Service division are providing aftermarket parts (“spares”), repair services and vendor managed inventory called on-site support (OSS).
Most spares have a catalog lead time to customers of seven (7) days, but in the event of an aircraft on ground (AOG) emergency where a plane needs a critical part, turnaround times could be required for the same day. Spares sales to external customers are generally serviced out of the main distribution centers, as are replenishments to the repair and onsite support locations. More recently, asset management programs have provided new opportunities for customers to “rent” parts by the in-service time rather than buy them outright.

Repair services are provided for repairable assemblies and parts at repair centers in each IATA region. Broken units arrive at the nearest facility associated with the product family where they are torn down and troubleshooted to determine the cause and repaired with the necessary spare parts and adjustments. The entire repair process is typically required to occur within a 15 day turnaround time. Spares for the repair services are stocked locally at the repair center.

OSS is a unique offering to customers that would like a vendor managed inventory solution for their Hamilton Sundstrand parts. A long term contract is signed which provides the customer with Hamilton Sundstrand owned and managed inventory at their own location, where the parts are only billed once the parts are consumed. These locations have very high customer service levels, requiring them to keep inventory for a wide variety of parts.

Among its other responsibilities, the Customer Service division manages the inventory and transportation of spares to support their direct customer orders and replenishments for their service locations. Ownership of this responsibility falls under the Materials Management group within the World Wide Repair and Supply Chain organization as shown in Figure 3. Due to the significant differences in order fulfillment and inventory controls, commercial and military spares are managed by separate teams within the Materials Management group.
The senior leadership of the Customer Service group believed that there were opportunities to reduce inventory levels within the aftermarket distribution network while still maintaining customer service performance. The six-month internship project was initiated by their concern in there being inefficient inventory throughout the network. The author worked with the Materials Management group to analyze the inventory and distribution policies currently in place and develop alternative approaches with the support of the group’s subject matter experts.

1.3. Achieving Competitive Excellence (ACE)

Hamilton Sundstrand is a performance oriented organization with a variety of metrics from customer service to financial performance. The metrics roll up into a proprietary performance management system, called Achieving Competitive Excellence (ACE). ACE is a framework similar to the Toyota Production System that has been adopted across all of UTC. ACE integrates a philosophy, a suite of well-established tools, and a commitment of total employee engagement to increase operating efficiency, reduce waste and improve customer satisfaction (Supplier Development, 2010).
The performance against metrics is tracked faithfully, validated with annual surveys to customers throughout the supply chain and used as the basis for continuous improvement efforts like kaizen events and value stream mapping. Through a rigorous, data-driven process assessed by internal assessors, employees and their organizations progress through the qualifying, bronze, silver and gold levels of ACE (Supplier Development, 2010). Many organizations have continuous improvement efforts in place, but often they are strictly a set of tools with limited executive support and become a “flavor of the month” in a string of new business initiatives. UTC and Hamilton Sundstrand have demonstrated early success at overcoming this tendency and integrated the ACE philosophy into all processes and more importantly their company culture.

The Customer Service group has used ACE as a framework to manage the performance of their ever increasing customer demand responsibilities. Providing high availability of parts and quick turnaround leads to high operating costs. ACE helps track and improve metrics like service level, stock outs, inventory turns and total inventory investment. The ACE suite of metrics presented a good opportunity to track past performance, establish a benchmark for the current state of operations and validate the recommended changes implemented as a result of the project. Many of the analysis approaches described in this thesis used the metrics as a barometer for how operational policies and strategies were driving performance, and where opportunities may be to improve the performance of the system.

1.4. Overview of Chapters

This introduction established a high level background of Hamilton Sundstrand and the aftermarket business managed by the Customer Service group, the setting of the internship. Chapter 2 will provide additional background on the specific task at hand, improving the cost and service performance of the aftermarket service network. Chapter 3 implements many of the
tools and methods used in academics and industry to develop an understanding of the current state of the network performance. Chapter 4 takes the findings from Chapter 3 and defines alternatives for deeper analysis. The ultimate result of Chapter 4 is a set of recommendations derived from the alternatives analysis that could be implemented to improve service and/or cost performance in the aftermarket service network.
2. Project Overview

Hamilton Sundstrand's Customer Service division manages, among other things, the aftermarket parts and repair service distribution network. The aftermarket distribution network is essentially a spare parts supply chain reaching from component suppliers through to end customers. As with any good supply chain design, the aftermarket supply chain is a product of its business strategy, providing high service levels. Even with a high service strategy, it is imperative to manage costs to maintain a profitable business. Managing that balance of service and cost efficiency is a primary focus of the Customer Service group. This project assists the group's ongoing efforts by analyzing the current network design and inventory policies to locate opportunities for minimizing cost while maintaining high service levels.

2.1. The Aftermarket Distribution Network

The aftermarket distribution network is a fairly simple design with just three main stages: suppliers, distribution centers (DCs) and customers as shown in Figure 4. Each stage has locations that are geographically dispersed creating a truly global supply chain.

![Figure 4 - Simplified Network Design](image)

The aftermarket distribution network supplies spare parts to “external customers” including over 800 airlines, maintenance repair and overhaul (MRO) organizations as well as providing parts to
their own “internal customer” sites. The internal sites include repair service facilities and vendor managed inventory sites for customers called on site support (OSS) locations.

2.1.1. Repair Service Sites

The repair sites receive parts or assemblies from customers that need to be refurbished and returned within 15 days or less. Repair centers specialize in certain product families and, in most cases, are duplicated in each market to provide quick turnaround. Markets are defined as the three major International Air Transport Authority (IATA) regions: the Americas; Europe, Middle East and Africa (EMEA) and Asia. In order to maintain high service levels on tight deadlines, repair centers carry their own inventory on parts, generally several thousand unique part numbers, required for their operations. Replenishments of parts for a repair center typically come from only one of the four main distribution centers as they too are dedicated to certain product families. The repair centers supporting IATA 1, the Americas, are located in the United States, typically in the same building as or adjacent to their supplying distribution center. The IATA 1 repair centers have the highest repair volumes and part usage of the repair network.

2.1.2. On Site Support (OSS) Locations

OSS locations are a vendor managed inventory solution that Hamilton Sundstrand provides for customers. These locations have a limited part list, generally about 2,000 unique parts, that is maintained locally to support the products used by that specific customer. Window service levels, or having the part immediately available when a request is made to the stockroom, at OSS sites are maintained above 97% and parts not immediately available must be supplied within three to seven days. Because these sites may support multiple product families to fulfill all of a customer’s needs, they need to be replenished by more than one distribution center. OSS
locations are dispersed throughout the world depending on contract agreements with customers, with at least one site in each IATA region.

![Figure 5 - High Level Supply Chain Flow](image)

2.1.3. Distribution Centers

All customers, internal and external, are supplied by the distribution stage: four main distribution centers, two forward stocking locations and a third party warehouse. The distribution centers are all located in or near the United States; the two larger distribution centers are in Rockford, IL and Windsor Locks, CT and two smaller sites located in Phoenix, AZ and Puerto Rico. Parts are shipped direct from each of the distribution centers to the customer sites based on received orders, which in the case of internal customers are replenishments for their local stock levels. Due to the difference in customer demand lead times (under seven days) and supply lead times (often greater than six months), distribution centers must carry inventory to buffer demand and supply. The two forward stocking locations, located in Asia and the Middle East, were originally set up to keep inventory of certain items in their local markets based on customer requirements, tax advantages and speed to market. The third party warehouse keeps stock of older parts that see very limited demand.
2.1.4. Suppliers

The supplier stage, like the customer stage, is divided into internal and external sources. Internal sources are Hamilton Sundstrand’s own manufacturing facilities that produce for original production as well as the aftermarket. Over the past decade Hamilton Sundstrand has transitioned from manufacturing most parts to today purchasing roughly 80% of their parts and manufacturing the remainder. The increase in outsourced parts has created a wide base of suppliers, however many of the outsourced parts used in the aftermarket still flow through the Hamilton Sundstrand manufacturing facilities. Only approximately 15% of parts are sourced directly from suppliers to aftermarket distribution centers, termed “direct receipt” parts, the remainder is sourced from the manufacturing facility associated with that product group. Like the IATA 1 repair centers, the domestic manufacturing facilities, or “internal suppliers,” are located at the same sites as distribution centers.

2.1.5. Transportation

Transportation within the aftermarket distribution network is almost entirely air freight, even replenishments from suppliers to the DCs and from the DCs to the remote repair and OSS sites. While this normally would not be cost effective for most supply chains, the nature of aircraft parts make this transportation method feasible. Most aircraft parts are very expensive, light weight products that fit the characteristics of air transportation. The high part costs also drive up inventory costs, so inventory on hand is typically kept as low as possible and expedited transportation is used to ensure service levels are maintained. Furthermore, most outbound shipments to customers are free on board (FOB) at the shipping dock, meaning the customer picks up the cost for transportation. As most Hamilton Sundstrand parts are run-to-failure rather
than life limited parts, a spare part is generally ordered only when needed or to refill a limited stock and is expedited.

2.2. Problem Statement

The high service level commitments and global reach of the aftermarket distribution network creates a difficult inventory and supply chain challenge for the Hamilton Sundstrand Customer Service group. One core issue is that the distribution network has a supply and demand lead time imbalance, requiring inventory to be held to meet customer demand. The high value aircraft parts drive up inventory cost quickly. Determining how much inventory to keep and at which locations in the supply chain to keep them to meet high service levels at a minimized cost is a strategic imperative for the Customer Service group. The intent of this project is to analyze the current aftermarket distribution network for improvements in network design, inventory policy and transportation to reduce operating costs while maintaining high service levels.

2.3. Project Objectives

A successful project outcome provides the Customer Service leadership team with a set of recommendations for improving their distribution network on the basis of service level improvements and cost reductions. The recommendations provide explicit actions to implement with respect to inventory policies, facility network design and transportation methods. Recommendations will be supported by a cost & benefit analysis as well as impact on customer service levels.

2.4. Approach

The aftermarket distribution network at Hamilton Sundstrand is a mature and continuously improving supply chain. Several enhancements have been made in recent years to increase service and cost performance, including the implementation of a new demand forecasting system
and improvements to inventory and distribution policies. With this in mind, a hierarchical approach to locate and rectify inefficiencies in the current system was taken rather than undertaking a complete redesign of the supply chain. A high level analysis was performed to identify potential sources of inefficiencies which were then refined through data analysis, modeling and interviews with subject matter experts. Alternatives showing the greatest promise, measured on reduced operating costs, maintained or improved service levels and impact to other operations, were prepared as recommendations to the Customer Service leadership team for implementation.
3. Current State Analysis

There are many approaches to find improvements in an organization’s supply chain. When faced with a broad goal of refining the cost and service performance of an entire distribution network, like Hamilton Sundstrand’s aftermarket business, there are benefits to first performing high level analyses to highlight problem areas and then “sharpening the pencil” in those areas to locate the specific gains. Following this hierarchal approach, the high level analysis of the current state begins with the overall supply chain strategy, continues on to network planning and a cursory analysis using the logistical drivers of inventory, transportation and facilities to identify problem areas.

3.1. Supply Chain Strategy

It is vital to begin a cost and service analysis at the supply chain strategy level to deliver an appropriate end solution. Many solutions can be identified that lower cost to serve, but if they move the supply chain out of alignment with the business’ competitive strategy then they ultimately have failed to deliver value.

3.1.1. Supply Chain Fit to Competitive Strategy

A firm’s competitive strategy defines, relative to its competitors, the set of customer needs that it seeks to satisfy through its products and services (Chopra & Meindl, 2007). There are a variety of competitive differentiators that companies typically seek to satisfy. Chopra and Meindl (2007) describe a key strategic decision in the tradeoff between cost and responsiveness. Another common framework for identifying customer needs segments on cost, quality, availability and innovativeness (Hayes & Wheelwright, 1984). No matter which framework you use it is universally understood that a firm cannot compete on all dimensions simultaneously.

Successfully delivering on one dimension requires sacrificing one or more of the other
dimensions. Chopra and Meindl (2004) represent the trade off as an efficient frontier curve, shown in Figure 6. Providing higher levels of responsiveness comes at the expense of higher cost as a firm moves along the curve to the upper left. This assumes, however, that the firm is operating on the efficient frontier and many organizations are in fact inside the curve where they can improve both cost and responsiveness by moving towards the efficient frontier.

![Figure 6 - Cost-Responsiveness Efficient Frontier](source)

**Figure 6 - Cost-Responsiveness Efficient Frontier**

**Source: Chopra and Meindl (2007)**

Determining the strategic fit of the Hamilton Sundstrand aftermarket business to the cost-responsiveness tradeoff is heavily impacted by its products' characteristics. For companies to be sure that they are taking the right approach, they must first determine whether their products are functional or innovative (Fisher, 1997). While a few of the characteristics Fisher (1997) describes as qualifying an innovative product (i.e., short life cycle and short lead time) do not necessarily apply to Hamilton Sundstrand's aftermarket parts, the key characteristics of uncertain demand and high margin certainly do.

Demand uncertainty is linked to the repair use nature of aftermarket parts. The majority of the company's parts are not life-limited, meaning they are only replaced when there are failures or pending failures rather than on routine maintenance schedules. The parts are also very expensive, leading to most companies carrying minimal stock to sustain their repair operations.
These two demand characteristics drive a significant amount of uncertainty. The high margins of the parts are typical of other aftermarket industries where initial contracts are won at thin margins and profits are realized through service and spare parts. With these key characteristics of high margins and uncertain demand, there is a strong strategic fit for Hamilton Sundstrand’s products with a high response supply chain.

A responsive strategy dictates the characteristics of the supply chain design. Fisher (1997) presents a comparison of these supply chain characteristics, shown in Figure 7, that directs the design based on factors like inventory strategy, lead time strategy and supplier strategy. For Hamilton Sundstrand’s supply chain this means a design with responsive suppliers, higher inventories and aggressively pursuing short lead times.

<table>
<thead>
<tr>
<th>Efficient Supply Chains</th>
<th>Responsive Supply Chains</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Goal</strong></td>
<td>Supply demand at the lowest cost</td>
</tr>
<tr>
<td><strong>Pricing strategy</strong></td>
<td>Lower margins because price is a prime customer driver</td>
</tr>
<tr>
<td><strong>Manufacturing strategy</strong></td>
<td>Lower costs through high utilization</td>
</tr>
<tr>
<td><strong>Inventory strategy</strong></td>
<td>Minimize inventory to lower cost</td>
</tr>
<tr>
<td><strong>Lead time strategy</strong></td>
<td>Reduce, but not at high expense</td>
</tr>
<tr>
<td><strong>Supplier strategy</strong></td>
<td>Select based on cost and quality</td>
</tr>
</tbody>
</table>

Figure 7 - Comparison of Efficient and Responsive Supply Chains
Adapted from Fisher (1997)

The design of the supply chain encompasses a wide breadth of topics including location and capacity of facilities, whether to outsource, transportation modes, which markets to serve from which locations, the inventory policies at each location and how to fulfill orders. Each of these topics requires design decisions with impacts over varying time horizons. Chopra and Meindl (2007) describe three categories for these decisions: supply chain design, supply chain
planning and supply chain operation. Supply chain operation decisions, like how to handle individual customer orders, have a tightly-defined scope and a time horizon measured in days. They are too micro-focused for an initial review. Only the supply chain design and supply chain planning focus areas will be used in the current state analysis.

3.2. Supply Chain Design

Supply chain design is comprised of decisions with time horizons of several years. These include whether to outsource or perform a supply chain function in-house, choosing the locations and capacities of production and warehousing facilities, which products to be made or stored at various locations, the modes of transportation to be made available along different shipping legs and the type of information system to be utilized (Chopra & Meindl, 2007).

These decisions are made for the long term and are very difficult and expensive to change. Making these decisions requires considering long term fluctuations in supply, demand, customers and the business environment. The impacts of these decisions become operating conditions that support or constrain the business for many years. Because of these long lasting impacts and reluctance to revisit decisions, it is not uncommon for companies to have supply chains that do not match their current environment. In many companies, supply chains were designed to reflect the company’s operating needs ten to twenty years earlier; it is a core source of poor supply chain performance for many businesses (Byrnes, 2010). The antiquated supply chain design decisions that fit earlier operating needs can be a large source of savings if corrected to meet current needs.

Since the production and sourcing component of the aftermarket distribution network is largely dictated by Hamilton Sundstrand’s OEM activities, the focus of the supply chain design
analysis is directed at locations of and uses of aftermarket network facilities, the products stored at each facility and the transportation methods employed.

3.2.1 Facilities

The facilities decision incorporates three main subject areas: facility role, facility location and facility size. Each subject area of facilities decisions has a significant impact on the capabilities and performance of the supply chain. Decisions in one area impact decisions in other areas, for example having multiple locations to serve customers may lead to smaller location sizes. The facilities analysis follows these subject areas for the purpose of discussion but overlaps to discuss associations between subject areas to reflect the relationships and tradeoffs.

3.2.1.1 Facility Role

Just as a single supply chain cannot meet the market needs of cost, quality, availability, variety or innovativeness without sacrificing in a few of the other areas, a single facility cannot effectively or efficiently meet all the needs of the supply chain. A factory cannot perform well on every yardstick, and simplicity and repetition breed confidence (Skinner, 1974). Beckman and Rosenfield (2008) discuss facility focus across four main dimensions: process-focus, product- or service-focus, market-focus and general purpose. Process-focused facilities fulfill the needs of a particular stage of the supply chain and may be differentiated by economies of size or scope, or technological complexity. Product-focused facilities may serve many supply chain functions, but are devoted to a certain product or product family. Market-focused facilities serve a particular market, typically a specific geographic area. Finally, general purpose facilities meet a variety of the other three foci to provide flexibility.

The Hamilton Sundstrand aftermarket facilities, grouped into distribution centers, repair centers and onsite support (OSS) locations, each have a specific role they fulfill. Distribution
centers are product focused, providing parts for specific product families. Each of the four domestic distribution centers has a group of product families that it stocks and fulfills orders for. Focusing on a set of product families allows for a manageable knowledge base of products served and combining comparable products for processing, but also provides sufficient scale to make the operation efficient. The exceptions to this rule are the two distribution facilities located in Asia and the Middle East which are market-focused, covering a variety of product groups for their market. Companies need to have presence in markets to compete locally, understand the needs of that market or deal with trade barriers and local content requirements (Beckman & Rosenfield, 2008). In the case of these two market-focused distribution centers the original motivations were essentially local content requirements (Asia and Middle East) and tax advantages (Asia). Since these two facilities operate counter to the typical distribution center focus the assumptions of local content and tax advantages were tested to see if they still applied. After reviewing regional customer contracts and current tax policies, the Middle East location still served a market-focus, but the motivations for the Asia DC no longer applied.

Repair centers are both market-focused and product-focused. Global companies find that they have to have separate facilities to service the larger markets (e.g., North America, Europe, and Asia), but when they have more than one facility in a market, they focus those facilities along product, process, or materials dimensions (Beckman & Rosenfield, 2008). This holds true for the repair centers as each key market has multiple repair centers to meet customer demand in the region, with each repair center in a region focused on certain product groups. Strategically it makes sense to have repair centers market focused as they the facilities most sensitive to responding quickly to customer demand. Repair centers must tear down, troubleshoot, repair and return a part within 15 days. This fast transaction requires local presence in a market to maintain
high service levels. With a wide product variety it makes sense that repair centers are product and market focused. There is sufficient volume to support multiple locations in each region and specializing in product families confines their replenishment supply to a single distribution center.

OSS locations are market-focused in the most extreme method, targeted to a single customer rather than a larger market. The unique requirements of these facilities demand that they be focused on a specific customer and support a wide variety of products. To be accurate, the facility belongs to the customer, but houses the Hamilton Sundstrand operation. These facilities fulfill a very niche role in serving a customer with high service levels based on contractual requirements creating a dedicated site. The tight operating relationship provides both access to the “market” and also effectively blocks competitor access to the market.

With exception of the Asia distribution center, the Hamilton Sundstrand aftermarket facilities have an appropriate focus for their strategic purpose. The Asia distribution center is reviewed in detail for impacts on inventory and transportation savings for determination of an overall fit despite its misaligned focus.

3.2.1.2 Facility Location

Facility location is one of the most complex decisions in supply chain design. To think through facilities location, the decision makers must understand the global nature of today’s businesses and the factors affecting them as they approach globalization (Beckman & Rosenfield, 2008). Determining the correct location for facilities, and how many to have, requires considering many different factors. Beckman and Rosenfield (2008) describe three factors for considering facility locations: market access, capabilities access and low-cost access.
Market access for location parallels much of the logic of market-focus for the facility role like access to customers and service commitments, but also includes logistic tradeoffs for transportation costs and having a presence to understand local norms. Capabilities access drives location decisions based on access to labor skills, technologies or a supply base with Lean or just-in-time manufacturing capabilities that require close proximity. Finally, low-cost access location decisions are driven by factor cost impacts like labor, energy, materials and tax advantages.

The aftermarket distribution network facilities are mainly driven by market access, with some crossover to capabilities and low-cost access in some sites. The domestic U.S. repair locations benefit from being placed near original manufacturing and engineering sites for access to capabilities of product and engineering groups. The pool of skilled labor is much larger near the original manufacturing sites which allows for cross training, skills development and career progression without relocation. Low-cost access drove the initial decision for the Asia distribution center as well as the Miramar, FL repair facility. As discussed in the facility role section, the Asia distribution center was driven by tax advantages in addition to the in-region customer requirements. The repair facility located in Miramar services products that were formerly supported in Rockford. Moving the operation to Florida provided advantages from lower labor costs.

The layout of Hamilton Sundstrand’s current aftermarket distribution network is a reflection of the company’s historical operations. It is driven largely by the logistical drivers of market access; a trade off of transportation, facilities and inventory costs creating the framework for most location decisions. As detailed in Chapter 1, Hamilton Sundstrand is the merger of Hamilton Standard and Sundstrand. Historically those two companies focused their operations in
Windsor Locks, CT and Rockford, IL, respectively. They located their manufacturing, distribution and repair facilities in or near the same core sites. As global business dynamics changed they adapted by adding repair sites internationally and off-shoring production in lower factor cost areas. Their main distribution centers stayed in Windsor Locks and Rockford, and smaller additional distribution centers were added by their new electronics assembly sites in Phoenix and Puerto Rico. After the merger in 1999 they continued to make network design changes, however the distribution network still has artifacts of two supply chains grown out of the original headquarters in Windsor Locks and Rockford.

The current state of the domestic aftermarket facility locations, as shown in Figure 8, has all of the distribution centers located adjacent to their largest suppliers, the internal OEM sites. Similarly, the repair centers, with the exception of the Miramar location, are also located next to their largest suppliers, the distribution centers.

Figure 8 - Domestic Aftermarket Facility Locations

This outcome is largely a product of the historical inbound and outbound traffic at each site and the ownership of transportation costs. Hamilton Sundstrand is responsible for all transportation
costs inbound to its sites and customers are responsible for the leg of travel to their sites. Figure 9 shows the volume inbound and outbound from the Windsor Locks, CT distribution center, the largest of the sites. Almost 80% of inbound volume (e.g., replenishments, etc.) measured in extended cost and 74% measured in lines comes from the Hamilton Sundstrand original equipment (OEM) production facility at the same location in Windsor Locks.

<table>
<thead>
<tr>
<th>Suppliers Type</th>
<th>Location</th>
<th>% Ext. Cost</th>
<th>% Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEM</td>
<td>Windsor Locks, CT</td>
<td>79%</td>
<td>74%</td>
</tr>
<tr>
<td>VEN</td>
<td>Italy</td>
<td>4%</td>
<td>1%</td>
</tr>
<tr>
<td>OEM</td>
<td>Puerto Rico</td>
<td>3%</td>
<td>7%</td>
</tr>
<tr>
<td>VEN</td>
<td>Great Britain</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>VEN</td>
<td>Connecticut</td>
<td>2%</td>
<td>4%</td>
</tr>
<tr>
<td>VEN</td>
<td>France</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>VEN</td>
<td>Pennsylvania</td>
<td>1%</td>
<td>3%</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>4%</td>
<td>5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distribution Center</th>
<th>Type</th>
<th>Location</th>
<th>% Ext. Cost</th>
<th>% Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windsor Locks, CT</td>
<td>REP</td>
<td>Windsor Locks, CT</td>
<td>22%</td>
<td>21%</td>
</tr>
<tr>
<td></td>
<td>CUS</td>
<td>Southeast U.S.</td>
<td>16%</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>CUS</td>
<td>Northeast U.S.</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>CUS</td>
<td>Midwest U.S.</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>CUS</td>
<td>Southwest U.S.</td>
<td>7%</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>CUS</td>
<td>Southeast Asia</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>CUS</td>
<td>France</td>
<td>3%</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>REP</td>
<td>Netherlands</td>
<td>3%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>CUS</td>
<td>Germany</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>CUS</td>
<td>Japan</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>CUS</td>
<td>Central Asia</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td>20%</td>
<td>28%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customers Type</th>
<th>Location</th>
<th>% Ext. Cost</th>
<th>% Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>REP</td>
<td>Windsor Locks, CT</td>
<td>22%</td>
<td>21%</td>
</tr>
<tr>
<td>CUS</td>
<td>Southeast U.S.</td>
<td>16%</td>
<td>15%</td>
</tr>
<tr>
<td>CUS</td>
<td>Northeast U.S.</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>CUS</td>
<td>Midwest U.S.</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td>CUS</td>
<td>Southwest U.S.</td>
<td>7%</td>
<td>9%</td>
</tr>
<tr>
<td>CUS</td>
<td>Southeast Asia</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>CUS</td>
<td>France</td>
<td>3%</td>
<td>2%</td>
</tr>
<tr>
<td>REP</td>
<td>Netherlands</td>
<td>3%</td>
<td>5%</td>
</tr>
<tr>
<td>CUS</td>
<td>Germany</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>CUS</td>
<td>Japan</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>CUS</td>
<td>Central Asia</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>20%</td>
<td>28%</td>
</tr>
</tbody>
</table>

**Figure 9 - Windsor Locks DC Inbound and Outbound Volume**

Remaining inbound volume comes mainly from two of the other Hamilton Sundstrand OEM facilities in Phoenix and Puerto Rico and a handful of vendors. With the inbound volume supply source being concentrated in Windsor Locks at a transportation cost of essentially zero it makes sense to co-locate the distribution center near the OEM site. Furthermore, when you look at the outbound volume, a significant portion (22% of total) is provided to the Windsor Locks repair center, a location that Hamilton Sundstrand would have to pay transportation to if the distribution center were located elsewhere.

The distribution center in Rockford is similarly situated to reduce transportation costs relative to inbound and outbound volumes. However, due to off-shoring production activities and

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1. Extended cost is the product of part cost times part quantity.
2. Lines are a sub-component of orders. Each order can have one or more lines with each line detailing a request for a quantity of a certain part number. Lines can be a reasonable representation of a part movement in the system.
moving Rockford repair work to Miramar there is not as strong a case for the current location as there is for Windsor Locks. A significant portion of inbound volume, especially when viewed in lines, now comes from Hamilton Sundstrand production in Singapore (28%), Puerto Rico (17%) and York (16%) leaving just 29% of lines coming from Rockford OEM.

<table>
<thead>
<tr>
<th>Suppliers</th>
<th>Type</th>
<th>Location</th>
<th>% Ext. Cost</th>
<th>% Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEM</td>
<td>Rockford, IL</td>
<td>49%</td>
<td>29%</td>
<td></td>
</tr>
<tr>
<td>OEM</td>
<td>Singapore</td>
<td>21%</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td>OEM</td>
<td>Puerto Rico</td>
<td>18%</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>OEM</td>
<td>York, NE</td>
<td>10%</td>
<td>16%</td>
<td></td>
</tr>
<tr>
<td>VEN</td>
<td>Kansas</td>
<td>1%</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>1%</td>
<td>4%</td>
<td></td>
</tr>
</tbody>
</table>

| Distribution Center | Rockford, IL |

<table>
<thead>
<tr>
<th>Customers</th>
<th>Type</th>
<th>Location</th>
<th>% Ext. Cost</th>
<th>% Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUS</td>
<td>Southwest U.S.</td>
<td>15%</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>REP</td>
<td>Miramar, FL</td>
<td>15%</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>CUS</td>
<td>Midwest U.S.</td>
<td>8%</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>REP</td>
<td>Rockford, IL</td>
<td>7%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>CUS</td>
<td>Southeast U.S.</td>
<td>7%</td>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>CUS</td>
<td>Northeast U.S.</td>
<td>7%</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>REP</td>
<td>Singapore</td>
<td>4%</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>REP</td>
<td>Ireland</td>
<td>3%</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>REP</td>
<td>France</td>
<td>3%</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>OSS</td>
<td>Germany</td>
<td>3%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>CUS</td>
<td>Central Asia</td>
<td>3%</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>25%</td>
<td>33%</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 10 - Rockford DC Inbound and Outbound Volume**

The outbound volume to Rockford repair is now only approximately five percent of Rockford DC outbound lines, being surpassed by Miramar which now makes up 17% of lines. Other repair destinations that Hamilton Sundstrand must pay transportation for are located overseas and have approximately the same shipping rates based on international zones\(^3\) regardless of origin within the United States. With these facts under consideration, the Rockford DC becomes a candidate for possible relocation or consolidation with other sites. Transportation costs are only one component of logistics, however, and further consideration is necessary to consider impacts on inventory levels, customer service and facility capabilities. These topics are discussed in more detail in the strategic planning section.

The two smaller distribution sites, Phoenix and Puerto Rico, are also co-located with their manufacturing sites and repair centers. Figure 11 displays the inbound and outbound volume for

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\(^3\) FedEx Rate and Service guides were studied from a variety of origins to determine transportation advantages to international destinations.
the two sites. Both Puerto Rico and Phoenix are even more dependent on their local OEM supplier base, essentially being a finished goods inventory stock room dedicated to aftermarket sales for their site. Similar to Rockford and Windsor Locks, the only non-external, large customers are the repair centers located on site.

<table>
<thead>
<tr>
<th>Suppliers</th>
<th>Type</th>
<th>Location</th>
<th>% Ext. Cost</th>
<th>% Lines</th>
<th>Distribution Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEM Phoenix</td>
<td>97%</td>
<td>75%</td>
<td>Phoenix</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OEM Puerto Rico</td>
<td>3%</td>
<td>24%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>&lt;1%</td>
<td>1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OEM Puerto Rico</td>
<td>98%</td>
<td>99%</td>
<td>Puerto Rico</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>2%</td>
<td>1%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customers</th>
<th>Type</th>
<th>Location</th>
<th>% Ext. Cost</th>
<th>% Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUS Northeast U.S.</td>
<td>41%</td>
<td>8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>REP Phoenix</td>
<td>20%</td>
<td>48%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUS Southwest U.S.</td>
<td>12%</td>
<td>9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUS Southeast U.S.</td>
<td>11%</td>
<td>7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>16%</td>
<td>29%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUS Midwest U.S.</td>
<td>25%</td>
<td>15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUS Southeast U.S.</td>
<td>22%</td>
<td>26%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>REP Puerto Rico</td>
<td>16%</td>
<td>15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUS Southeast U.S.</td>
<td>13%</td>
<td>11%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>24%</td>
<td>33%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 11 - Phoenix and Puerto Rico DC Inbound and Outbound Volume**

The remaining sites in the aftermarket distribution network, the Middle East forward stocking location, the OSS locations and the international repair centers in IATA regions 2 and 3 are all located based on drivers of market access and service commitments. OSS locations are located explicitly on customer sites. The Middle East forward stocking location is similarly located to serve certain customers in the region with a limited part list. The international repair centers provide services for their associated product groups in the region to maintain quick turnarounds. Throughout the network, all sites are located near airport facilities enabling easy access to air freight for transportation.

3.2.1.3 Facility Size

Referencing the size of a facility typically refers to its production capacity rather than its physical size. In terms of distribution or warehousing the size or capacity generally refers to the holding capacity of the building. In developing a facilities strategy, it is critical to consider (a)
ways in which volumes may be built and then leveraged globally and (b) the economies of scale associated with breaking up that volume among facilities (Beckman & Rosenfield, 2008). Sizing a facility is a tradeoff between storage requirements and minimizing fixed costs per unit. While inventory levels fluctuate over the short term, facility size remains constant and the cost of maintaining the space must be covered regardless of how much space is used. In most cases the fixed costs related to a facility size are step functions where facility size and the related costs can only be adjusted in larger increments by adding or removing capacity.

Hamilton Sundstrand facilities, in contrast, benefit from economies in scope with mixed use sites. Sharing distribution sites with manufacturing and repair facilities allows distribution space allocated to aftermarket parts to be more variable. Within the limits of the larger buildings and other business needs, they can adjust the space required for aftermarket distribution space based on changing inventory levels. The forward stocking locations also benefit from a more flexible sizing option as they use contracted space from third party logistics (3PL) providers. The domestic repair centers, being co-located with the production and distribution locations, also have flexible capacity. OSS location sizes are determined by the terms of the customer agreement and use the customer’s defined space.

The remaining facilities for sizing consideration are the international repair sites. While these sites may benefit from relative adjustments in size or layout to benefit costs locally, they do not lend themselves to larger economies of scale consolidation. Each site within a region handles unique product groups and has little to gain from consolidating with another repair center in the area.
3.2.1.4 Network Design

A distribution network is more than just a collection of facilities of various roles, locations and sizes. Each facility fulfills a function as part of the larger system, creating a network of paths and locations through which products are delivered to the customers. Firms can make many different choices when designing their distribution network. The appropriate choice of distribution network results in customer needs being satisfied at the lowest possible cost (Chopra & Meindl, 2007). Design decisions for distribution networks balance number of facilities and network design with response time and operating cost.

Typically, a higher response distribution network requires more facilities, located close to the customer. Adding facilities comes at the expense of higher facility and inventory costs but saves on transportation cost. In Hamilton Sundstrand’s aftermarket network, however, the use of air freight provides a quick response time between the distribution center and the customer without being located nearby. Adding facilities would only marginally increase response time, while duplicating costly inventory storage locations and increasing facility costs. Additionally, the high priced parts lead to high inventory costs at each location, further motivating fewer inventory stocking locations.

The design of the part flow through the system also impacts response and operating costs. There are many distribution network designs including direct shipping, cross dock operations and various distribution center approaches; however the characteristics of the Hamilton Sundstrand aftermarket narrow the field to just a few appropriate models. Due to the uncertainty of supply and demand, inventory must be kept somewhere in the system. Not having a retail presence leaves manufacturing sites or distribution centers as options. While the Hamilton Sundstrand manufacturing sites do have finished goods inventories, they are typically reserved
for original production inventory destined for the large air framers, not for the aftermarket. The aftermarket network’s need for dedicated parts and reliance on receiving parts from multiple suppliers supports consolidation of inventories into a middle tier of dedicated distribution centers.

The final design choice is how the parts will flow from the distribution center to the customer. With a wide array of customers across the globe, maintaining a delivery fleet would be cost prohibitive, so final mile delivery by a common carrier is appropriate. Chopra and Meindl (2007) discuss a distribution model similar to these characteristics called distributor storage with carrier delivery, shown in Figure 12. This model provides fast response time, better customer experience and better order visibility than other models but coming at the cost of higher inventory levels.

![Figure 12 - Distributor Storage with Carrier Delivery](image)

To validate the network design used in the current state a model was built by the author to show the actual flow of parts in the aftermarket distribution system. Each location in the network was added to a Microsoft Excel model in a network layout shown in Figure 13. The model was laid out similar to the distributor storage model described by Chopra and Meindl.
(2007), with suppliers on the left, customers on the right and distribution centers in the middle. Locations were further organized by geography to give some representation of regional part flow. Sales and inventory transactions data were aggregated and formulated to show point to point part movements. The aggregated sales and inventory data was added to the model by drawing arcs between the supplying node and the receiving node. The resulting model shows real part flow demonstrating the actual, implemented network design.

Figure 13 - Aftermarket Distribution Network Design Model

The model closely matches the distributor model described by Chopra and Meindl (2007) as a good fit for high responsiveness, but also correspondingly higher inventory costs. Further analysis of the model reinforced the limited role played by the Asia forward stocking location in
servicing the customers in its region. Rockford and Windsor Locks distribution centers are reinforced as the primary distribution centers, having high volumes and serving wide customer bases, yet supplied by a minimal set of suppliers.

3.2.2. Strategic Inventory Placement

Inventory serves a unique purpose in buffering the uncertainty in supply and demand. It also requires a significant investment in capital that could be used elsewhere in the business to create value. Locating inventory in the distribution network effectively can meet customer demands while minimizing the capital investment. Because inventory offsets supply and demand imbalance it is best located at the push-pull boundary where customer orders initiate the “pull” of parts to fulfill orders and the upstream supply chain “pushes” product to that point based on a forecast. The push-pull boundary is the point along the supply chain time line where there is a need to coordinate the two supply chain strategies, typically through buffer inventory (Simchi-Levi, Simchi-Levi, & Kaminsky, 2003).

In the aftermarket distribution network the push-pull boundary occurs at the distribution centers. Up through that point the parts are moved based on forecasts and after that point parts are moved based on customer demand or replenishments to repair centers and OSS locations. For that reason it would make sense that the majority of the inventory be placed at the distribution centers. Inventory is also necessary in a multi-echelon system where downstream sites, like repair and OSS locations, have demand lead time shorter than supply lead time. With each distribution center being dedicated to particular product groups it would be expected that very little inventory would be held in common at the DC tier, but with each repair center duplicated in each region and OSS location serving multiple product groups, inventory would likely be duplicated at the downstream tiers.
An analysis of inventory was performed on the aftermarket distribution network to determine where stock was held for each part and if the locations matched the expected outcome. Data was pulled from the Hamilton Sundstrand enterprise resource planning (ERP) software for each part number and location pairing and aggregated in a matrix to visualize part duplication. The part matrix is arranged with the same facilities listed on the rows and columns in the same order and where they intersect the percentage of parts in common between those two sites is shown. The matrix, shown in Figure 14, is conditionally formatted to show darker colors where greater percentages of parts in common are held (e.g., >10% yellow, >60% orange, etc.).

![Image of the part matrix](image)

**Figure 14 - Inventory Part Matrix Organized by Facility Type**

As expected, the parts held in distribution centers are unique between the sites. In other words, a particular part is only kept in one of the main distribution centers. This is visible in the upper left corner of the diagram. The exceptions, or the dark areas off of the diagonal, are
attributed to the two forward stocking locations in Asia and the Middle East. This is intuitive as these distribution locations are intended to have duplicate inventory to serve the local market. However, as determined in earlier analysis, the market-access case for the Asia distribution location was not substantiated, so this duplicate inventory may provide a savings opportunity without sacrificing service. Continuing through the part matrix to the OSS cross section, the very middle area, the expected high degree of part duplication is seen. The repair center cross section, in the lower right corner, also displays the expected duplication. The repair inventory duplication is not as common as in OSS sites, but is clustered around repair centers that support the same product groups.

The part matrix organized by facility type matches the expected outcome, showing stock in the locations where demand outpaces supply. What seems counterintuitive is the amount of stock at repair facilities that are co-located with their supply source distribution centers. The replenishment lead times at these locations should be short enough to dictate little to no inventory. Rearranging the part matrix to be sorted by facility location and limiting the facilities included to only co-located sites, as shown in Figure 15, magnifies this issue.

Figure 15 - Inventory Part Matrix Organized by Facility Location
The duplicate inventory between distribution centers and repair facilities at these four physical locations presents a large opportunity for cost reduction. Approximately 20% of network inventory is located at these four repair sites. Across these four locations the total duplicate inventory accounts for almost $4 million dollars. Refining inventory policies at those locations may save a significant amount of that inventory investment without impacting service levels. Further analysis into the inventory policies at each facility is reviewed in the supply chain planning section.

3.2.3. Transportation Methods

Managing distribution logistics in any industry requires a balance of inventory and transportation costs, but the characteristics of the products managed can heavily impact the optimal policies. Cheaper, high volume products like coal are best transported via slow, cheap methods (e.g., train or ocean freight) and stored in large inventories. High value, low volume goods like electronics may be transported expeditiously (e.g., air freight) and kept with minimal inventories. In the aerospace industry, the majority of parts fall into that latter group. Most parts used in aircraft are crafted of specialized materials, comprised of proprietary electronics or sophisticated mechanical systems that all must fit in a relatively light and small package. These characteristics typically result in very expensive, light weight parts that lend themselves to minimal inventory stores and rapid transportation methods.

The low weight, high value motivation for air freight is further amplified by the replacement use nature of aircraft spare parts, especially non-life limited parts. Many parts on airplanes are life limited, requiring that they be replaced based on some pre-determined maintenance schedule. These parts are easier to predict and schedule replacement parts for which reduces uncertainty to some extent and allows for slower transit modes. Most of Hamilton
Sundstrand’s parts are not life limited and are replaced on less regular intervals. These parts are more difficult to forecast needs for and the airline customers typically need the parts expedited to replace a broken part or replace minimal on hand inventories. Even in non-critical orders the cost of air freight is a small fraction of the cost of the part as a percent of the total transaction.

3.3. Supply Chain Planning

Chopra and Meindl (2007) describe supply chain planning as the set of decisions regarding which markets will be served by which locations, the subcontracting of operations, the inventory policies to be followed and the timing and size of marketing and price promotions. These decisions apply to a tighter time horizon than supply chain design, generally on a quarterly or annual basis. As most Hamilton Sundstrand aftermarket locations have specified markets, limited promotions and minimal subcontracting, the focus of the planning decisions for the current state analysis is on their inventory planning methods.

3.3.1 Inventory Planning

As discussed in the strategic inventory placement section, Hamilton Sundstrand has located inventory in the preferred locations to buffer supply and demand uncertainty. However, placing inventory in the right locations is only one component of a successful inventory investment. Poor inventory management can lead to having too much inventory on parts that are not needed and not enough for parts in high demand. It may make sense to keep fast moving parts in distribution centers, repair centers and OSS locations to meet demand, but slow moving parts located only in distribution centers to minimize inventory expense. To keep inventory at ideal levels, inventory policies are used to meet service performance goals while controlling costs.
The service performance in the aftermarket is measured with two key metrics, customer service level (CSL) and “stocked out” percentage. Customer service level is measured in line fill rate, or the percent of order lines that are filled on time, a common distribution performance measure. Silver Pyke and Peterson (1998) describe fill rate as the fraction of customer demand that is met routinely; that is, without backorders or lost sales. Fill rate service level goals vary based on the type of customer. For most customers a goal of 95% is targeted for lines filled within the demand lead time and for OSS locations the goal is 97% or higher. “Stocked out” performance measures the percent of parts during a reporting period that do not have inventory on hand to fulfill orders. The target for “stocked out” parts is to remain below 2.5% of total parts at distribution centers and 1.0% at repair centers. Hamilton Sundstrand has had strong performance in meeting or exceeding their service level performance measures both in aggregate and at individual sites. While “stocked out” performance is a useful measure for reporting overall part inventory performance, it is not the key statistic used to set inventory levels. Inventory policy is set by trying to meet the fill rate service level performance.

Inventory cost performance is measured in aggregate by total cost and the inventory turns metric. Total cost of inventory is limiting as a performance benchmark as it does not relate directly to changes in number of products or demand. Inventory turns is more directional by comparing average inventory to actual sales and, as such, attracts more attention as a cost measure. The inventory turns goal fluctuates, but generally is close to 4.0. The Customer Service materials management team has also been successful in coming close to or meeting this goal in most months as well.

While the inventory turns metric is helpful, it hides the problem of slow moving parts by averaging turnover performance across large product families (typically the lowest visibility into
performance). These parts drive cost up while not supporting service levels. For example, out of 4,515 active parts in one repair facility the average inventory turns performance was 3.55 but had a mean of 1.84. The distribution of those parts, displayed as a histogram in Figure 16, showed that 67% of the parts had turns lower than the mean of 3.55 but were compensated for in the metric by a minority of parts with high turns. Refining inventory policies can help minimize the inventory of slow moving parts and raise the overall performance of the site.

![Inventory Turns Histogram](image)

**Figure 16 - Inventory Turns by Part Histogram**

To minimize the cost of inventory, like reducing the slow moving parts discussed above, while also meeting service levels the Customer Service team maintains a broad set of inventory policies. The policies dictate which parts are authorized to be stocked based on demand, called the Authorized Stock List (ASL), and what the service levels and order quantities should be for those on the ASL. For parts that have insufficient demand to not be placed on the ASL they have their inventory targets set to 0. The requirements to qualify for the ASL and the service levels and order quantities for ASL parts differ based on facility type (i.e., distribution center or repair center) and part cost. Figure 17 shows a representation of the current qualifiers for ASL and the associated inventory parameters for ASL parts.
The inventory policies are implemented in the planning tool, Servigistics, which uses them to administer inventory levels, trigger orders and manage demand. As mentioned previously, parts that are identified to be on the ASL get their ordering policies set to allow for replenishment based on the dictated service levels, ordering cost and carrying cost (20%). Order quantities are determined by the lesser of economic order quantity (EOQ) or months of supply maximum. The policies, while specialized to facility roles (i.e., DC or RC), are not customized to each site. For instance, the ordering cost, which drives the EOQ calculation, is set to $15 for all repair locations regardless of supply source. A repair facility in Europe that is supplied by Windsor Locks DC and requires transportation has the same $15 order cost as the Windsor Locks repair center located in the same building as the DC. The $15 amount had been reduced from its original value of $35; however this value is still arbitrary with remaining opportunity for refinement. Similar to the ordering cost, the ASL qualifier policies are also generic to facility roles. The European repair center likely should have more parts on ASL than the Windsor Locks repair center to account for the different replenishment abilities. Refining the ASL policies, service levels and inventory parameters should aid in reducing the $4 million in duplicate inventory identified in the strategic inventory placement analysis.
3.4. Chapter Summary

Reviewing the aftermarket distribution network in terms of supply chain design and supply chain planning decisions helped focus the improvement efforts on a few areas of opportunity. While much of the aftermarket network aligns with meeting customer service needs in a responsive, cost-effective way there are a few opportunities for refinement that require further analysis:

- **Asia distribution center**: the Asia distribution center has high duplicate inventory and does not appear to be necessary based on market-access or responsiveness needs.

- **Rockford distribution center**: the off shoring of manufacturing and relocation of former Rockford repair work weakens the case for the Rockford distribution site.

- **High duplicate inventory in co-located distribution center and repair facilities**: while inventory is necessary to buffer supply and demand uncertainty, the repair centers located adjacent to domestic distribution centers appear to have a surplus amount.

- **Generalized inventory policies**: the policies that drive order replenishment, safety stocks and stocking policy are non-specific to each facility, despite proximity to supply source.

In the next chapter alternatives are generated and further analyzed to address these opportunities with the intent of realigning the design and planning of the aftermarket distribution network with current operating conditions.
4. Alternatives Analysis

This chapter builds on the observations made in the current state analysis by providing alternatives that intend to improve the Hamilton Sundstrand aftermarket distribution network. Each alternative is analyzed for the estimated impact in reducing annual operating costs as well as the impact on the design and planning of the distribution network. Other benefits and drawbacks are presented in addition to the financial impact to discuss the broader issues of making the proposed changes. Finally, each alternative is accompanied by a final recommendation with a proposed implementation method.

4.1. Closing Asia Distribution Center

The Hamilton Sundstrand aftermarket parts distribution network is chiefly serviced by four main distribution centers (DCs) located in Windsor Locks, Rockford, Phoenix and Puerto Rico. The practice of the industry to fulfill orders and replenishments by air transportation allows for adequate servicing of global demand from a centralized distribution source. As such, the distribution network has been maintained so that each unique part is only serviced from one distribution center, specific to its product family. However, over time two additional sub-DCs have been added, in Asia and the Middle East, to meet customer service commitments. These two sub-DCs are the only locations that operate as forward stocking locations or otherwise stock a significant amount of parts that are carried at one of the other DCs. The analysis presented in this section reviews the business case for the continued use of the Asia DC location.

4.1.1. Estimated Impact

The savings from closing the Asia facility is derived from two main categories, the annual operating lease with the third party logistics (3PL) provider and the carrying cost of the inventory kept at the facility. The 3PL lease totals approximately $250,000 per year; however,
the 3PL distribution contract actually includes services for Hamilton Sundstrand beyond the aftermarket needs, so the full amount would not be recoverable. It is estimated that half of the services in the contract, or $125,000/year could be reduced by removing the aftermarket services. The inventory at the Asia DC is currently valued at $540,000 at domestic standard costing rates. Closing a DC and repositioning inventory to another DC is generally not a true cost savings as it just moves expense from one location to another. With the Asia DC, however, the relatively high inventory on hand is due to initial provisioning, not to support regular customer demand. The Asia DC parts have been largely sitting in inventory without servicing demand in the region. An analysis of current demand on Asia DC parts showed that only $70K of current inventory would become long term inventory at other network locations, with the majority of the remainder able to be depleted in 6-12 months after relocation. The short term inventory of $470,000 has an annual holding cost of $94,000 using the corporate carrying cost rate of 20%. The combined savings of reduction in the annual 3PL service contract and inventory cost burn down is $219,000 per year. There would be additional costs savings realized from transportation to Asia DC in the form of existing replenishment activity, however due to low demand at the site this expense and the related savings were estimated to be insignificant.

4.1.2. Supporting Facts

The business case for opening the Asia DC originated from existing assumptions of customer requirements for in-region parts, tax incentives for routing parts through Asia and the ability to provide rapid turnaround for IATA III customers. An analysis of these factors under current conditions showed that each of these benefits or requirements have limited impact.

- **Customer agreements do not require in-region parts:** A review of existing product service agreements does not strictly require the parts to be fulfilled from within the
region. As long as customer service levels can be maintained from other sources the customer requirements are met.

- **Tax benefits no longer require shipment origin from Asia:** Originally it was understood that parts had to be shipped from within the region to get associated tax benefits. However, in recent years new information and/or policies have come available that attribute tax benefits simply to arrival and consumption in the region rather than origination.

- **IATA 3 market demand can be fully met by domestic distribution centers:** The Asia DC is currently only servicing 5% of IATA 3 demand, with the remaining 95% of demand being fulfilled by the domestic DCs\(^4\). The existing Asia demand can easily be absorbed by the other core distribution centers while still meeting customer service levels. There are no parts unique to the Asia DC; each part has a duplicate source in the U.S. Furthermore, in many cases external customers will benefit from consolidated orders shipping from a single site.

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\(^4\) Based on 2009 sales figures sourced from the Hamilton Sundstrand enterprise resource planning tool J. D. Edwards (JDE).

**Figure 18 - Sales Demand for IATA 3 in Cost of Goods Sold**
4.1.3. Opposing Facts / Alternative Views

While there are significant benefits to closing the Asia distribution center there are also drawbacks and alternatives that were evaluated during the analysis.

- **Inventory policies could be adjusted to fulfill more demand from Asia DC:** The current five percent of sales to IATA 3 that originates from Asia could be increased by adjusting sourcing policies in JDE and order administration. While more demand could be driven through Asia DC, it still would not create significant value over shipping from domestic locations.

- **Customers may push back on increased freight charges:** One disadvantage to the external customer is that the few orders that do originate from Asia today would now ship from an origin farther away, increasing the transportation cost that they are accountable for. The increase in freight charges would be marginal and customs fees would be similar to what they experience from Asia today.

- **Long term Asia market strategy may require a regional distribution center in the future:** With the increase in passenger miles, addition of new airlines and emerging air framers in Asia there may be a need for a distribution center in the region in the coming years. Even with probable customer demand and likely new service agreements in the region, the appropriate location of an Asia regional distribution center is not yet certain. Additionally, using third party vendors for distribution lowers switching costs attributed to leaving now and potentially returning later are outweighed by the savings achieved by closing the location.
4.1.4. Recommendation

After a thorough review of the facts relevant to the continued operation of the Asia Distribution Center, the author recommends closing the facility, or in this case removing the aftermarket parts from the 3PL contract, and serving the demand from the domestic DC network.

As the Asia distribution center is outsourced on an annual contract, exiting from the arrangement should be done at the next annual contract renewal or prior to that if there are no early termination fees associated. The inventory at the Asia DC should be redistributed to the appropriate domestic distribution centers in consolidated shipments as soon as possible to expedite the burn down in excess network inventory. Prior to relocating the inventory, customers must be notified of the change in the service network and the order administration system must be updated to remove the option of shipping parts from the Asia distribution center.

4.2. Relocate Rockford Distribution Center Volume

The key drivers in the location of the distribution centers in the aftermarket network are the reduction of transportation costs, primarily on inbound, the use of existing facilities at the OEM and repair site, and the use of air freight to reach global demand of customers regardless of location. A high mix of parts supplied from the local OEM and relatively high mix of internal customer demand going to the local repair site made co-location with OEM and repair a perfect placement for most of the core domestic distribution centers. The Rockford DC, however, showed only 29% of inbound lines coming from the local supplier (Rockford OEM) and only 5% of outbound lines going to the local Rockford repair. Recent changes in the business had increased sourcing of parts internationally and a significant portion of the Rockford repair business had moved to Florida, changing the key parameters of the Rockford location equation.
In an effort to realign the aftermarket distribution network with current business conditions a number of alternatives were considered.

First, an idea was considered that followed the recent industry preference for placing a central mega-dc in a low cost area close to major package carrier locations like FedEx in Memphis, TN and UPS in Louisville, KY. This option works for many organizations because they centralize multiple regional stocks of the same parts and benefit from consolidated inbound shipments (Andreoli, Goodchild, & Vitasek, 2010). In the Hamilton Sundstrand business these major gains do not apply. The four distribution centers carry different part families that would not benefit from further consolidation and moving them farther from their source OEMs would only increase transportation expense while adding increased facility expenses of a new site.

The second option considered, realizing there would not be significant gains in inventory, was to consolidate the Rockford DC with the Windsor Locks location. A thorough analysis of transportation costs, inventory savings and opportunity for consolidated outbound shipments was prepared. The outcome was that any gains in inventory and consolidated shipping were offset from the added transportation of product still sourced from Rockford OEM and consumed in Rockford repair. The consolidated outbound shipping was minimal as repair sites tied to only one distribution center leaving only small volume OSS centers that benefited. Furthermore, consolidating the two largest DCs added significant additional workload for outbound shipping dock in Windsor Locks and reduced flexibility in their distribution network if operations in Windsor Locks halted due to work stoppage, weather, equipment failure or some other event.

The final alternative considered was to relocate portions of the Rockford DC volume to better align with the change in sources and uses. Rather than completely relocate the DC, the parts that serviced mainly the Miramar, FL repair center would be moved to that location, the
parts that did benefit from consolidation in Windsor Locks would be moved to that DC and the
remaining parts would stay in Rockford. This alternative appeared to make the most sense based
on initial calculations and was pursued for further analysis to consider it as a final
recommendation.

4.2.1. Estimated Impact

The Rockford DC split alternative benefits the network by rebalancing the inventory to
locations with existing facilities, minimizing unneeded transportation costs and allowing for the
application of the proposed repair-related inventory reduction methods to be applied in Miramar,
a large repair facility. In addition, relocating the DC inventory would also change the required
staffing at each site; a shift in staffing to the lower cost facility in Miramar would have
associated labor savings.

To begin the analysis the demand for each part family was reviewed to see what percent
of internal customer demand was used at each location or its subordinates to determine its best fit
with the three locations. The demand-driven split of the part families resulted in 76% of parts
being allocated to Miramar, 8% to Windsor locks and 16% staying in Rockford. With each of the
proposed changes in part family locations the impact on transportation costs and inventory
reduction opportunity was tracked.

Over 25% of parts moved to Miramar and Windsor Locks were internationally-sourced
and had no cost difference from intra-U.S. destination changes. The remaining inbound volume
had to be reviewed for zone changes and associated cost differences per line. The resulting
impact was an increase in freight costs of $30,600 per year for inbound shipments. On the
outbound side the savings on replenishments to Miramar repair and consolidated shipping out of
Windsor Locks to OSS sites resulted in a decrease in annual freight costs of $66,700. The net
transportation savings from the split of Rockford DC volume was approximately $36,100 per year.

The impact on inventory due to the proposed changes was also positive. Generally, when adding a new distribution center, like would be required in the Miramar facility, the impact would be an overall increase in inventory as part locations increase. In this instance there is no net increase in part locations because the inventory is not retained in the original site. In fact, relocating the parts to Miramar and Windsor Locks allowed for the benefits of inventory reduction from the approaches proposed in section 4.3. The savings in annual inventory carrying costs by reducing the average inventory and safety stocks from having co-located repair and DC was approximately $99,000.

The final impact on costs was the change to labor across the three sites. Moving 84% of parts from the Rockford DC would reduce the workforce needs there, but would shift them to the other locations. Through discussions with management two of the 20 current Rockford staff would remain, one would be needed in Windsor Locks and 18 (17 moved from Rockford and one additional) in Miramar. While Windsor Locks has a similar wage rate to Rockford and would have no net cost change, Miramar has a considerably lower wage rate. The savings from the lower, fully burdened labor rates including overtime for the seventeen staff being transferred, less the addition of one more staff resulted in an annual labor savings of $292,000. The inventory carrying cost reduction of $99,000 per year, transportation savings of $36,100 per year and labor savings of $292,000 per year resulted in an estimated impact of $427,100 per year.

4.2.2. Supporting Facts

Splitting the Rockford DC volume is a large undertaking with long term impacts to the Hamilton Sundstrand aftermarket distribution market. Successfully making the transition would
update the distribution network to the current operating environment and have several positive side effects:

- **Reduces network transportation expenses:** Currently Hamilton Sundstrand pays over $38,000 per year to supply parts to the Miramar repair facility from Rockford. Those parts have little use in Rockford, just being stored locally there based on historical operating procedures before being re-routed to a repair facility, OSS location or external customer. Moving those parts, as well as the other part family location changes, can save up to $66,700 per year in outbound transportation costs. Although there is an increase in inbound transportation expenses, the net savings is $36,100 per year.

- **Reduces average inventory in Windsor Locks and Miramar repair:** With the change in part locations comes an increase in the co-located DC and repair inventory stocks. Implementing the strategies discussed in section 4.3 results in reduced average inventory at both Windsor Locks and Miramar for a total of $99,000 per year.

- **Lowers cost to serve:** The relocation of the parts to Miramar saves on transportation and inventory expenses in the network, but it also provides a lower factor cost for a high labor content operation. Relocating the parts also relocates the associated staff to the lower cost area, resulting in annual labor savings of $292,000 per year.

4.2.3. **Opposing Facts / Alternative Views**

There are significant savings and other benefits to relocating parts out of the Rockford DC and into the two other sites, but there are negative effects as well as a few large assumptions to moving the parts, including:

- **Assumes space is available in Miramar facility for distribution center:** One major assumption in this proposed recommendation is that there is actually space available in
the existing Miramar facility to support a DC operation. If there is not, leasing space at a nearby facility would be add costs and may reduce the ability to implement inventory savings methods.

- **Adds a new distribution center:** Although there is no increase in inventory cost from adding the new location from parts it does add management complexity as one more site to monitor and maintain performance.

- **Splits customer and Hamilton Sundstrand shipments:** Many of the parts that would be relocated to Windsor Locks will benefit the network in consolidated shipments to OSS locations, and benefit customers in ordering parts from multiple product families from one site. Most of the parts being relocated, however, increase the operational footprint, adding more sites from which parts can ship from. This impacts both Hamilton Sundstrand and external customers in potential reduction of consolidated shipments.

- **Labor relationships:** Moving staff positions from one location to another is a very delicate subject, especially when headcount is being moved from a union operation to a non-union operation like in the proposed alternative. Although there are related savings, there may be significant impacts to labor relationships, morale and existing contract provisions that outweigh the gains.

**4.2.4. Recommendation**

With the caveat that enough space is available in the Miramar repair facility to build out a distribution center, the author strongly recommends splitting a portion of the volume in the Rockford DC to Miramar and Windsor Locks. The change will provide substantial annual cost savings and matches the supply chain strategy of the distribution network.
Implementation of the change requires first working with the Miramar repair facility to identify potential space. Recent lean manufacturing efforts and other refinements at the repair facility should be able to provide the required space needed for a small footprint distribution center. Second, the parts targeted for relocation should be reviewed by stakeholders across the company, suppliers and customers to ensure they would not have other undesirable side effects of being moved. Finally, if the proposed part relocation is adopted, the parts targeted for Windsor Locks should be moved first to test the impact on network operations with a small change. Next a portion of the parts targeted for Miramar, perhaps one product family, should be moved and serviced from the new DC to slowly scale up the new operation and train a core set of the new workers. Once Miramar DC operations have stabilized the rest of the part families can be relocated.

4.3. **Optimize Co-located Domestic Repair Center Inventory**

The strategic inventory placement review found that inventory was placed in mostly optimal places to buffer supply and demand uncertainty, but that there was significant shared parts inventory in repair centers that are located adjacent to their supplying distribution centers. The proximity of the supply source and associated short replenishment time should mean minimal to no stock for the co-located repair locations, which was not the case with nearly $4 million in duplicate inventory. The supply chain planning review found what may be a key source of the high levels of inventory in generic inventory policies across the repair sites. While the distribution centers get significant attention and use time phase planning to optimize inventory, the repair centers largely depend on a min-max inventory system that uses the provided parameters to achieve a certain service level. Ensuring optimal parameters, stocking policies and service levels are in place can make a big impact on the inventory performance.
4.3.1. Repair Center Inventory Planning

Hamilton Sundstrand uses a sophisticated inventory management software tool called Servigistics that continuously monitors repair center inventory levels and determines order quantities and order levels based on the desired fill rate. The policy is a commonly used continuous order-point, order-up-to-level known as an \((s, S)\) or min-max policy. This policy places an order when the inventory position (IP) is at or below the re-order level \((s)\) with an order sufficient in size \((S - IP)\) to bring the IP back up to the optimal order-up-to-level \((S)\). Figure 19 shows an example of the min-max \((s, S)\) policy shown over time.

![Figure 19 - Min-Max \((s, S)\) Continuous Review Order Policy](image)

*Figure 19 - Min-Max \((s, S)\) Continuous Review Order Policy*  
*Sourced from (Simchi-Levi, Simchi-Levi, & Kaminsky, 2004)*

The order-up-to-level \((S)\) is determined by calculating an optimal order quantity \((Q)\) and adding it to the re-order level \((s + Q)\). With the usual demand rate of one unit per order, the replenishment order size is typically close to or equal to the optimal order quantity. The effective optimal order quantity is determined as the lower quantity from two approaches, either the economic order quantity \((Q^*)\) or the months of supply maximum. Economic order quantity \((Q^*)\) is determined using Equation 1 with the key inputs of demand, order quantity, unit cost and
holding (carrying) cost. Sometimes the economic order quantity can result in an order size that could sustain demand for a long period of time, which could be problematic with aircraft parts that can be made obsolete by engineering changes. The maximum months of supply quantity caps the maximum order size to control for this; its source is the inventory parameters, recapped in Figure 17.

\[
EOQ (Q^*) = \sqrt{\frac{2 \times A \times D}{v \times r}}
\]  
(Equation 1)

Where:
- \(A\) = Order cost
- \(D\) = Annual demand
- \(v\) = Unit cost
- \(r\) = Carrying / holding cost rate (%)

The re-order level (s) is determined by adding the demand over lead time (\(X_L\)) and the safety stock (ss) for a desired service level together. Typically safety stock (ss) is determined using the normal distribution with a formula similar to Equation 2.

\[
ss = Z \times \sqrt{L + R} \times \sigma
\]  
(Equation 2)

Where:
- \(Z\) = safety factor determined from the desired service level
- \(L\) = Lead time
- \(R\) = Review period (0 if continuous)
- \(\sigma\) = Standard deviation of demand
Assumes time intervals (L & R) are independent

The normal distribution is a good representation for demand characteristics on fast moving parts and is widely known and used in practice. Many of the parts in the distribution centers do have sufficient volume to match the normal distribution; however the slow moving and intermittent nature of a large portion of spare parts demand, especially those at repair centers, is more appropriately represented by a discrete distribution like Poisson.
Silver, Pyke and Peterson (1998) propose that the Poisson distribution is appropriate to use when the observed standard deviation over lead time ($\sigma_L$) is within ten percent of the square root of lead time demand ($X_L$), and when $X_L$ is below 10 units. This test is both quick and effective, as the Poisson distribution has a characteristic of equal mean and variance which is easy to determine from a data set. The parts at the Windsor Locks repair facility, one of the larger volume co-located repair sites, were examined to determine their fit to the Poisson distribution based on these tests. A random selection of the parts tested is shown in Figure 20.

<table>
<thead>
<tr>
<th>Product</th>
<th>Lead time demand ($X_L$)</th>
<th>$\sqrt{X_L}$</th>
<th>Lead time Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product A</td>
<td>4.741</td>
<td>2.177</td>
<td>1.987</td>
</tr>
<tr>
<td>Product B</td>
<td>2.533</td>
<td>1.592</td>
<td>1.496</td>
</tr>
<tr>
<td>Product C</td>
<td>2.325</td>
<td>1.525</td>
<td>1.551</td>
</tr>
<tr>
<td>Product D</td>
<td>1.511</td>
<td>1.229</td>
<td>1.135</td>
</tr>
<tr>
<td>Product E</td>
<td>3.259</td>
<td>1.805</td>
<td>2.054</td>
</tr>
<tr>
<td>Product F</td>
<td>1.067</td>
<td>1.033</td>
<td>1.064</td>
</tr>
<tr>
<td>Product G</td>
<td>7.777</td>
<td>2.789</td>
<td>3.005</td>
</tr>
<tr>
<td>Product H</td>
<td>1.141</td>
<td>1.068</td>
<td>0.872</td>
</tr>
<tr>
<td>Product I</td>
<td>8.889</td>
<td>2.981</td>
<td>3.227</td>
</tr>
<tr>
<td>Product J</td>
<td>1.319</td>
<td>1.148</td>
<td>1.187</td>
</tr>
</tbody>
</table>

Figure 20 - Poisson Test Part Sample

Over 95% of parts had $X_L$ below 10 units and over 75% of parts had $\sigma_L$ within ten percent of the square root of $X_L$. The strong supporting evidence through these tests and Servigistics’ own demand distribution identification approach support a Poisson approach to inventory policies.

The use of a Poisson distribution both simplifies and complicates setting inventory levels. For slow moving items, it is important to be able to deal with discrete units. On the other hand, discrete mathematics creates problems in implementation (Silver, Pyke, & Peterson, 1998).

With a normal distribution the safety factor ($z$) is relatively easy to determine given a desired item fill rate (IFR) using the unit normal loss function ($G[z]$). As shown in Equation 3, the

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5 Servigistics identifies part demand distributions by analyzing the coefficient of variation (CV = std. dev / mean) for each part. Parts with CV greater than one are attributed a Poisson distribution.
normal loss function value can be determined using the desired item fill rate, standard deviation over lead time ($\sigma_L$) and order quantity ($Q$). The safety factor can then be found using the normal loss function value on a common reference table or using functions in Microsoft Excel, plugged into the safety stock formula of Equation 1 and a resulting re-order level is found.

$$G[z] = \frac{Q}{\sigma_L} (1 - IFR) \quad \text{(Equation 3)}$$

With the Poisson distribution, finding the correct re-order level is slightly more involved. Due to the discrete nature of the distribution there is no quick inverse loss function to reference. Instead the appropriate re-order level necessary to meet a desired item fill rate must be found by incrementally adding units and testing the expected units short based on the demand characteristics. At each incremental re-order level the expected fill rate can be determined using Equation 4.

$$IFR = \sum_{k=0}^{\infty} \frac{e^{-\lambda} \lambda^k}{k!} \quad \text{(Equation 4)}$$

Where:

- $\lambda =$ mean (and variance) of demand
- $x =$ re-order level

Calculating the fill rate for a given re-order level is straightforward using Microsoft Excel's POISSON() formula. However, there is no built-in inverse Poisson formula to quickly arrive at a re-order level for a desired fill rate. To test alternative inventory policies without having to iterate through re-order levels on each part manually the author wrote an Excel function to perform the task efficiently.

The average inventory on hand for a part is half of its cycle stock ($Q/2$) plus its safety stock. Both components are heavily impacted by the inventory parameters dictated to the system. The cycle inventory relies heavily on the provided ordering cost parameter driving the economic order quantity and the maximum months of supply. The safety stock is a direct result of the
service level as well as the replenishment lead time over which demand uncertainty must be met. The service level is provided by the inventory parameters, and the replenishment lead time is manually updated in Servigistics. With the right parameters and ASL policies the inventory levels can be optimized to meet service level needs without driving unnecessary costs.

4.3.2. Reduce Average Inventory

Reducing inventory for the sake of cutting costs is not a good decision if it goes counter to service level goals. Generally inventory reduction plans are soon followed by a plan to increase service levels and vice versa in a constant pendulum effect of balancing costs with service. However, occasionally there are opportunities in locating inefficiencies in the system where inventory reduction can be achieved without service impacts. The co-located repair center parts inventory is one of those opportunities.

To determine the ability to reduce the average inventory on hand while maintaining service levels two areas were addressed: cycle inventory and safety stock. Cycle stock was analyzed in the domestic repair centers to determine the optimal parameter levels, primarily ordering cost, to reduce the average order size. Safety stock levels were analyzed to determine the appropriate levels based on acceptable service levels and actual replenishment times versus current parameters.

4.3.2.1. Estimated Impact

For each repair center an analytical model was built that held all of the commercial ASL parts managed at the facility and their associated planning parameters. The models provided the ability to input new parameters, specifically order cost, replenishment lead time and desired service level, and see the impact on the average inventory levels. With each change in input parameters the parts would have new order quantities calculated using the current approach of
economic order quantity or maximum months on hand, whichever was less. The model would
also dynamically determine the appropriate re-order level based on the InversePoisson function
written by the author given desired service level and lead time demand, a function of
replenishment lead time. In addition to determining the resulting change in average inventory the
model would also predict the increase in replenishments necessary to meet the new parameters.
This was necessary because driving ordering quantities down means increasing frequency of
orders, which increases distribution center fulfillment activity and associated labor costs.

The average cycle stock inventory was optimized using the ordering cost parameter and
the tradeoff between resulting inventory gains and additional picks in the distribution center. The
original ordering cost, for all repair sites, was $15. This number was believed to be too high for
the domestic repair sites as there were no transportation expenses, transactions were electronic
and automated in ordering systems, and labor expense was limited to picking, consolidating and
carting to the stock room in the adjacent building. With this in mind the ordering cost was
progressively lowered to determine the impact on average inventory costs and additional
distribution picks. This process was repeated individually for the Windsor Locks, Phoenix and
Rockford repair centers. Figure 21 shows the tradeoff at Windsor Locks repair between reduction
in average inventory and additional DC picks as the ordering cost was lowered. Through this
process the optimal ordering cost was determined to be $3.00 as this level resulted in a $391,000
reduction in average inventory while only requiring an estimated 23 extra picks per day, a 26%
increase in distribution work related to local repair replenishment, but only a 2-3% increase in
total picks at the local DC. Going beyond $3.00 at Windsor Locks quickly resulted in a spike in
extra distribution picks without significant gains in inventory reduction. Completing the process
at each facility in resulted in similar ordering costs of approximately $3.00 and a grand total of
$512,000 in average inventory reduction across all sites, or approximately $102,000 in annual carrying costs.

![Graph showing inventory cost savings and additional DC picks vs. order cost.]

**Figure 21 - Windsor Locks Ordering Cost Optimization**

The safety stock was optimized using the two inputs of target service level and replenishment lead time. As each part has a unique service level determined by its demand and cost characteristics, the service levels were adjusted by a ratio of their current service level premium, the amount above a 50%, zero safety stock level. For instance, if a part had a current service level of 90% (service premium of 40%), adjusting the service premium ratio from current (100%) to half (50%) would result in a 70% service level (50% base + [40% premium x 50% ratio] = 70%). This approach made it easier to scale down each part at the same time instead of setting new parameters manually for each part. Reducing the service level would creating more stock outs in the repair center, but with DC stock close by the customer’s repair order would not be dramatically affected. The replenishment lead time was adjusted down from the current level of four days (in Windsor Locks repair) to zero in one day increments. The actual order
replenishment history was analyzed to validate that the current four day replenishment lead time was indeed too high and that repair center stock outs were not as critical. Seventy-seven percent of orders were fulfilled same day and over 90% within two days, as demonstrated in Figure 22. There are significant opportunities to improve the actual replenishment lead time even further, but even with this outcome a reduction from the four day parameter in the system seemed reasonable.

![Figure 22 - Windsor Locks Repair Replenishment Lead Time from Local DC](image)

Similar to the average inventory reduction approach, each of these parameters were reduced incrementally to gauge the impact on service performance and inventory reduction. The resulting inventory reduction for Windsor Locks repair is shown in Figure 23.
While there are significant savings for more aggressive reductions in replenishment lead time and service levels, the gain from just reducing system lead time by two days without a reduction in service level was $290,000 in Windsor Locks, and totaled $362,000 across the network. The annual carrying cost for this inventory is $72,400.

4.3.2.2. Supporting Facts

There are several facts supporting the reduction of inventory at the co-located repair centers including:

- **Significant savings in inventory reduction with minimal impact to service levels:** Between cycle stock average inventory and safety stock the total inventory reduction would be $874,000 with an annual carrying cost savings of $174,800. These savings can be realized without substantial risk to service levels.

- **Smoothens demand pattern for source distribution center:** Reducing the average order size provides a better demand signal to the distribution center that replenishes the repair center. Although the distribution centers already incorporate repair demand into their forecasts and ordering pattern, the larger repair replenishments could trigger stock outs more frequently than a smaller replenishment size. An analysis of smaller repair replenishments on sample parts showed critical DC shortages reduce by almost half and fill rate increase by 1.5%.

- **Reduces network excess and obsolescence:** The volatile demand patterns on repair parts often leads to increased inventory that has a high likelihood of becoming excess or obsolete when the demand patterns inevitably change. Refining the policies to carry a more appropriate amount of inventory in repair centers reduces the exposure to this risk.
4.3.2.3. **Opposing Facts / Alternative Views**

The adjustment in inventory policies leading to the cost savings also carries with it some drawbacks, including:

- **Additional picks in distribution centers:** The reduction in order sizes leads to more frequent ordering and the associated increase in distribution activity. Although the increase in total picks related to the proposed alternative only increase approximately 2-3% that could approach capacity limits for the facility or staffing.

- **Additional complexity in inventory policies:** One of the benefits of the current policies is that they are simple to administrate and communicate. Changing the ordering cost per site and the replenishment lead time may require changes in the Servigistics platform and burden on management to maintain additional standards.

4.3.2.4. **Recommendation and Implementation Approach**

Given the substantial savings in inventory reduction from the proposed changes and the positive side effects of smoothed demand at the distribution centers, it is recommended that the alternatives are implemented. The drawbacks of additional picks in DCs and additional complexity can be mitigated by a slow implementation of the changes and if needed, minimal head count increase in the DCs.

The recommended method to implement the proposed changes is to slowly draw down the inventory parameters over the course of several months. The first parameter to change would be the ordering cost which should be reduced by $3 increments each month for four months to gauge the true impact on added picks in the DC. Similarly, the replenishment lead time should be reduced from the four day current level to two days, by removing one day per month for two months. This should occur after the ordering cost reduction to minimize potential issues in
identifying causality if problems do arise. The slow adoption will help identify replenishment
issues and could lead to process improvement that could support further reduction in the
parameters. If the replenishment lead times are adequate at the reduced levels it is recommended
that the organization attempt to draw down the replenishment lead time to zero days at a slower
rate to remove the need for local stocking all together.

4.3.3. Optimize ASL Stocking Policies

Reducing the inventory levels for ASL parts as discussed in the previous section has
substantial gains in inventory reduction. However, it is only optimizing the inventory for parts
that see enough demand to be considered an ASL part at the repair centers. As detailed in the
inventory turns analysis of the inventory planning section, there are many parts that have very
low or no demand that should not be stocked at all. The current ASL policy is too broadly scoped
in its part cost and order event parameters and too conservative in allowing parts to be stocked
within those groups. The proposed alternative for repair center ASL policies is to separate the
cost and event ranges into smaller tiers and determine the optimal trade off in stocking locally
versus sourcing directly from the distribution center (a non-ASL repair part).

4.3.2.1. Estimated Impact

The optimization of the ASL policies was completed in an iterative process to first
determine the appropriate amount of segments to create in order events and part costs, and then
in locating which of the resulting “buckets” of parts should not be included on the ASL list. The
segmenting process involved aggregating the annual demand for all parts at the repair centers
which are sourced from their local distribution center. Then segment cut offs were created and
adjusted to ensure each “bucket” had enough parts to substantiate the additional complexity of

71
more segments, but not too many parts in a bucket to reduce the benefits of a more specific ASL policy.

<table>
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<th>2-3x / year</th>
<th>Every 2-3 mos</th>
<th>Monthly</th>
<th>1-2x/month</th>
<th>Weekly</th>
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**Figure 24 - Revised ASL Policy Segments**

The resulting grid of segments, shown in Figure 24, minimized the buckets with more than 250 parts and buckets with fewer than 20 parts. Fewer parts were allowed in the high dollar ranges as the increased policy complexity was justified by the potential reduction in inventory savings. The green cells in the grid represent those part buckets that currently qualify for the ASL list, approximately 78% of all parts with demand.

The next stage of optimizing which buckets of parts should be allowed on ASL policy involved several steps. For each bucket a tradeoff between holding and ordering costs had to be found. The ordering cost used in the model was the recommended new value of $3 per order. That value was used to determine the estimated annual ordering cost on a per part basis should the part be sourced directly from the distribution center. This resulting cost was then compared with the average annual holding cost per part if it were included on the ASL list and stocked locally.
The holding and ordering costs were calculated for each part bucket. Buckets where the holding cost was lower than the ordering costs identified them as qualified for ASL. Figure 25 shows the part grid for Windsor Locks repair with the holding cost per part displayed and ASL qualified buckets highlighted in pink. The result shows several buckets, colored in green, that are on the ASL list per the current policy, but were not cost justified to be stored locally. It is only a few buckets of parts, but that accounts for 418 parts (approximately 9.3% of total) and $138,800 in annual inventory savings (reduced holding costs less additional ordering costs) for Windsor Locks. Across the other domestic repair centers the same buckets were implemented with an estimated total network annual savings, including Windsor Locks, of $204,800.

4.3.2.2. Supporting Facts

The benefits of the proposed ASL policy change are similar to the reduction in average inventory. There are both direct cost savings as well as related positive improvements, including:

- **Significant low demand inventory in repair facilities:** Much of the inventory in the co-located repair sites sees only minimal demand and can easily be served from the nearby distribution centers. Approximately $204,000 in annual savings can be realized by adjusting the ASL policies and relocating parts to the distribution centers.
• **Reduces network excess and obsolescence:** Over 7,000 parts with inventory in the Windsor Locks Repair center do not have sufficient demand to be placed on the ASL list. More than 2,500 of those parts were on the ASL list for less than 60 days before being removed as demand changed, and account for $1,031,000 in inventory on hand. Changing the ASL policy won’t benefit these parts, but it will prevent a large amount of future parts from being classified as ASL and building up stock in the repair site.

**4.3.2.3. Opposing Facts / Alternative Views**

Changing the ASL policies has much of the same side effects as reducing EOQs in an effort to reduce average on hand inventory, as the change effectively increases order fulfillment in the distribution center. The side effects for the ASL policy changes include:

- **Additional picks in distribution centers:** Relocating additional groups of parts to be served from the distribution center increases the order fulfillment activity significantly. Instead of carrying stock locally and replenishing in larger order quantities the parts must be sourced as needed, typically in single unit increments.

- **Additional complexity in inventory policies:** One of the benefits of the current ASL policies is that they are simple to administer and communicate. Increasing the ASL policy complexity may require changes in Servigistics to accommodate more business rules and would require occasional revisiting to determine if they are still optimal for the current operating environment.

- **Increased exposure to stock outs:** The repair centers have very quick turnaround requirements for customer repair work and need parts stocked with high availability to meet their commitments. Reducing the number of safety stocks by only stocking at the distribution center increases the likelihood of that a part may not be available in time.
4.3.2.4. **Recommendation**

Following the analysis that just a few small refinements in ASL policy could lead to over $200,000 in annual cost savings, it is recommended that a more detailed policy be put in place. The short term gains in reducing inventory on active ASL parts will be just a small fraction of the long term gains in preventing excess and obsolete parts building up in the repair centers.

As with the other recommendations, the proposed method of implementation is to slowly expand the ASL policy into the more segmented approach. The process should begin with the higher dollar parts as those have significant gains as well as require more DC stocking for higher use parts that should provide a reasonable test of the ability to serve common parts directly from the DC. The remaining tiers of part costs should be implemented in two additional stages, first with the $500 and above parts tiers followed by the remaining tiers. It might also be appropriate to test delaying the addition to or removal from the ASL list by a month or more to gauge the impact on operations and to weather short term demand spikes before committing volume to the repair center. Co-located repair center parts not on the ASL should be regularly reviewed, aside from the current quarterly excess and obsolete reviews, to determine additional inefficiencies in the ASL policy that could benefit inventory performance if resolved.

5.0 **Summary**

The recommendations proposed in this thesis address inefficiencies in the network design and inventory planning of the aftermarket distribution network. The estimated combined savings from closing the Asia distribution center, relocating Rockford DC volume and refining co-located repair inventory policies is over $1 million per year. This significant impact in cost savings results from changes that maintain high service levels, modernize the distribution network to current conditions and reduce duplicate inventory. While the changes do optimize in
very explicit areas, they are the result of a broad analysis of the distribution network that
identified those areas specifically. The universal theme is that it is important to first identify the
right problems before attempting to solve them.

5.1 General Takeaways

The various recommended changes proposed in this thesis were for specific challenges
faced by Hamilton Sundstrand’s aftermarket network, but neither the challenges nor the solutions
are restricted to their network. The hierarchal approach can be applied to any supply chain
network with similar benefits. The general characteristics of the analysis that could be used in
other organizations include:

- Ensuring supply chain strategy matches business strategy
- Refining supply chain practices for current needs
- Revisiting and validating assumptions

Matching the supply chain strategy with the overall business strategy is a critical process
that can build significant value if done correctly or destroy value if done poorly. In Hamilton
Sundstrand’s aftermarket network the business strategy aimed to deliver high customer service in
terms of high availability, quick response and quality parts. An appropriate supply chain strategy
for the business required high service levels, relatively high (but efficient) inventory and rapid
transportation methods. For other business strategies, for instance in low cost wholesalers, this
supply chain would not be appropriate. There is no one-size-fits-all supply chain, they must be
tailor fit for the specific needs of the business.

The practice of matching the supply chain with the business strategy is not a one-time
occurrence. Business needs change significantly over time as products change, competitors enter
or exit the market and customer needs evolve. Trying to force a supply chain built upon
historical needs to meet current conditions will lead to shrinking profits and missed opportunities. Hamilton Sundstrand has kept pace with their changing needs by adding facilities in new markets, focusing on new service levels and developing innovative supply chain relationships like the OSS locations. Periodically taking a step back from the daily operations to revisit the match of supply chain strategy with current business needs is important to remaining competitive.

Revisiting the explicit and tacit assumptions made in operating the supply chain is a critical step in aligning with current business needs and moving closer to the efficient frontier. Assumptions are present in many systems and analysis like business cases of investment decisions, inputs in planning systems and cultural operating practices. In the analysis of the Hamilton Sundstrand aftermarket there were examples of outdate assumptions in business cases like the Asia distribution center and untested inputs to the planning system like ordering costs and stocking policies. Typically the models that are used for business decisions are accurate and perform appropriately; it is the assumptions that power the model that lead to poor outcomes. Testing the assumptions with sensitivity analysis or revisiting the logic behind them can lead to very different decisions.

5.2. Follow-up Analysis

The analysis of the aftermarket network resulted in a limited group of proposed solutions based on the initial review of network needs and the time available for analysis. With additional time and effort a few additional topics could be analyzed in more detail to provide additional improvements in the network. Other topics include revisiting excess and obsolescence inventory policies, lead time reduction efforts and full consolidation of inventory at co-located repair and DC sites.
Excess and obsolescence is a challenging issue for aircraft parts providers. The product life cycles can be very long with high variation in usage patterns. Additionally, design issues with parts may be addressed with engineering change orders that immediately make previous part versions obsolete in some cases. Current network stocking policies may have room for improvement by increasing review frequency, centralizing stocks and adjusting inventory planning parameters to optimize very slow moving parts without sacrificing service levels substantially.

As described several times in this thesis, inventory is used to buffer against lead time differences in supply and demand. With supply lead times far in excess of demand lead times no amount of inventory optimization is going to rid the network of large stocks of parts. Only efforts to reduce the supply lead time or increase the demand lead time will dramatically impact the inventory levels. With high availability goals and stringent customer lead time requirements, lengthening the demand lead time is probably not appropriate for many customers. That leaves reducing the supply lead time to impact inventory. Hamilton Sundstrand already has many lead time reduction efforts in place both with internal OEM suppliers and through supplier integration. Continuing to seek out methods to reduce the lead times will pay dividends in reduced inventories by decreasing the demand over lead time component of the safety stock calculation (see Equation 2 in section 4.3).

Finally, additional gains can be made in co-located repair and DC inventory reduction by completely consolidating the shared inventories. Although full stock consolidation would not be possible due to point-of-use inventory and parts sourced directly from other suppliers, the majority of inventory could be combined into the DC to reduce overall inventory. The pooling of inventory at a central location saves inventory costs by reducing the required safety stocks due to
lower overall variability in aggregate demand. This effect, called risk pooling, generally reduces network safety stocks by the square root of the number of locations, but it is dependent on the underlying variation in demand. With high demand variation, like that experienced in aftermarket parts, the benefits of inventory pooling can be even greater. Accomplishing complete consolidation of DC and repair inventories would require changes in daily operating activities and could face organizational and political barriers to implementation. Gradual shifts in increased consolidation using more aggressive ASL policies could be used to surface issues and allow time to adapt for a successful implementation.
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