Service Bulletin Inventory Management and Modeling for Aerospace Parts in Customer Service Organization

By

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Submitted to the MIT Sloan School of Management and the Department of Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration
and
Master of Science in Engineering Systems Division

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Abstract

The Customer Service department of United Technology Corporation (UTC) Aerospace System is primarily responsible for providing spare parts, repair services, training, and technical support for products that UTC Aerospace Systems develops. The goal for spares turn-around time is a 7-day or less and for repair turn-around time is a 15-day or less. In reality, most of parts needed to support spare parts' order and repair operations have lead times that are greater than the targeted turn-around time, which leads to a costly build-to-stock inventory policy. Proper inventory management becomes the focus of the department, given that both inadequate and excess inventory can have a financial impact and damage the overall health of the business. This thesis presents a project to develop a method and implement improvements to the current inventory management.

Service Bulletins (SBs) are recommended procedures for repairing products. A SB is issued by UTC Aerospace Systems Customer Service to their customers when there is a safety concern to the current product, or when improvement to the original product design results in either increased performance or lower maintenance costs. Management of a Service Bulletin begins with an engineered solution to an existing product, followed by a ramp up in inventory to support the retrofit activities. Management of the inventory to support these Service Bulletins can be complex and very difficult as it depends on estimates of units in service and timing of units to be returned to UTC Aerospace Systems Repair, and part replacement rate estimates of certain components. Actual units returned, the timing of the returns, and the actual part replacement may vary from earlier estimates made by UTC Aerospace Systems technical personnel during the preparation stages, and therefore require good inventory planning.

The author began the project by conducting interviews with key personnel, assessing the current state of service bulletin process, and documenting challenges faced with the current process. An initial hypothesis of the units returned model was made based on the nature of service bulletins (Safety, Retrofit, and Attrition). Data extraction and analysis of existing service bulletin units returned was conducted, focusing on the descriptive texts that were provided by repair personnel. Detailed reviews with subject matter experts were conducted to confirm the observations and analysis. Finally, a consensus was reached on the type of service bulletin that the author should focus on assessing. Mechanistic growth models of units returned were developed and proposed. The models could be used to determine order points based on average return rates and variance. Utilizing the models to build process monitoring tool in turn could support inventory reduction by at least 30% while reducing the amount of work order shortages.

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Glossary

Aircraft on Ground (AOG): A term used in aviation maintenance indicating that a problem is serious enough to prevent an aircraft from flying.

Airworthiness Directives (ADs): It is used by the certifying authority such as FAA to notify aircraft owners and operators of unsafe conditions and to require their correction. It prescribes conditions and limitations, including inspection, repair, or alteration under which the product may continue to be operated. It normally consists of additional maintenance or inspection or design actions that are necessary to restore the type certificate's worthiness.

Committed Order: It is a stock that cannot be used for other purposes in the short run.

Federal Aviation Administration (FAA): The national aviation authority of the United States of America with an authority to regulate and oversee all aspects of civil aviation in the U.S.

International Air Transport Association (IATA): An international industry trade group of airlines whose mission is to represent, lead, and serve the airline industry. IATA represents some 240 airlines comprising 84% of scheduled international air traffic. Currently, IATA is present in over 150 countries covered through 101 offices around the globe.

Inventory Position (IP): IP is defined by (on-hand stock) + (on-order stock) – (backorders stock) – (committed order or stock).

Line Replaceable Unit (LRU): A support product that is removed and replaced at the field. It is used to restore the end item to an operational ready condition. In UTC Aerospace Systems SB system, LRU denotes an assembly part number and NOT a detailed part number.

On-order Stock: It is a stock that has been ordered but has not been received at the UTC Aerospace Systems warehouse.

Repair turn-around time: A total time taken from the receipt of customer's product for repair to the return of the repaired product to the customer.

Service Bulletins (SBs): Notices issued by product manufacturers to customers when one of the following conditions occurs: a safety of flight issue that should be addressed within a certain time frame, a defect in the manufacturer's product or published documentation, an improvement made by the manufacturer resulting in either lower maintenance costs or increased performance.

Spares turn-around time: A total time taken between the placement of customer order from spares catalog and the shipment of the spares to the customer.

Type Certificate: It is awarded by aviation regulating bodies such as FAA to aerospace manufacturers when a particular design of aircraft, engine, or propeller has fulfilled the current regulating bodies' airworthiness requirements for the safe conduct of flights under all normally conceivable conditions.

1. Introduction

This chapter provides a brief introduction to the UTC Aerospace Systems Company, including the departments, teams, and stakeholders relevant to this thesis project. An overview of the project covers the drivers, objectives, and deliverables of the author's internship project. Finally, the thesis overview is presented to highlight the topics to be discussed in more details in each chapter.

1.1 Company Background

1.1.1 United Technologies Aerospace Systems

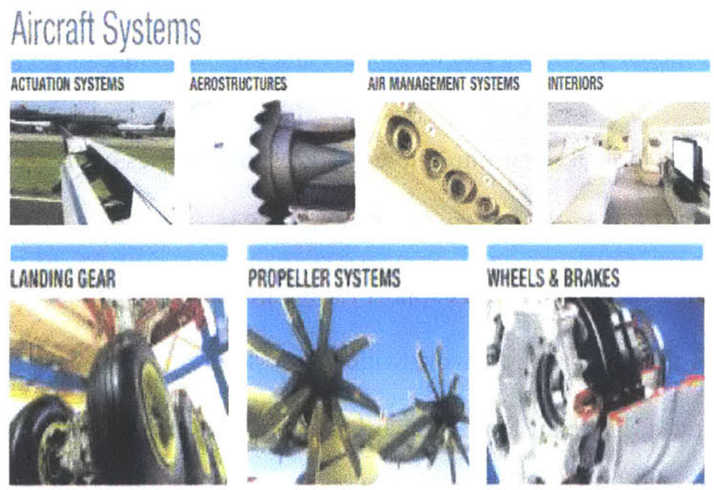
UTC is a diversified company that provides a broad range of high-technology products and services to the global aerospace and building systems industries. Its commercial businesses are Otis elevators and escalators and UTC Climate, Controls & Security, which includes *Carrier* heating and air conditioning and UTC fire & security products. Its aerospace businesses are *Sikorsky* aircraft and UTC Propulsion & Aerospace Systems, which includes *UTC Aerospace Systems* and *Pratt & Whitney*.[1]

In July 2012, UTC Aerospace Systems was formed through a merger between UTC-owned Hamilton Sundstrand Corporation and Goodrich Corporation, creating an organization with key positions on a wide range of aircrafts flying today with its headquartered in Charlotte, North Carolina. Both Hamilton Sundstrand Corporation and Goodrich Corporation are subsidiaries of the United Technologies Corporation (UTC). Hamilton Sundstrand Corporation provides aircraft systems from tip to tail for both commercial and military aircraft, and integrates them to operate seamlessly at the aircraft level. Goodrich Corporation provides aircraft wheels and brakes, evacuation systems, landing gear and avionics. The new merged company is expected to greatly advance UTC core business strategy and strengthen UTC position in the growing commercial aerospace market.

[1] http://www.reuters.com/finance/stocks/companyProfile?symbol=UTX.

UTC Aerospace Systems is one of the world's largest suppliers of technologically advanced aerospace and defense products. UTC Aerospace Systems employs more than 40,000 people worldwide with approximate annual sales of $13 billion. UTC Aerospace Systems designs, manufactures and services systems and components and provides integrated solutions for commercial and military aircraft, helicopters and other platforms. UTC Aerospace Systems is also a major supplier to international space programs.

UTC Aerospace Systems business is organized in two main business segments: Aircraft Systems and Power, Control & Sensing Systems. In addition, UTC Aerospace Systems also has 14 strategic business units (SBUs) offering a broad portfolio of complementary systems and products.



The Aircraft Systems business segment produces systems, components and structures that enable aircrafts to take off and land, control aircrafts while in flight and enhance aircraft cabin environments. Aircraft Systems also produces safety systems for pilots and passengers.

The Power, Controls & Sensing Systems business segment produces systems and components that power aircraft, control aircraft engines, and monitor aircraft systems and the external environment.

UTC Aerospace Systems also offers reliable, convenient and cost-effective aftermarket and support services across the globe 24/7/365. More than 6,000 customer service employees across 26 countries are dedicated to the operation of 64 maintenance, repair, overhaul and service centers.

1.1.2 Customer Service Department

UTC Aerospace Systems Customer Service group is responsible for the overall customer experience and customer-related services. The group includes experts located globally to provide customers with responsive service and to support and tailoring support programs to customers' unique requirements.

Even though the group's roles and responsibilities evolve slightly after the merger, the primary function of UTC Aerospace Systems Customer Service group is to provide aftermarket spare parts, repair services, training and technical support for the product lines that UTC Aerospace Systems provides. It supports customers through a worldwide network of facilities, with four major distribution centers in the United States, 12 repair facilities worldwide located in each of the International Air Transport Association (IATA) regions, and On Site Support (OSS) at numerous customer locations. In addition to the distribution and service infrastructure, a state-of-the-art Customer Response Center was added in 2010 to provide 24-hour global service to customers with a single contact point for their AOG (aircraft on ground) and technical support needs.

Most after-market spare parts have a catalog turn-around time of seven (7) days to customers, but in the event of an aircraft on ground (AOG) emergency, critical parts could be delivered to AOG aircraft within the same-day turnaround time requirement. Spares sales to external customers are generally serviced out of the main distribution centers, as are replenishments to the repair centers.

Repair services are provided for parts and assemblies at repair centers in each IATA region. Repairable units arrive in the nearest repair facility associated with the product family. They are torn apart and diagnosed to determine the cause and repaired with the necessary spare parts and adjustments. The entire repair cycle turnaround time is typically required to be completed within a 15 day period. Spares for the repair services are stocked locally at the repair center.

1.1.3 Supply Chain Management Group

In the era of market globalization and business outsourcing, UTC Aerospace Systems, similar to many other companies, has a dedicated Supply Chain Management (SCM) group to manage its supply chain and logistics. The role of the SCM group is as important to UTC Aerospace Systems' success as any other functional group within the company. One of the main responsibilities within the SCM group is to manage the spares inventory and the transportation of spares to support UTC Aerospace Systems direct customer orders and replenishments for the repair service locations.

Requiring high availability of parts and quick turnaround leads to high operating costs. Repair work order shortages (stock outs) and part inventory values are the two main metrics that the SCM group is responsible for. The ability to strategically manage inventory to reduce operating costs while minimizing stock outs frequency becomes a challenge. An individual missing part can delay the repair activity of an end item product. Hence it impacts the company turnaround time commitment to customers.

1.2 Project Information

1.2.1 Project Drivers

The Customer Service department of UTC Aerospace Systems is committed to deliver high customer service level of 95% or above. The 95% customer service level is measured as a probability that all customer orders arriving within a given time interval will be completed within their committed turn-around time. This commitment brings with it significant operating costs. 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 imbalance of supply's lead time and demand's turn-around time requires UTC Aerospace Systems to adopt *a build-to-stock* inventory policy to meet customer demand. From the supply side, parts have to be ordered from suppliers or manufactured internally within UTC Aerospace Systems facility. Most if not all parts have a lead time of greater than four months. This four months account from the time the part is ordered to the time the part is received at one of UTC Aerospace Systems' warehouses. From the demand side, UTC Aerospace Systems is required to ship within 7 days from the time the customer order part to the time part is shipped to customer. If it is related to repair order, UTC Aerospace Systems is committed to 15 days turn-around time from when product is received at one of UTC Aerospace Systems' repair centers to the time product is shipped to customer. Hence the imbalance between supply's lead time of greater than four months and the turn-around time commitment to customer which is much less than four months as illustrated in Figure 1.

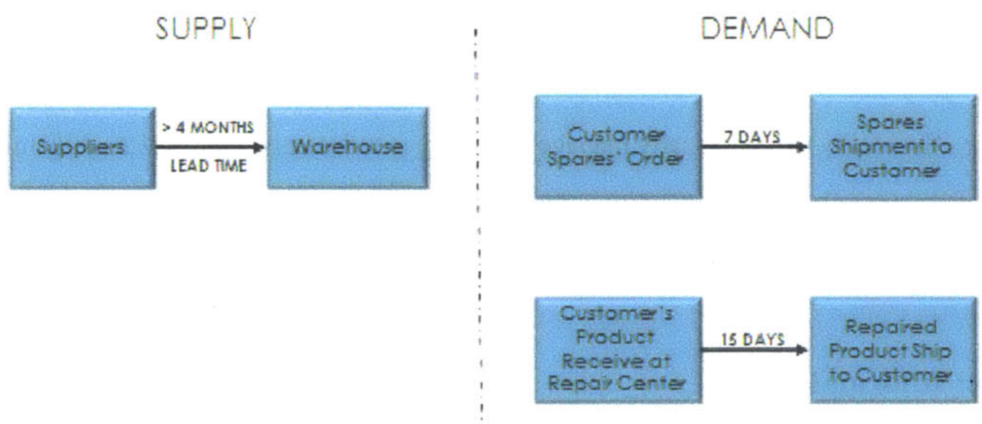


Figure 1: Imbalance of Supply's lead time and Demand's turn-around time

The policies governing inventory management can significantly impact the costs and customer service level. Deciding how much inventory to keep, where to place those inventories, and how to fulfill orders are critical to balancing meeting customer expectations and keeping costs in check.

Moreover, management of service-parts inventories requires capabilities above what is considered adequate for production inventories. Applying traditional forecasting, planning and procurement capabilities that are well-suited for stable, dependent demand inventories is not sufficient. New probabilistic techniques to determine target stock levels are required, which may not be available even in advanced service parts planning applications. In these cases, reliance on a time-series forecast to derive monthly safety stock values for stochastic parts is an exercise in futility; a typical result is that either too much or not enough inventory is held, as the forecasting system confuses a random demand pattern as a changing demand trend.

1.2.2 Project Objectives

The project focuses on two main objectives. The first project objective is to develop a method for regular updates on Service Bulletin progress. The critical data to be included are (but not limited to) both forecasted and actual unit return and part replacement. The progress report will provide guidance to key management personnel to periodically make decisions if any changes to the inventory planning are needed. Changes to the inventory plan may be the result of different unit return rates than planned or different part replacement factors than planned.

The second project objective is to develop and recommend models for service bulletin inventory that will improve service performance on service bulletins. Critical information collected such as unit return will be used to model service bulletin progress and to plan for future inventory. It is expected that inventory management of Service Bulletin would be improved. Key metrics such as inventory values and repair work order shortages would be the measure for operational performance.

1.2.3 Project Goals and Deliverables

Supporting UTC Aerospace Systems Customer Service 15-day turnaround time while maintaining cost control over inventory, requires careful and competent management of inventory and service. Silver, Pyke, and Peterson (1998) suggested based on prior consulting experience that total cost savings of at least 20 percent can be achieved in more than 90 percent of cases by improvements in inventory management.

The main goal of the internship is to develop a method for providing regular updates on service bulletin progress. The updates will include actual units returned and actual part replacement, compared against the original forecast. The % service bulletin completion can be calculated from the units returned numbers and the adjustment to the original inventory plan can be made based on the actual units returned data and replacement rate. When this progress report is in place, it is expected that the UTC Aerospace Systems inventory management of service bulletin will improve. The desired outcome will be $1 million less inventory values and fewer repair work order shortages.

Furthermore, with the units returned and part replacement rate data, the service bulletin inventory can be modeled and changes to the current inventory policy can be proposed to closely match the demand.

1.3 Thesis Overview

The thesis is organized as described below:

Chapter 1 introduces the company, provides the general motivation for the thesis, and provides an overview of the thesis contents.

Chapter 2 provides literature review on inventory management.

Chapter 3 provides definition of service bulletin and its type, and the hypothesis assumed for each of service bulletin type.

Chapter 4 explains the current service bulletin state, inventory management process, and UTC Aerospace Systems cultural elements.

Chapter 5 describes the method for creating, updating, and maintaining service bulletin management report.

Chapter 6 outlines the inventory modeling process for both units returned and part replacement rate.

Chapter 7 provides summary from units returned models and recommendation for forecasting and process- monitoring tool.

Chapter 8 provides a discussion on UTC Aerospace Systems inventory policy, and how the analysis from this project could be utilized to build process-monitoring tools to support inventory reduction by at least 30%.

2 Literature Review

This chapter provides high-level reviews of literatures in the field of inventory management. The costs of inventory in general and the dollar value of inventories in UTC Aerospace Systems Q4 2012 balance sheet are discussed. The fundamental of inventory management is subsequently presented, followed by various policies around inventories adopted by modern companies.

2.1 Cost of Inventory

Inventory is commonly used to describe the goods that a business acquires and holds for the ultimate purpose of resale, manufacturing, or service. Inventory costs money to business. Improper inventory management could lead to inefficient use of capital in businesses. If at all possible no businesses would want to carry any inventory. In the lean six sigma management, excess inventory is considered as one of the 7 wastes (Six Sigma Material, 2013).

A few reasons why business carries inventory are:

1. To handle uncertainties in supply and demand
2. To handle the imbalance in lead time
3. To satisfy customer demand

Poor inventory management could lead to having too much inventory on low demand parts and not enough inventory on high demand parts. Companies frequently target inventory reduction to free up cash.

Balance Sheet (USD)					Annual | **Quarterly**
QUARTER ENDING	31-MAR 2012	30-JUN 2012	30-SEP 2012	31-DEC 2012	31-MAR 2013
Cash & Equivalents	6.29B	16.7B	6.24B	4.82B	4.77B
Short Term Investments	0	0	0	0	0
Accounts Receivable	8.83B	9.54B	10.6B	11.1B	10.8B
Inventories	8.37B	8.50B	10.5B	9.54B	10.2B
Pre-paid Expenses	0	0	0	0	0
Deferred Tax Assets	0	0	0	0	0
Other Current Assets	4.36B	4.42B	4.37B	4.16B	3.44B
Total Current Assets	27.8B	39.1B	31.7B	29.6B	29.2B
Property, Plant & Equipment	5.83B	5.72B	8.24B	8.52B	8.43B
Goodwill & Intangibles	19.9B	21.0B	42.8B	43.0B	42.6B
Other Long-term Assets	8.10B	8.79B	9.25B	8.29B	8.28B
Total Long-Term Assets	33.9B	35.5B	60.3B	59.8B	59.4B
Total Assets	61.7B	74.7B	91.9B	89.4B	88.5B
Accounts Payable	5.28B	5.75B	6.16B	6.43B	6.19B

Figure 2: UTC Quarterly Balance Sheet[2]

Figure 2 shows that at the end of 2012, UTC carried more than $9.5 billion of inventories on its balance sheet. This number represents almost a third of UTC's $29.6 billion of Total Current Asset. Reducing the size of its inventories would allow UTC to increase cash flow to invest in other opportunities.

Inventory Turnover and *Days Cost of Goods Sold in Inventory* are two metrics that are commonly used to indicate operational and financial performance. Inventory turnover is a measure of the number of times inventory is sold or used in a year. It is equal to the latest 12-month Cost of Goods Sold divided by the average Inventory. High inventory turnover means reduced holding cost which leads to increase cash flow. Low inventory turnover may be a result from overstocking or obsolescence.

Figure 3 shows UTC operation's competitive landscape in comparison to three big aerospace companies in the Aerospace and Defense industry: Boeing, GE, and Mitsubishi Electric. UTC's inventory turnover of 4.86 is above the industry median of 4.19; however, it is lower than those of GE and Mitsubishi Electric.

[2] Source from Wikinvest.com. Retrieved 5/17, 2013, from: http://www.wikinvest.com/stock/United_Technologies_(UTX)/Data/Balance_Sheet. Note: The balance sheet number reflects quarterly financial report.

2012 Operations

	United Technologies	Boeing	GE	Mitsubishi Electric	Industry Median
Days of Sales Outstanding	65.29	25.47	35.29	73.04	44.37
Inventory Turnover	4.86	1.96	5.39	5.24	4.19
Days Cost of Goods Sold in Inventory	75.05	186.08	67.67	69.70	87.20
Asset Turnover	0.77	0.97	0.20	1.12	0.97
Net Receivables Turnover Flow	5.59	14.33	10.34	5.00	8.23
Effective Tax Rate	24.76%	33.96%	28.52%	36.67%	30.96%

Figure 3: 2012 UTC Competitive Landscapes[3]

Days Cost of Goods Sold in Inventory is an efficiency ratio that measures the average number of days the company holds its inventory before selling it. It is equal to the average of inventory levels at the beginning and end of an accounting period divided by total Cost of Goods Sold per year, multiplied by 360 days. Companies should aim to minimize this ratio. Figure 3 shows that, on average, UTC holds its inventory for 75 days before selling it. UTC's Days Cost of Goods Sold in Inventory is lower than the industry median, but definitely higher than those of GE (68 days) and Mitsubishi Electric (70 days).

As the customers' demand for service quality increases, strategic management of inventory in a supply chain becomes important and critical. As shown in the 2012 UTC Balance Sheet, about 33% of UTC asset is tied to inventory (or ~10% after adjustments). Even though UTC's inventory turnover and days cost of goods sold in inventory numbers are better than the industry median, it is essential that costs associated with inventory should be evaluated, and proper trade-offs, with necessary performance measures, should be implemented.

One risk for having too much inventory is the risk of obsolescence. Especially when dealing with after-market parts, changes to design might cause current parts to be obsoleted, or a new product line can cannibalize the old product line. However, as the original equipment manufacturer (OEM), UTC

[3] Source from Hoover.com. Retrieved 2/21, 2013, from: http://subscriber.hoovers.com.libproxy.mit.edu/H/company360/competitiveLandscape.html?companyId=11559000000000

Aerospace Systems is required to carry old and new parts as customer's demands still need to be met. This creates an additional issue for the industry, which is called a slow moving parts inventory problem. It is an inventory problem where the inventory is moving so slowly that at some point it has to be written-off from the balance sheet. UTC Aerospace Systems and other businesses are suffering from this very issue, and a good inventory management strategy can help to minimize this damage. For more reading on slow moving inventory, please refer to Disposal of Excess Inventory article (Rosenfield, 1989).

2.2 Inventory Management

Economy goes through cycles where there are periods of growth where money flowing in the system creates high demand for products and services, resulting in high employment rate. This is typically followed by periods of contraction, where money is tight, creating lower demand for products and services, resulting in increased unemployment rate.

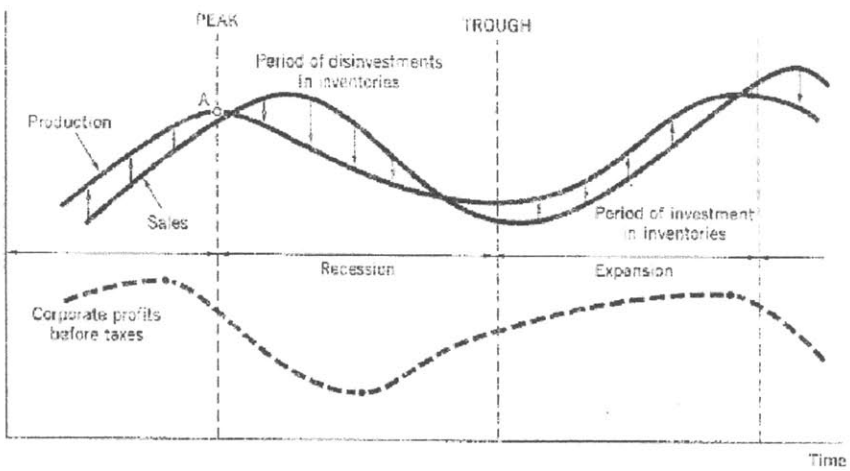


Figure 4: The Business Cycle[4]

This business cycle shown in Figure 4 impacts how businesses plan on meeting customers' demands, hence inventories. During the period of growth leading to the "PEAK", businesses are optimistic about potential growth in demand and tend to produce more than needed, hiring employees and creating

[4] Source from Silver, Pyke, Peterson, 1998.

inventory in anticipation of sales growth. Then it is reversed when there is a sign of the economy's slowdown.

Most companies will reduce their production and lay off excess employees in anticipation of weak sales and often stop building any inventories. Low inventory level might lead to stock-out situations, however. When the economy's turns around, the cycle begins again, where business increase their production, hire new employees, and start building inventories. These business cycles will continue, and the key for management is to adapt to this cyclical business environment and create a robust inventory management system that will minimize inventory values and stock-out conditions at the same time.

Every piece of inventory has a physical cost associated with it which means that cash that is tied-up in inventory is not available to be used elsewhere in the business. Overproduction leads to excess inventory that is used as a buffer for the "just in-case" condition when things do not go as planned. One of the reasons for overproduction is due to mistrust of suppliers, process, or in the sales forecast. Companies often take the approach of "instead of losing sales opportunities, it is better to build inventory."

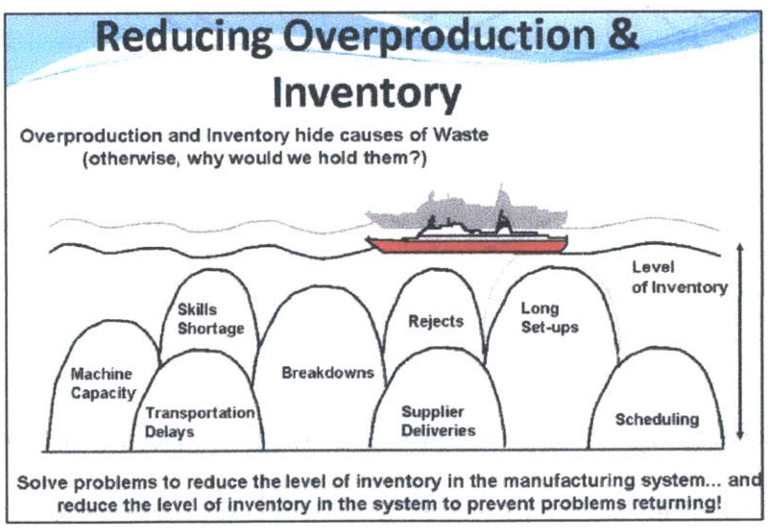


Figure 5: Inventory Visualization[5]

[5] Source from Lean Manufacturing Tools, 2013.

One of the illustrations used by the lean manufacturing organizations to visualize inventory as a waste is to think of inventory as a water level of the sea (Figure 5). The boats represent manufacturing processes and operations. The rocks beneath the water level represent uncertainties or variation in the process. When inventory level or water level is reduced, in order to keep the boats afloat, the rocks need to be reduced in size or removed. If this does not happen, the boat will hit the rocks and manufacturing process stops. Customer deliveries will be missed, profits will be sacrificed, or inventories will build-up again. Hence, a systematic approach is needed to reduce or remove the rocks/uncertainties in the process, or at least make them more predictable.

Much research has been performed to quantify inventory uncertainty. Langenbrunne, et. al, proposed an approach to quantify uncertainty by defining *Uncertainty Inventory* as an organizational set of all the information relating to different types of uncertainties in a given application.[6] Examples of uncertainties applicable to this thesis project include "prediction uncertainty" from a given event (what is to be learned or inferred) and "non-specificity uncertainty" which arises from the lack of specific information.

In addition, managing after-market inventories is more complex than managing production inventories. Traditional forecasting and planning suited for stable, dependent demand inventories is not adequate. Accenture stated that applying a more "scientific" approach and using advanced capabilities such as deployment strategies for stochastic inventories, multi-echelon optimization, and service target optimization are required to optimize inventories. For example, an aircraft engine manufacturer saved more than 25 percent in 12 months in aftermarket and spares inventories, while holding constant service level and supporting increasing sales.[7]

Figure 6 depicts a system dynamics model with simplified assumptions to show the underlying relationships between inventory management reinforcing loop and company profitability.

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[6] Langenbrunner, Booker, Hemez, and Salazar, 2009.
[7] Jacoby, 2005.

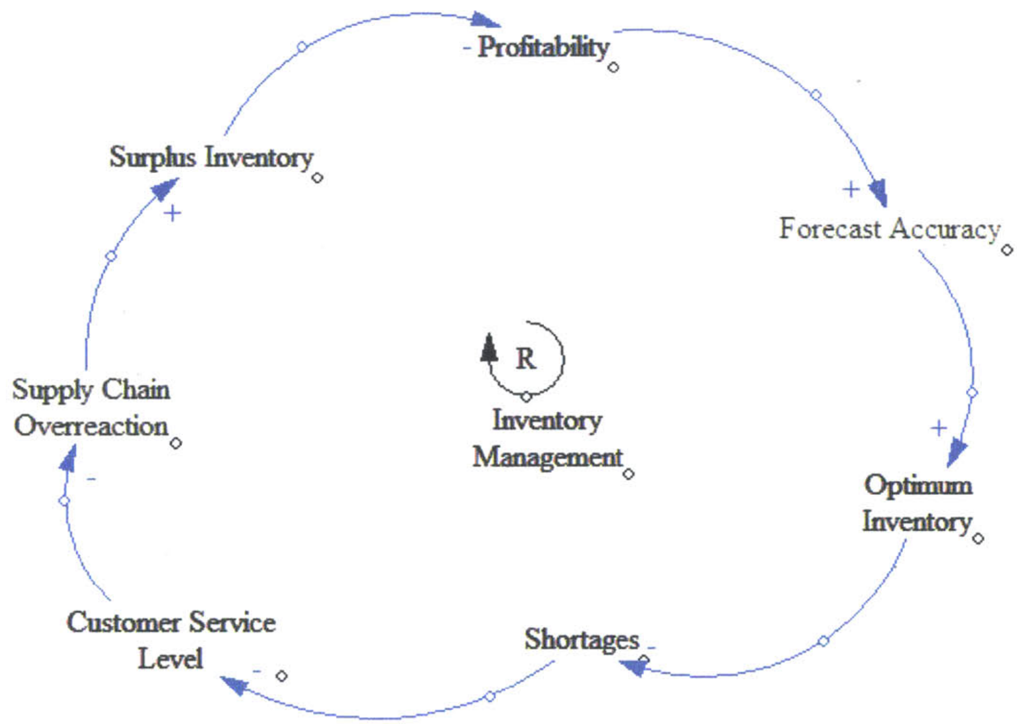

Figure 6: Inventory Management Feedback Loop

Starting from the top-right side of the diagram, improvement in *forecast accuracy* leads to increase in *optimum inventory* level. On the basis of cost function, the optimal inventory level is when the cost of inventory is at a minimum. An increase in optimum inventory level will cause less work order *shortages* that will increase *customer service level*. As UTC Aerospace Systems increases customer service level commitment, there is less pressure put on the *supply chain* group. Consequently, there is less buildup of sludge *inventory* that reduce the risk of having to have inventory write-off at the end of product life that leads to increase *profitability*, hence maximizing the company and shareholders value.

2.3 Inventory Policy

UTC Aerospace Systems deploys a sophisticated inventory management software solution called Servigistics.[8] Servigistics continuously monitors repair or distribution center inventory levels, determines order quantities, and sets order levels based on the desired service level. It is adopting an inventory policy known as Order-Point, Order-Up-to-Level *(s, S)* system which assumes continuous review. The *(s, S)* system is also known as a *min-max* system because the inventory position is always between a minimum value of *s* and a maximum value of *S*, except for a possible momentary drop below the reorder point.

Figure 7 shows a diagram about *(s, S)* inventory policy. Under this policy, order replenishment is made whenever inventory position *(IP)* drops to the reorder point *s* or lower. An order size of *(S – IP)* is placed to bring the IP back up to its optimal Order-Up-to-Level *(S)*. If all order transactions are of unit size, then the replenishment order will always be made when the inventory position is exactly at *s* and every order is of size *(S – s)*.

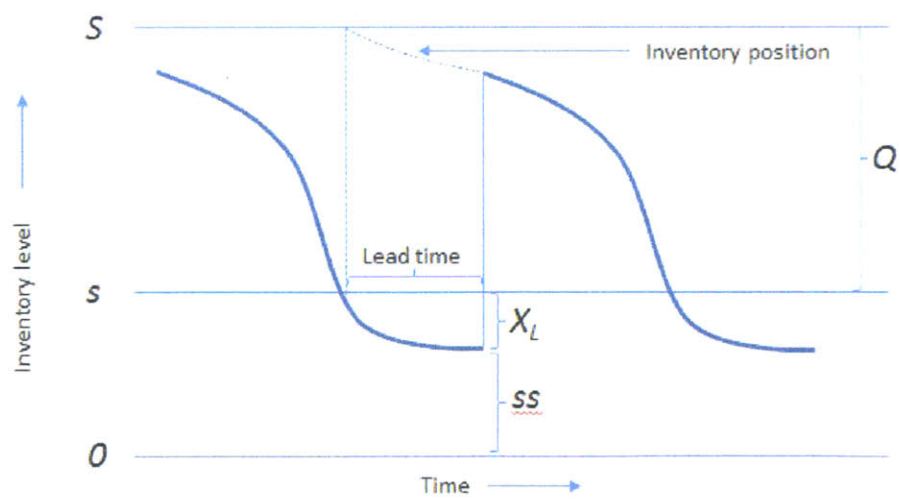

Figure 7: Continuous Review Inventory Policy - Order-Point, Order-Up-to-Level *(s, S)*[9]

[8] Servigistics is the leading provider of Service Lifecycle Management solutions that enable companies to transform their service business operations and access new sources of revenue, profits, competitive differentiation and customer loyalty (http://www.servigistics.com/).

[9] Source from Simchi-Levi, Kaminsky, Simchi-Levi, 2004.

The order quantity of $(S - s)$ can be thought of as an order quantity Q where Q is typically set to be close to the Economic Order Quantity (Q^*) which is calculated using Equation 1.

$$EOQ\ (Q^*) = \sqrt{\frac{2AD}{vr}} \tag{1}$$

Where $EOQ\ (Q^*)$ = Economic order quantity
A = Ordering cost incurred with each replenishment, in \$
D = Demand rate, in parts/unit time
v = Unit cost of the part, in \$/part
r = Carrying or holding cost, in \$/\$/unit time

As depicted in Figure 7, the reorder point (s) is established by adding safety stock (ss) for a desired service level and quantity of demand over lead time (X_L) shown in Equation 2.

$$s = ss + X_L \tag{2}$$

Where s = Reorder point
ss = Safety stock set to achieve a desired service level
X_L = Demand over lead time

Equation 3 shows the formula for calculating safety stock.

$$ss = Z(\sqrt{L + R})\sigma \tag{3}$$

Where ss = Safety stock set to achieve a desired service level
Z = Safety factor set to achieve a desired service level
L = Lead time
R = Review period (= 0 for continuous review in this case)
σ = Demand standard deviation

Servigistics uses a Poisson approach to characterize demand distribution in setting up its inventory policy (Wessels, S.A., 2011). Service level calculation for Poisson distribution is shown in Equation 4.

$$Service\ Level = \sum_{i=0}^{s} \frac{\lambda^i e^{-\lambda}}{i!} \tag{4}$$

Where λ = mean and variance of demand
S = re-order point

Note: UTC Aerospace Systems sets 95% as its customer service level target.

The inventory management for UTC Aerospace Systems service bulletin is complex and does not follow the regular service parts forecasted in Servigistics. In Section 4.3, the author explains that the service bulletin is treated as a non-regular maintenance schedule; hence the non-recurring demand field is utilized. This demand order is inputted manually by the inventory planner based on average demand over the service bulletin implementation period. Demand for service parts most likely will not follow the average distribution; hence demand number gets adjusted manually based on shortages seen at the repair centers or based on high inventory values.

Since no data has been collected on service bulletins to understand demand behavior, once demand data is collected, it will be modeled to generate probability-based forecasts of parts. In a separate study involving a network device manufacturer, the use of demand histories to generate probability-based forecast of parts requirements along with re-designing of internal system helped Cisco reduce its spare parts inventory by 21% while boosting customer satisfaction.[10]

2.4 Forecasting

Forecasts of future demands are essential for effective decision making in inventory management, especially since it takes longer for UTC Aerospace Systems to procure or manufacture associated parts needed for repair activities than to complete service bulletins within the committed turn-around-time to customer. Forecasts will certainly contain error. The goal for any organizations is to minimize forecast error and to provide the right amount of safety stock to avoid stock outs when the forecast is lower than the actual demand and at the same time, minimize the cost for carrying inventories.

[10] Cohen, Agrawal, & Agrawal, 2006.

Forecasts may be based on informed judgments about future events, or a combination of an extrapolation of what has been observed in the past. Informed judgments may include knowledge of firm orders from external customers or preplanned usage of spares parts in repair service.

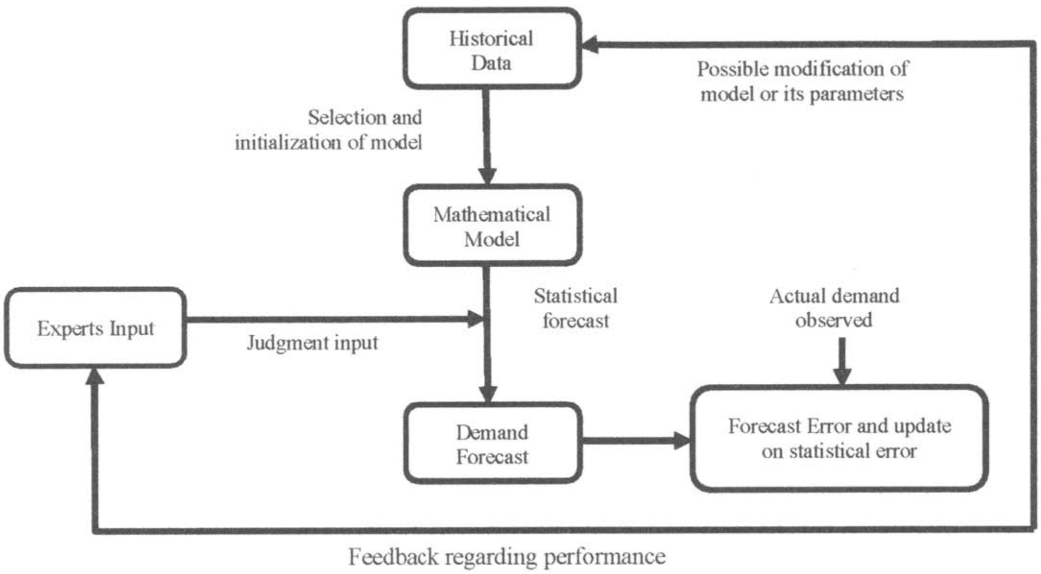

Figure 8: Forecasting Framework[11]

Figure 8 shows a framework for a forecasting system. Experts input are utilized at the beginning to create a demand forecast. Once the actual demand in the period is observed, it will be compared with the earlier forecast and the associated error is calculated. A mathematical model for forecasting is created and the model will be used to refine the demand forecast. The loop will continue and further refinement of the model will be made until an acceptable forecast error is achieved. At the end, a change proposal to the existing inventory policy is made in order to reduce inventory cost and at the same time maintain or increase customer service level.

The current forecasting method employed by UTC Aerospace Systems technical team is the average forecasting as described in Section 4.1.1. For example, a service bulletin is issued with a forecast of 1080 units impacted and an implementation period of 36 months. An average forecast method employed by UTC Aerospace Systems stated 30 units are forecasted to be returned by customers every month for the

[11] Source from Silver, Pyke, Peterson, 1998, with slight modification.

next 36 months. Hence supply chain planning needs to place an order every month to ensure that UTC Aerospace Systems has spares that are needed to support 30 units rework. This average forecasting method will produce significant amount of forecasting errors when it is compared to the actual units returned data. Therefore, the focus of this project is to apply better forecasting strategy in order to minimize forecasting error and at the same time minimize inventory cost.

There are three steps involved in statistical forecasting (Silver, Pyke, Petersen, 2008):

1. Select an appropriate underlying model for the demand pattern through time
2. Select the values for the parameters inherent in the model. Once a general form of model is selected, estimate the model's parameters value
3. Use the model and the parameter values to forecast the future demands. Once satisfied with the assumed model, forecast future demand

The three steps are aligned with the framework shown in Figure 8 and to which the author shows the application in Section 6.

Mean Squared Error (MSE) is often used to measure variability that is used in fitting squared errors of a straight line to historical data. MSE is shown in Equation 5:

$$MSE = \frac{1}{N}\sum_{t=1}^{N}(x_t - \mu)^2 \tag{5}$$

$$where\ \mu = \frac{1}{N}\sum_{t=1}^{N} x_t$$

Where N = Number of active service bulletins in each implementation period t

x_t = % service bulletin completion at implementation period of t month

μ = mean of *% service bulletin completion*

MSE is directly related to σ which is the standard deviation of forecast errors by Equation 6.

σ is calculated for the purpose of setting safety stock levels as discussed in Section 0.

$$\sigma = \sqrt{N * MSE} \tag{6}$$

Where σ = standard deviation of x

3 Service Bulletins

This chapter introduces several definitions used in the project. The types of Service Bulletins are then presented, followed by a discussion of each type. Initial hypotheses around the types of Service Bulletins are described, along with the basic interplay between repair capacity, total units impacted, and implementation period.

3.1 Definitions

Service Bulletins, or SBs, are recommended procedures to address:

1. Inspection of a certain type of product
2. Replacement of certain components
3. Specific performance maintenance
4. Limiting operation under specified conditions

They are issued by product manufacturers to customers when one of the following conditions occurs:

1. A safety of flight issue that should be addressed within a certain time frame
2. A defect in the manufacturer's product or published documentation
3. An improvement made by the manufacturer resulting in either lower maintenance costs or increased performance

Depending upon the manufacturer, a service bulletin may also be called a "mandatory service bulletin", "technical service bulletin", "service letter", or "service instructions". Compliance with a service bulletin may be triggered by the occurrence of a particular event, such as an aircraft accident or product malfunction. SBs can become mandated by relevant Airworthiness Directives (ADs) especially when it is related to safety of flight. Unless otherwise specified, customers may exercise their discretion whether or not to incorporate a particular service bulletin.

Note: Although a service bulletin may be denoted by the manufacturer as "mandatory," it is important to know that compliance with a service bulletin is not specifically required under the Federal Aviation Regulations (FARs) unless the service bulletin is accompanied by an Airworthiness Directive (AD). AD affects safety of flight AND compliance to AD is mandatory.

3.2 Service Bulletin Types

In aerospace industry, there are two types of service bulletins issued by aircraft manufacturers:

1. Safety of Flight
2. Attrition

The "safety of flight" service bulletin is mandated by aircraft regulators such as the Federal Aviation Administration (FAA) in United States. An aircraft may encounter problems that may compromise its safety during its service. Such problems are typically not anticipated or detected in product or prototype testing. When this happens, the aircraft design is compromised. A recent 787 battery problem is an example of a problem encountered during service. In this case, the regulators will issue an AD to the type certificate holder and to all aircraft owners globally. The directive will normally consist of an additional maintenance or inspection or design actions that are necessary to restore the type's worthiness.

The second type of service bulletin is known as "Attrition" service bulletin. With increasing in-service experience, the type certificate holder may finds ways to improve the original product design resulting in either increased performance or lower maintenance costs to the aircraft owners. These improvements are suggested through service bulletin released to the customers as an option and may be done at an extra cost. The customers may exercise their discretion whether or not to incorporate this type of bulletin.

In addition to the two types of bulletin mentioned above, however, UTC Aerospace Systems manages a third bulletin type which is called "Retrofit campaign" bulletin. The reason for having this third bulletin type is to differentiate product improvement that will be beneficial to UTC Aerospace Systems as well as the customers. One reason why this bulletin is beneficial to UTC Aerospace Systems is because the suggested modification increases product lifetime to meet the initial intent of the product warranty. Another reason is to protect UTC Aerospace Systems against part's obsolescence, since it costs UTC Aerospace Systems more money to manage obsolete parts.

UTC Aerospace Systems assigns a Retrofit team to focal the management of Retrofit campaign bulletins. The team is responsible to ensure that UTC Aerospace Systems has adequate inventory in-house to support the customer's modification work and that customers return the products in the assigned timeslot.

3.3 Initial Hypotheses

Based on the discussion the author had with UTC Aerospace Systems subject matter experts, initial hypotheses on customer units' return are made based on service bulletin's type.

3.3.1 Safety of Flight bulletin

Based on the criticality and the urgency of the service needed to comply with regulatory requirements, the author assumes that most of the customers will want to return their product as soon as possible. The only limitation at this point is the repair centers' capacity. Therefore, a uniform distribution is foreseen with peak (Y max) equal to repair centers' capacity, and tapers off at the end of the service bulletin implementation period. Assumption: There will be UTC Aerospace Systems assigned administrators coordinating with customers when they should return their units. This will ensure that demand for service does not exceed UTC Aerospace Systems capacity. This coordination will help to mitigate the risk of not meeting the 15-day turnaround time commitment. The purple line of Figure 9 shows an example model of the customers' units returned behavior for safety of flights bulletins.

The brown line shows the units returned pattern during a Retrofit Campaign. This will be discussed in more details in the section 3.3.2. The green line shows the pattern of units returned during an Attrition process, which is discussed on Section 3.3.3 below.

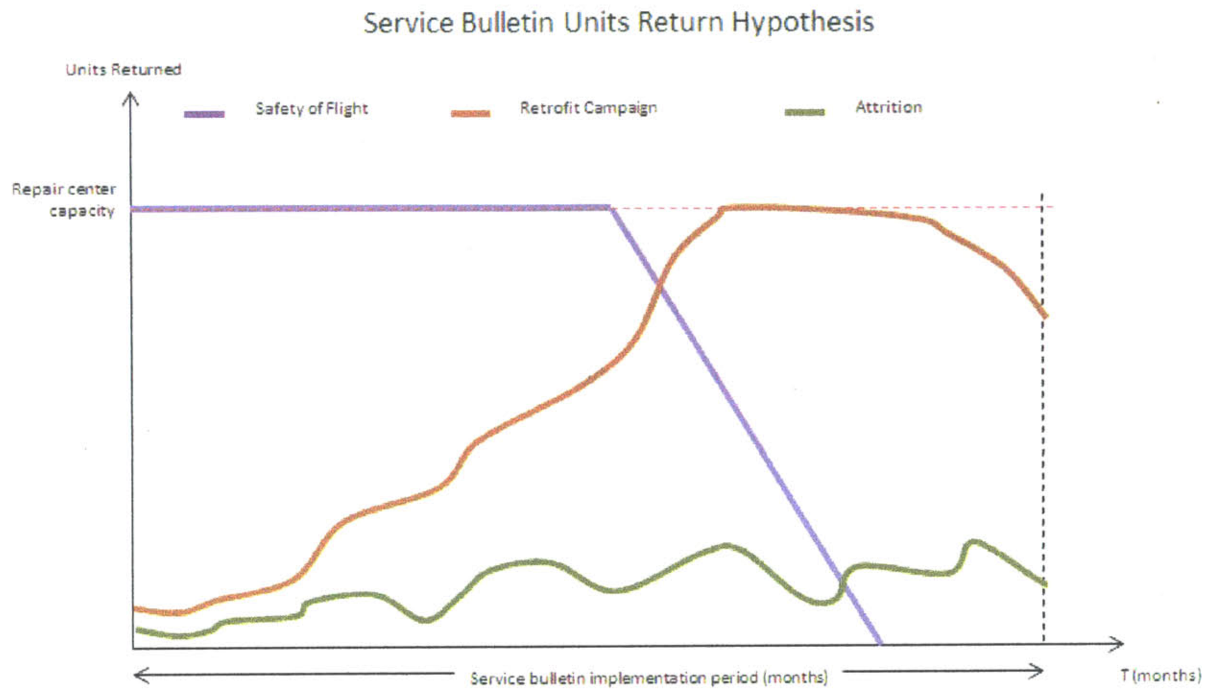

Figure 9: Service Bulletin Units Returned Hypothesis

3.3.2 Retrofit campaign bulletin

The Retrofit group is in constant communication with customers to ensure customers are returning their product for service per the Retrofit plan. The group will monitor the progress of the service modification. Note that from a customer's perspective, removing an end item from any airplanes for service is expensive. It will require the airplane to be on the ground until repair modification is completed which causes a huge financial impact, or in UTC Aerospace Systems case, the retrofit team will work with customers by sending spares units to allow customers to send their units back to UTC Aerospace Systems for repair work. Due to this reason, the author assumes that at the beginning of the implementation period units returned will be trickling-in from the customers. Close to the last implementation period year, UTC Aerospace Systems will see an aggressive effort made by the Retrofit team to get the customers to return their units. This is done with the purpose of ensuring 100% campaign completion at the end of the implementation period.

The brown line on Figure 9 shows this type of behavior. The author assumes low volume of units returned from customers probably in the first few months of the campaign. When it hits the last implementation year, we should expect many customers returning their units at the repair's capacity or close to the capacity and taper off to complete the campaign. It is also assumed that some units will be returned after the campaign period and re-plan activities needed to be discussed.

3.3.3 Attrition bulletin

The purpose of the Attrition bulletin is to let customers know that a design improvement made to their existing product would improve their product performance or reduce expected on-going maintenance cost. It will be the customer's choice to return the product for service. There is typically no group within UTC Aerospace Systems to manage this type of bulletin once it is issued to the customers. It is assumed that units returned from customer will be random and the majority of customers might not bother to return their units for modification work. The green line of Figure 9 shows an example of this random behavior.

4 Current State

This chapter discusses the state of UTC Aerospace Systems Service Bulletin process as first understood by the author during the initial weeks of her assignment. The critical steps from service bulletin initiation to the return of customer's product after rework modification is completed are presented. Critical information and resources needed to complete the initiation and execution of the bulletin is explained, along with the complexity for managing the bulletin. A brief discussion on the management and culture of the department is presented at the end of the chapter.

4.1 Service Bulletin Process

Based on interviews with UTC Aerospace Systems management, technology, and operation personnel, the author constructed a diagram depicting the Service Bulletin Life Cycle as shown in Figure 10. There are two major phases that exist in service bulletin life cycle in the Customer Service department of UTC Aerospace Systems:

1. Issuance Phase
2. Execution Phase

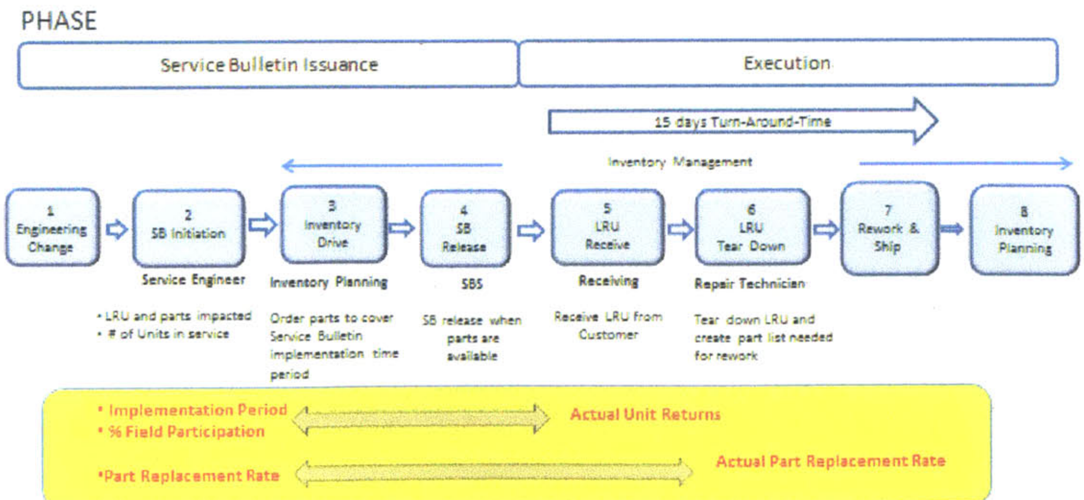

Figure 10: Service Bulletin Life Cycle

The issuance phase focused on the internal UTC Aerospace Systems planning and preparation activities (Steps 1 through 4). Activities included, but were not limited to, providing detailed change information impacting end product and associated parts, forecasting number of end item units and parts impacted, forecasting the timeframe of when customers will return their units, and planning for inventories needed to support the service bulletin campaign.

The execution phase focused on activities occurring after service bulletin was issued to customers (Steps 5 through 8). Activities involved in this phase included, but were not limited to, receiving units at the UTC Aerospace Systems repair center, tearing down and inspecting the unit, pulling replacement parts from inventory, reworking of the unit, rebuilding, and finally shipping back to customer.

Critical information for the project was:

1. Original forecast for units returned
2. Implementation period
3. Part replacement rate

This forecast data would be compared to the actual units returned and replacement rate. Forecast error would be calculated and adjustments to the original forecast would be made. This critical information is shown in the yellow rectangular box in Figure 10.

4.1.1 Service Bulletin Issuance

Steps 1 through 4 of Figure 10 show a high-level version of the service bulletin issuance process to help explain the detailed steps taken during this stage. There were more internal players involved that are omitted here. Program managers played a critical role in approving each service bulletin content and implementation. The finance department provided needed approval to the budget to support the bulletin campaign. The Retrofit team played a focal role for service bulletins designated as a Retrofit campaign. Finally, the provisioning team ensured that engineering and manufacturing configuration management was in place in the ERP system.

The process shown in Figure 10 assumes that assembly and parts modification are required to support each service bulletin campaign. If no parts are impacted, inventory planning will be omitted from the process. Description for each step is outlined below.

Step 1: Engineering change is introduced to an existing product design, a change notification is sent to the Service Engineering group.

Step 2: Service engineer initiates a service bulletin in the Service Bulletin System (SBS). Example of information entered at the initiation stage is listed below:

i. **SB Number and Title**: denotes external service bulletin number and title going out to customers
ii. **SB Type**: indicates Mechanical or Electrical rework
iii. **Safety of Flight (SOF) indicator**: set to Yes if the modification is related to safety of flight
iv. **Implementation Period**: indicates the number of months the SB will be implemented
v. **Free of Charge**: identifies if rework is free of charge to customers
vi. **Retrofit Campaign**: set to Yes if this SB is designated as a Retrofit Campaign bulletin
vii. **Number of Assemblies**: identifies the total number of units that are at UTC Aerospace Systems customers' hands. This number is provided by Service Engineering team
viii. **Percent of Field Participation**: denotes % of customers that will participate in the rework. The percentage is determined by Service Engineering as a guideline and it is based on past experienced
ix. **Number of Units related to this Model**: indicates the total number of units planned to be returned by customers for this service bulletin. It is a result from multiplying the number of assemblies and percent of field participation. Example: Out of the 1000 units that have been shipped out to UTC Aerospace Systems customers, only 80% of customers are expected to participate. Therefore the total units impacted for becomes 800 units

x. **LRU (Line Replaceable Unit):** set to Yes if the part is an LRU or an end item assembly

xi. **Replacement Rate**: indicates replacement rate of part. 80% replacement rate means 80% of the time when the part is removed, it has to be replaced

Step 3: Once SB is initiated by Service Engineering, it goes through a review and an approval process from different functional teams until it stops at Inventory Planning team for review and approval. Inventory Planning will verify the forecast and plan for parts ordering. Examples of information being verified are:

i. **New or Revised Part Number**: denotes the new part number needs to be plan and stock to support the service bulletin campaign

ii. **Total Quantity**: indicates the total number of parts needed to support the service bulletin campaign

iii. **Lead Time**: shows supplier's lead time in days

iv. **Average Quantity per Month**: identifies the number of parts needed to be ordered to support a monthly campaign

v. **One Shot Order Up To Lead Time**: denotes the total quantity needs to be ordered up-front to account for supplier's lead time. An example: if a part's lead time is 3 months and quantity needed per month is 10, the one shot order up to lead time quantity is 30

vi. **Total Inventory Cost:** shows the initial estimate of inventory cost to support the particular service bulletin life cycle. It is an automated calculation field of $/part multiplied by # of parts

The service bulletin system will also provide the first available part date which is an estimated date when the last part number will be arriving at UTC Aerospace Systems warehouse (based on the longest part lead time). That first available part date will become a planned date for service bulletin issuance to the customers.

Step 4: Service bulletin is issued to UTC Aerospace Systems impacted customers.

4.1.2 Service Bulletin Execution

Steps 5 through 8 of Figure 10 show a high-level version of the service bulletin execution process. The process shown assumes that customers will return their units to one of the UTC Aerospace Systems repair centers for rework to be completed. In reality, some of the big airliners own their own repair facilities and hence opted to perform the modification work themselves. Typically, these airliners will order parts from UTC Aerospace Systems and send UTC Aerospace Systems a bill for labor reimbursement, provided that the service bulletin is classified as a free of charge bulletin.

Description of the process is detailed out below.

Step 5: UTC Aerospace Systems repair center receives units returned from customers

Step 6: Units returned is torn down by repair technician and parts needed to be replaced will be ordered from repair storage

Step 7: Repair Technician completes rework and prepare units for shipment back to the customers[12]

4.2 Service Bulletin System

Service Bulletin System (SBS) is an internal centralized web database system developed in 2006 with the intent to manage the entire value stream around initiating, publishing and maintaining service bulletins. The objectives were to reduce inventory due to retrofit and SB activity, increase customer service level, and increase inventory turnover. It was originally designed to be a communication tool that contains work flow and visibility/accountability of the process. Some key features proposed were to track materials and to prevent premature SBs from being published, to shut down inventory when done, and to change SB status after it has been released to completion (100% close out of campaigns) or inactive (Attrition SB after 12 months of publication) or other statuses.

[12] UTC Aerospace Systems maintains a15-days turnaround time commitment from receives to shipment.

SBS was originally designed to be a great tool; however, not all of the features were fully implemented. In 2011, a value stream mapping (VSM) event was sponsored to improve the quality, effectiveness, and turn-around time of the commercial SB process. It was concluded that the current state is cumbersome, resulting in internal user and customer dissatisfaction, duplication of effort, and confusion.

The author was not involved in the VSM project but can attest that the system needed modification in order to create a more efficient process. The author used SBS as the main database to extract all SBs data. Unfortunately, the database does not track material status as it is not designed to handle new data after a service bulletin was released. It does not shut down inventory when completed because inventory was handled in an independent system called Servigistics. It does not perform SB status changes, and this might be have been related to user training instead of a system issue. Finally, the author had to manually determine which of the 1200 SBs released in the system were active, since all of them were shown as active even though many SBs were no longer active.

4.3 Service Bulletin Inventory Management Complexity

UTC Aerospace Systems uses the Servigistics inventory management system to manage its after-market inventory planning. In Section 0, the author explains Servigistics as a good basic planning tool to manage aftermarket parts. Parts required to be replenished to support regular scheduled maintenance is entered into the scheduled forecast demand field to be managed and to trigger orders. Parts required to support service bulletin demand is entered into the field called non-recurring demand field which is a manual field. Servigistics' benefit for managing inventory based on historical data cannot be utilized to manage service bulletin inventory.

Management of the inventory to support Service Bulletins depends on two elements:

1. Estimates of units in service and timing of units to be returned to UTC Aerospace Systems Repair, and
2. Piece part replacement rate estimates of certain components

Actual units returned, the timing of the returns, and the actual part replacement may vary from earlier estimates made by UTC Aerospace Systems technical personnel during the preparation stages, and therefore require good inventory planning change management.

UTC Aerospace Systems adopted a monthly average demand policy to plan and order service bulletin parts. An example how the monthly average demand is calculated: If the total units impacted by a particular service bulletin is 720 units, with an implementation period of 36 months, and 100% forecasted replacement rate, inventory planner will enter an order of 20 parts per month [(720/36) * 100%] as the service bulletin monthly demand. Due to lack of historical data, the average monthly demand calculation might be an acceptable method at the beginning. However, most inventory usage varies significantly and does not follow average values. In addition, the system's inability to differentiate parts being used to support regular maintenance vs. service bulletins adds to the complexity in managing service bulletin inventory.

4.4 Cultural Elements

The author started her internship in February 2012 when the organization was still called Hamilton Sundstrand (HS). During this internship period the acquisition of Goodrich was finalized and the new UTC Aerospace Systems organization was announced in July 2012. Despite the uncertainty in the organization and the change in leadership, the author extends her respect and gratitude to the UTC Aerospace Systems project champion and stakeholders for supporting her for the six months she was at UTC Aerospace Systems.

Along with positive cultural existence within the organization, the author also observed opportunities for improvement in the culture that exists typically in big company settings. People tend to work in silos within their own functional team. There is a lack of integrated effort being driven to improve a known inefficient process.

One example is the effort to improve SBS functionality. From SB value stream mapping (VSM) 2011 event, one of the outcomes identified was to make SBS more flexible by allowing future change to SB be saved to the original SB. However, along with any effort towards making changes, there is a cost associated to make the change. Regardless of the known benefits from the change that outweigh the cost of the change, there is a lack of integrated leadership to absorb the cost. The effect of not having a flexible system is pronounced when different teams maintain their own Excel file to track changes made after SB release. The inflexible system encourages different teams to document their own deviation to the process, and therefore preventing the company from having an integrated and streamlined communication system.

5 Service Bulletin Management Report

This chapter provides details of the author's attempt to establish a centralized and automated Service Bulletin Management reporting system. The process overview obtained by interviewing various stakeholders is first discussed, followed by an overview of agreed-upon report template. The author prepared a 50-page report update and maintenance document to help UTC Aerospace Systems understand how to best utilize the system. A brief discussion of some key opportunities for improvement is presented, followed by an in-depth discussion on inventory modeling based on data analysis of UTC Aerospace Systems Service Bulletins.

5.1 Process Overview

When the author first started the project in February 2012, there was no known service bulletin report. What existed was process flow for service bulletin issuance, showing different stakeholders involved in the process, which was documented in SBS. The author used the process flow and began interviewing different stakeholders involved in the process.

Main objectives for the interview are:

1. To gain fundamental understanding of service bulletin process
2. To understand roles and responsibility of each functional team in the issuance process
3. To capture critical information related to parts: how part numbers are captured, who determines the quantity needed to be ordered, and who orders the parts
4. To know where the campaign information is stored and how to extract those information
5. To gather information on what happen after the release process

The author brainstormed with personnel from repair center and business IT to find a method to extract units returned data from customers. The author decided to follow a repair technician for a couple of days to gain understanding how the units get tracked once it was received at the repair center and how the replacement parts from the warehouse were ordered. When data extraction was possible, the extracted data needed to be clean and manipulated before it could be used for analysis. The various work on data clean-up and manipulation steps are described in Section 0.

The author concurrently worked with project champion and supervisor to get an agreement on the data needed to be captured for the report and to brainstorm data analysis needed to support strategic decision making.

5.2 Report Template Overview

Figure 11 shows the report agreed upon template. The report is built with decision criteria such as:

1. Service bulletin cost/unit
2. % units received deviation from plan, and others

Note: All data are disguised and replaced by generic information to show an example of the reporting created. The reporting is created in Excel using pivot table reporting capability.

Status	Publis d/Monitoring
Active SB	(All)
Inv Cost Range	(All)
Cost/Unit Range	(All)
SOF	(All)
Retrofit	(All)
FOC	(All)

Recommendation:
QTY - 5 SBs (Top 10% SBs deviated from Plan)
Cost/Unit > $10,000 (Row M)
% Units received deviation from plan > +/- 50% (column V)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
															Last Six Months Units Received						
External #	Title	Service Enginee	APM	PM	AM Plann	Repair Planne	Pub Date	Imp Period (mo)	End Peri	Units Affected	Cost/unit	Total Units Receive	Units Remainin	% SB Completion	12/11	1/12	2/12	3/12	4/12	5/12	% Dev From Plan (past 6 mo)
SB1	Title 1	SE1	APM1	PM1	AMP1	RP1	Pub Date 1	36	End Date 1	500	$ 50,000.00	50	450	10%	10	15	5	2	1	1	-57%
SB2	Title 2	SE2	APM2	PM2	AMP2	RP2	Pub Date 2	36	End Date 2	200	$ 21,500.00	35	165	18%	3	0	2	6	2	3	-58%
SB3	Title 3	SE3	APM3	PM3	AMP3	RP3	Pub Date 3	36	End Date 3	50	$ 12,500.00	35	15	70%	5	10	5	2	2	10	-94%
SB4	Title 4	SE4	APM4	PM4	AMP4	RP4	Pub Date 4	36	End Date 4	150	$ 23,000.00	90	60	60%	3	5	10	40	20	7	18%
SB5	Title 5	SE5	APM5	PM5	AMP5	RP5	Pub Date 5	36	End Date 5	200	$ 18,000.00	50	150	25%	5	10	0	0	0	0	-50%

Figure 11: Service Bulletin Management Report

These criteria enable Management Team to obtain the top 5 service bulletins to review on a quarterly basis based on cost/unit value and % units received deviation from plan. The report is currently created in Excel that utilizes a pivot table reporting capability to enable robust decision making.

5.3 Report Update and Maintenance

The author created a 50-page standard work document (Figure 12) to document the project background, data source location, report creation, and periodic update process. The author used SQL commands for extracting data from JDE ERP system. Due to the proprietary nature of the dataset extracted from the ERP system (in particular the record's column labels), the SQL commands cannot be included in this thesis.

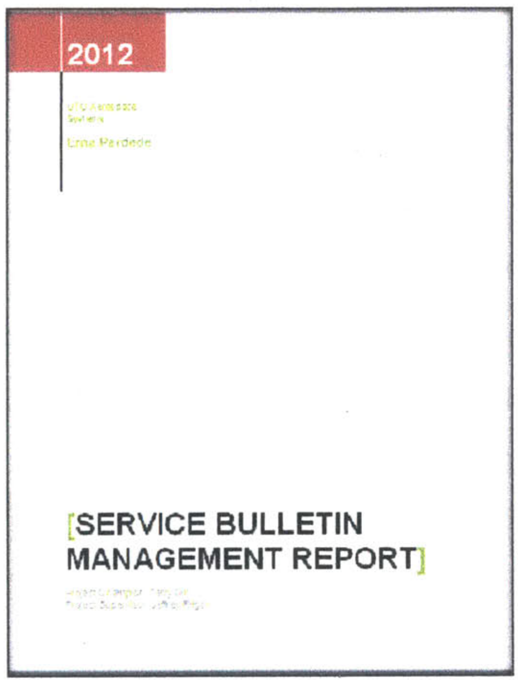

Figure 12: Service Bulletin management report standard work

One month before the internship ended, the author worked closely with the assigned focal from supply chain material group to contemplate the report update process, ensuring continuation after the author leaves UTC Aerospace Systems. The focal was also tasked with automating the update process which will be done in SAS, the database system primarily used for reporting.

5.4 Improvement Opportunities

The author provided a list of improvement opportunities that can be done to enhance the current reporting environment in UTC Aerospace Systems Customer Service department. These opportunities are listed in Table 1 .

Item	Opportunities	Corrective Action
Data Accuracy		
1	Improve accuracy of units received by standardizing JDE Sales Order Labor Line data entry	Standard work and training Utilize Labor Catalog to enter active SB #. Follow standard work process when entering SB#. Preference: "-SB" followed by "full SB #" as released in SBS Example: **-SBJFC160-10-73-23** if full SB number is JFC160-10-73-23
2	Non-JDE repair facilities: Request SB data	Request Shannon, Xiamen, and Malaysia to send SB data in a standard format (Refer to standard work document created for UTC Aerospace Systems)
Part Replacement Rate		
3	Expand Material Replacement Rate (MRL) database capability to search not by individual LRU part number BUT allow selection of LRU base number	Business IT to expand system's capability.
Service Bulletin System Data Clean-up		
4	Improve accuracy of data entered in SBS such as identification for Safety of Flight (SOF), or Retrofit Campaign in order to create a reliable centralized database. NOT relying on different team saving their own information	Training – Service Engineering group
5	Utilize archive, revise SBS function to archive old SB and its end item part numbers when a revision to the SB and its LRU is made	Training – Service Engineering group

Table 1: Service Bulletin Improvement Opportunities

6 Inventory Modeling

This chapter focuses on the author's effort to find relevant mathematically models service bulletin data collected from UTC Aerospace Systems internal systems. The section starts with modeling concept, types of data collected, data sources, and their limitations, followed by an explanation about data transformations and normalizations needed to be done prior to data usage. Finally, conclusions are presented based on observations and analysis from the models.

6.1 Modeling Concept

As mentioned in Section 4.3, the management of service bulletin inventory depends on two elements:

1. Estimates of units in service and timing of units to be returned to UTC Aerospace Systems Repair
2. Piece part replacement rate estimates of certain components

The forecast data would be compared to the actual units returned and replacement rate. Forecast error would be calculated and adjustments to the original forecast would be made.

The author's original plan to test the hypotheses stated in Section 3.3 for the different service bulletin types (safety of flight, retrofit, and attrition) could not be performed due to limitation of the information that could be extracted from units returned data (Section 6.2.2). Instead, with the guidance provided from the author's thesis advisor, it was decided to look at units returned as a % cumulative unit returned. Hence, the modified plan was to aggregate % cumulative units returned as a function of the number of months after SB was released. In addition, the author would also include the one-sigma confidence interval that serves as a safety stock as shown in Figure 13. Section 6.2.4 shows the calculation and the inclusion of the one-sigma upper confidence interval for % cumulative units returned for each period t, where t is defined as the number of months after service bulletin is issued.

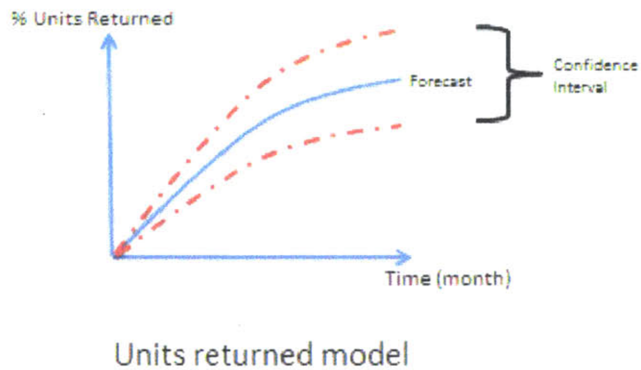

Figure 13: % Cumulative Units Returned Model

To complete inventory modeling, the author created the "% replacement rate model" and calculated associated errors compared to the plan. Figure 14 shows the intended model.

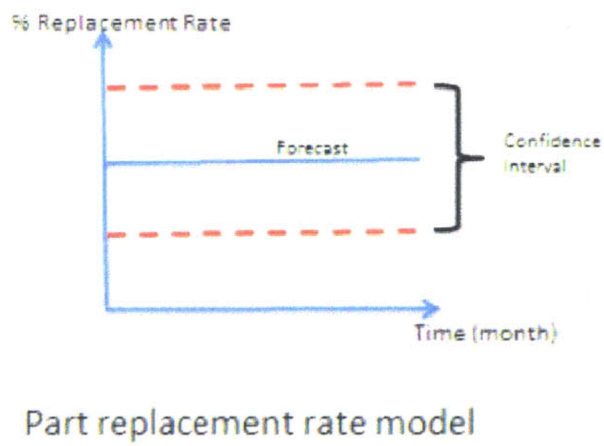

Figure 14: Part Replacement Rate Model

The shape of Figure 14 would show whether replacement rate error is independent or dependent on the replacement rate size. If the replacement rate error is independent of the replacement rate size, Equation 7 will be used to model replacement rate, otherwise Equation 8 will be used.

$$Part\ Replacement\ Rate = Planned\ Replacement\ Rate + Replacement\ Rate\ Error \quad (7)$$

$$Part\ Replacement\ Rate = Planned\ Replacement\ Rate * Replacement\ Rate\ Error \quad (8)$$

The combination of "% Cumulative Units Returned" model and the "Part Replacement Rate" model would determine the inventory forecast for each individual piece part needed to support SB campaign and safety stock required to maintain high customer service level. The author assumes that an event of a unit being returned by customers and an event of a part being replaced is independent.[13] This means that the probability of a customer returning his or her unit for repair does not affect the probability of a part being replaced. This assumption is reasonable since the first event -- which is a customer deciding whether to return his or her unit for repair -- is a financially driven decision where the customer weighs the cost and benefits of service bulletin repair. The second event, on the other hand, where parts of a unit are replaced during the repair activity, is a decision driven by the part's mechanical failure rate, part's life time and usage.

6.2 Units Returned

Units returned captures the number of units that are returned from customers that initiate service bulletin modification work.

6.2.1 Data Source

Based on the author's research to get to the source for units returned from customers, the units returned data is grouped into Retrofit Campaign and Attrition service bulletin as shown in Figure 15.

[13] It is important to note that a unit refers to a line replaceable unit which contains many parts, and when the unit is returned for service its parts may or may not be replaced.

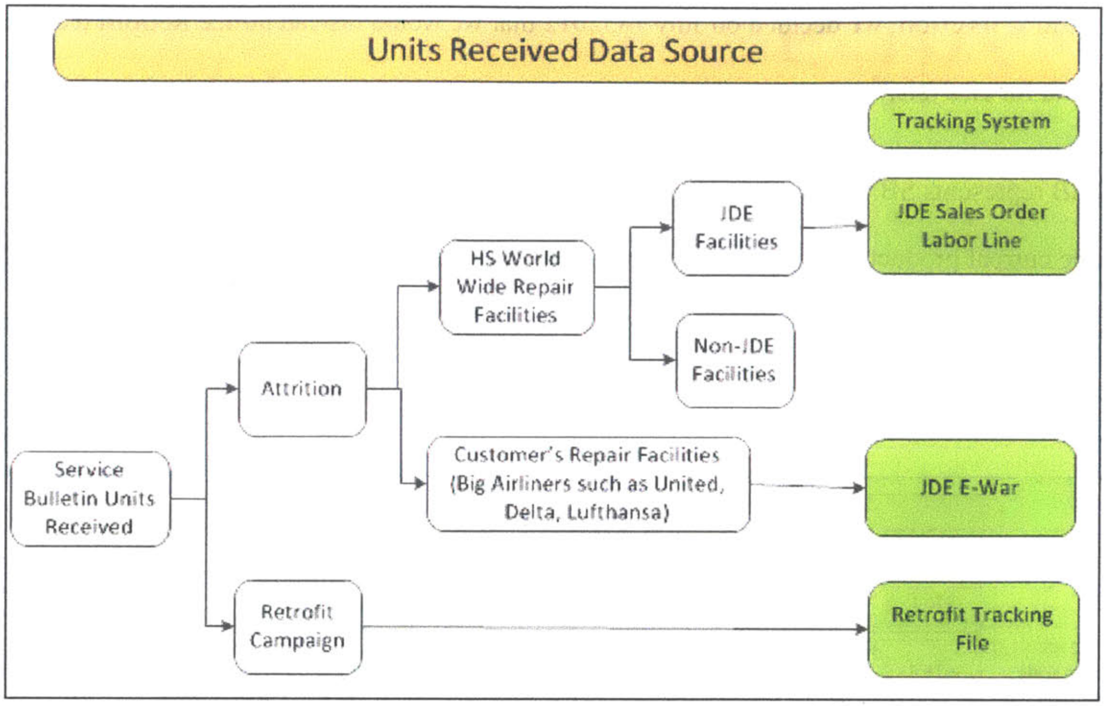

Figure 15: SB Units Returned Data Source

Note: The original hypothesis described in Section 3.3 also included Safety of Flight bulletin. For the scope of the project, Safety of Flight bulletin will be excluded unless the data are included in the Retrofit Campaign bulletin.

Retrofit Campaign SB is the SB identified for UTC Aerospace Systems to campaign the work to ensure product safety requirement is met or to benefit UTC Aerospace Systems Business in supporting customers' needs. In this case, Retrofit team is involved and acts as a focal in the campaign effort by having continuous communication with customers and ensuring UTC Aerospace Systems repair facilities have the capacity and parts to support SB modification work. Due to the nature of this communication, there is constant modification being made to the original campaign which is not documented in SBS. Instead, Retrofit team manages their own internal excel files to document adjustment to the plan. Rather than duplicating its effort, we decided on July 18, 2012 that we would instead utilize Retrofit team units returned data for analysis.[14]

Attrition SB represents SB that is released to customers to let them know of any product improvement made to the current product they own. Customers have the freedom to decide if they want to return their units for SB modification work. UTC Aerospace Systems does not typically have any type of communication with customers or monitor the progress of the SB work.[15]

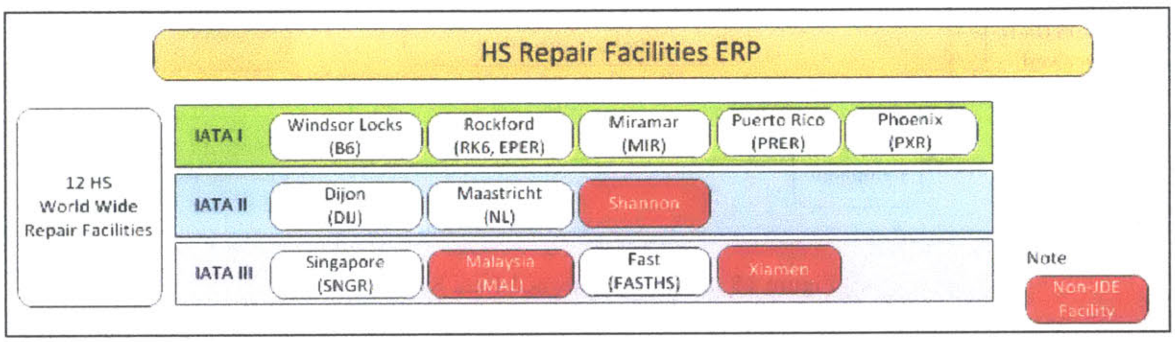

Figure 16: HS Repair Facilities JDE ERP Status

In general, customers can return their units to one of the twelve UTC Aerospace Systems repair centers shown in Figure 16, where the data can be extracted from JDE Sales Order Labor Line table with limitation that 3 out of the 12 repair centers are non-JDE facilities. Hence if customers return their units to Shannon, Malaysia, or Xiamen repair centers, those data is omitted from our report or analysis. In the case of big airliners that own their own repair facilities, some but not all[16] units returned data can be obtained from JDE E-War table which is a Customer Warranty table located in UTC Aerospace Systems JDE ERP system (Figure 15). The author used SQL commands for extracting data from JDE ERP system. Due to the proprietary nature of the dataset extracted from the ERP system (in particular the record's column labels), the SQL commands cannot be included in this thesis.

[14] Retrofit SB represents 20% of the current released SBs.
[15] Attrition SB represents 80% of the current released SBs.
[16] See Section 6.1.2.3 for limitation.

It is necessary to mention that there is lack of JDE standard work to enable quick SB data extraction, especially for capturing SB#. It uses a free form text field to document SB#. JDE does not enforce strict input validations. This required the author to spend significant amount of time for data clean-up and transformation before the data can be used to create report or analysis (Section 0).

Figure 17: JDE Sales Order Labor Line Standardization[17]

A quick survey was performed to capture standardization effort done in any of the 9 repair centers (Figure 17). A request for standardization was discussed and submitted to UTC Aerospace Systems Repair Center Business IT team, with a focal identified to lead the effort.

6.2.2 Data Limitation

During the data mining for units returned, the author faced with data limitations that reduced the ability to prove the hypotheses made at the beginning (Section 3.3). As the limitations became known, the author worked with UTC Aerospace Systems project champion and supervisor, and MIT thesis advisor to modify the desired outcome based on selected service bulletins. Specific information on those limitations is not included in this thesis due to the nature of the information.

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[17] Status as of June 6, 2012.

6.2.3 Data Manipulation: Normalization, Matching and Transformation

6.2.3.1 Normalization of SB format

Data required for analysis came from various systems in UTC Aerospace Systems. Different data sources applied different formats for different fields. One of the first tasks prior to performing data analysis from these sources was to ensure that data were of the same format. This required a normalization process of data across all sources.

One particularly important attribute was the Service Bulletin identifier. This field came from all data sources; however, the format of Service Bulletin varies from one source to the next. For examples, Service Bulletin "`015864-79-3`" might be denoted as "`015864-79-3 Basic & Rev. 1`", or simply "`015864-79-3 R1`". The various representations of Service Bulletin identifiers were normalized to a single representation to allow for accurate analysis of data coming from multiple sources.

6.2.3.2 Service Bulletin System Data

The first set of data contained information about all Service Bulletins. The Service Bulletin System (SBS) data was obtained in the format shown in Table 2. Due to proprietary nature of the dataset, arbitrary information is used for SB identifiers *SBS_One* and *SBS_Two*.

1	Internal #	SBS_One_Internal	SBS_Two_Internal
2	External Raw #	SBS_One_External	SBS_Two_External
3	External #	SBS_One	SBS_Two
4	Title	SBS_One_Title	SBS_Two_Title
5	Status	Published/Monitoring	Published/Monitoring
6	FOC	No	No
7	Type	Type_One	Type_Two
8	Compliance Code	8	1
9	Pub Date	10/31/2008	11/10/2004
10	Imp Period (mo.)	36	2
11	End Period	11-Nov	5-Feb
12	Active SB	N	N
13	Units Affected	21	18
14	Total Inv Cost	$0	$2,270
15	Total Inv Cost Range	< $200K	< $200K
16	Cost/unit	$0	$162
17	Cost/Unit Range	<$1K	<$1K

18	Inv Drive?	Y	Y
19	JDE Labor Line Units Received	2	
20	JDE E-War Units Received		
21	Total Units Received	21	18
22	Avg Units Received (Past 6 mo.)	2	0
23	Imp Period Units Plan/mo.	0	7
24	% Dev From Plan (Past 6 mo.)	COMPLETE	COMPLETE
25	Include In Report?	N	N
26	On Order Inv Values	$22,545	$11,945
27	On Hand Inv Values	$0	$44,031
28	COMMENT		

Table 2: Service Bulletin System (SBS) sample data

Out of the 28 fields available in the file, only 14 were utilized in the analysis. These 14 fields were indicated as orange-shaded rows in the table above.

The `Internal #` and `External #` columns represented identification of SBS internally (within UTC Aerospace Systems) or externally (to clients). The `Status` field indicated the latest state of SBS. The `Type` field could either be Mechanical or Electrical, to indicate the nature of the issue being addressed by the SBS. Other fields were mostly self-explanatory.

The two most important fields for the analysis, however, were the `Pub Date` and `Imp Period`. The `Pub Date` indicated the month & year of when the SBS was first published. The `Imp Period` indicated the duration (in months) of the Service Bulletin.

6.2.3.3 *JDE ERP Data*

The second part of data for our analysis came from the UTC Aerospace Systems' JDE ERP system. This set of data contained information about the Customer and the Service Bulletins associated with them. The following Table 3 shows samples of JDE ERP data. Note: Customers' names are replaced with arbitrary names.

1	Order Date	5/23/2012	12/27/2011	1/2/2008
2	LRU#	789842-6-009	822823-4-007	170101-106A
3	Customer	Customer 1	Customer 2	Customer 3
4	Business Unit	B6	NL	SDREP
5	NormSB	SBS_One	SBS_Two	SBS_Three
6	Total	1	2	1

Table 3: JDE ERP Data

The `Order Date` indicated the date for which the Service Bulletin was ordered by the customer. Customer name can be seen on row 3 above, and the Service Bulletin identifier is shown on row 5.

6.2.3.4 *Matching*

The two data sets (SBS and JDE) were combined by matching the SBS' data "External #" with JDE's "Norm SB" field.

In the example above, we can see that data from the first table with `External #` = `SBS_One` has a corresponding match in the second table of JDE customer.

It is also worth noting that one Service Bulletin might correspond to several customers. Conversely, one Customer might be associated with many Service Bulletins.

6.2.3.5 *Aggregation of Service Bulletin orders by Month*

By performing the above matching on all Service Bulletins (from SBS Data) against all Customers (from JDE data), the author constructed a matrix of the number of orders for all Service Bulletins by the publication month. A collection of Java programs were created to automate massive data clean-up and data aggregation needed before data analysis could be performed. The programs were coded using the system that was equipped with a Java compiler, to enable Java programs to be run. The sample programs could not be shown in the thesis.

A portion of the matrix is shown in Table 4:

ExternalNo	Pub Date	Units Affected	Imp Period	FOC	T-110	...	T-2	T-1	T+0	T+1	T+2	T+3	T+4	T+5	...	T+200	Total
015864-79-3	2-Feb-09	122	36	No													5
025850-73-10	20-Sep-06	2345	36	No							6	2					23
025850-73-8	4-Apr-06	82	36	Yes													2
025850-73-A9	11-Apr-06	20	36	Yes						7							7
025851-4-73-6	4-Apr-06	138	36	Yes						3							5
1000393-75-2	30-Jan-09	500	36	Yes						8	25	12	7	7			379
1000700-21-01	13-Jun-11	1300	109	No			12			43	30	18	11	12			400
1001050-21-02	3-Feb-05	90	36	Yes						1			1	2			12
1001050-21-03	31-Jan-06	84	36	Yes						2	1		1				4
1001050-21-04	16-Jun-06	120	36	Yes						14		1					15
1001050-21-06	31-Jul-09	838	36	Yes			2			3	16	17	18	13			838
1001050-21-09	2-Jun-10	1300	12	Yes						16	21	9	27	22			180
1001250-21-01	30-Sep-10	1120	48	No													140
1001497-21-01	17-Dec-10	228	36	Yes						4	7	5	4	4			112
1002166-36-02	16-May-06	70	36	Yes													56
1002166-36-03	1-May-07	267	36	Yes						5	4	3	1				267
1007086-36-01	19-May-10	600	36	No						20	42	49	52	51			539
115EGS01I-24-41	16-Mar-09	1485	48	No						1	6	7	12	9			402
115EGS01I-24-42	20-Apr-09	1524	36	No						5	4	5	4	2			269

Table 4: Aggregate SB Orders by Month

The first column shows the `Service Bulletin` identifier, also called `External #`. The next 3 columns show additional attributes for the Service Bulletin, such `Publication Date`, number of `Units Affected`, and `Implementation Period` (in months).

The focus of the matrix starts from the "T-110" to "T+200" columns. These columns represent the -110 months to 200 months after the Service Bulletin `Publication Date`, which is depicted in the second column. The numbers in T + *x* column represent the number of orders for the Service Bulletin still outstanding *x* months after or before the `Publication Date`.

For examples, Service Bulletin "1000700-21-01" (highlighted in orange) has Publication Date of 13-Jun-11, affects 1300 units of UTC Aerospace Systems products. The Service Bulletin has Implementation Period of 109 months (slightly longer than 9 years). For this Service Bulletin, the T+0 is June 2011, the month of the Publication Date. There are no orders for this Service Bulletin for June 2011, because the T+0 column contains no orders. There are, however, 43 orders for this Service Bulletin for July-2011, as depicted by the number in column T+1.

6.2.3.6 Pre-Publication Orders

The numbers that appear on the columns to the left of T+0 indicate the number of pre-orders by various Customers for the given Service Bulletin. This may happen because UTC Aerospace Systems may socialize the issues to be published in their Service Bulletin to their Customers prior to the official publication date of the Bulletin. Customer may choose to immediately order the services described by the Bulletin. These orders are captured in the matrix in columns prior to T+0.

6.2.4 Data Modeling

Due to data limitation explained in Section 6.2.1 and 6.2.2, it was decided to look at the units returned as a % cumulative units returned number for all released service bulletin. Initial data screening (10 years units returned data) on % cumulative units returned is shown in Figure 18 for both Retrofit and Attrition SBs. The data shows % cumulative units returned for Retrofit SB is about 70% to the plan on average. The original hypothesis made by the author that retrofit service bulletin should reached closed to 100% completion at the end of implementation period is off, regardless of the fact that there is a UTC Aerospace Systems team assigned to follow up with customers to ensure that customers return their units for rework. This shows the author that the retrofit bulletin rework modification might not be seen as critical to customers as the author originally thought. A different reason of explaining this gap is probably due to the manual modification being made to the original campaign plan which is not reflected in the SBS as described in Section 3.3.2.

On the other hand, % cumulative units returned for attrition service bulletin is roughly about 20% to the plan. Even though the author expects a much lower % cumulative units returned based on the discussion in Section 3.3.3, the average of 20% returned is not expected especially when the data that is being used span over 10 years period[18]. Further data segregation is performed as described in Section 7.2. The purpose is to get a better result by adding needed variables that serve as a differentiation within attrition service bulletin. However the initial data screening result shown in Figure 18 should be read as potential opportunities for reducing the inventory values tied to service bulletin, especially when attrition bulletin represents 80% of the service bulletin population.

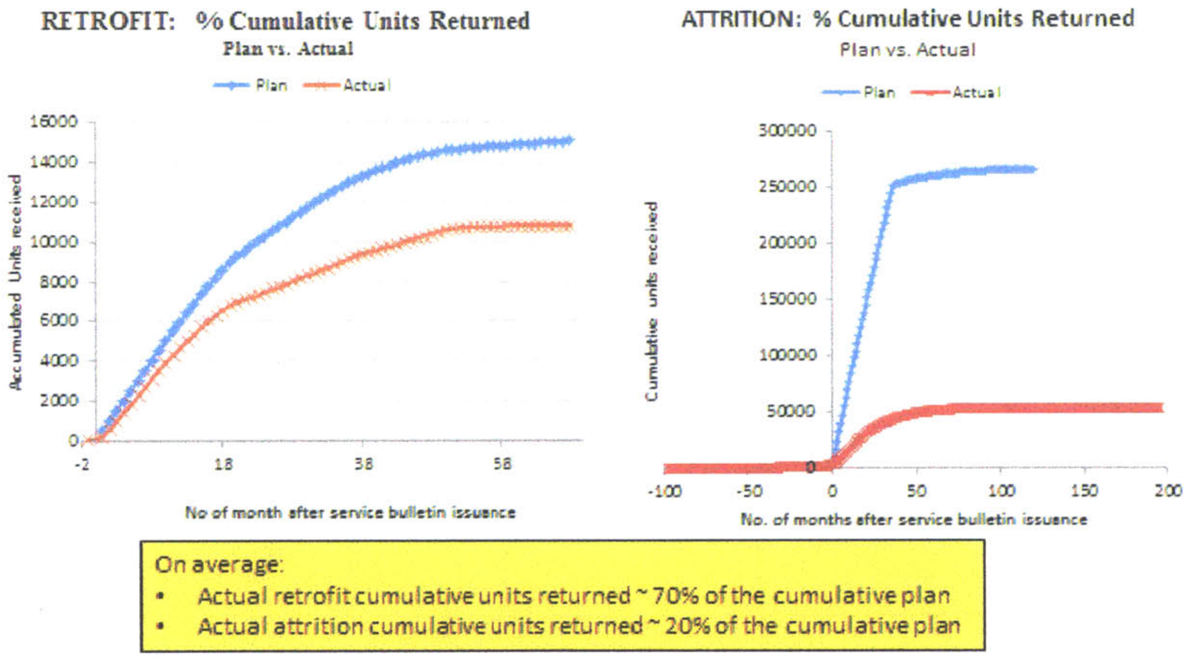

Figure 18: Initial Data Screening - % Cumulative Units Returned

Moving forward, units returned data will be analyzed using non-linear regression with mechanistic growth model for fit curve. The model was chosen because it reflects the patterns of actual % cumulative units returned, both for Retrofit and Attrition service bulletins. Mechanistic growth model always shows gradual increase in growth in the beginning period, but the growth slows and tapered off asymptotically toward a final level which closely describes % cumulative units returned shown in Figure 18.

[18] Default implementation period for service bulletin is 3 years and most of the service bulletins released are released under the 3 years implementation period.

The mechanistic growth prediction model is shown in Equation 9:

$$\% \, Service \ Bulletin \ Completion = a(1 - b \, e^{-ct}) \tag{9}$$

Where a = Asymptote is showing the final % SB completion number
b = Scale is showing the original %SB completion at $t = 0$
c = Growth rate as a function of t
t = Number of months after service bulletin released

6.2.4.1 Retrofit Service Bulletin

Non-linear regression with mechanistic growth model for fit is used by the author for data analysis. JMP software[19] is used to perform the analysis. The regression result is shown in Figure 19 below.

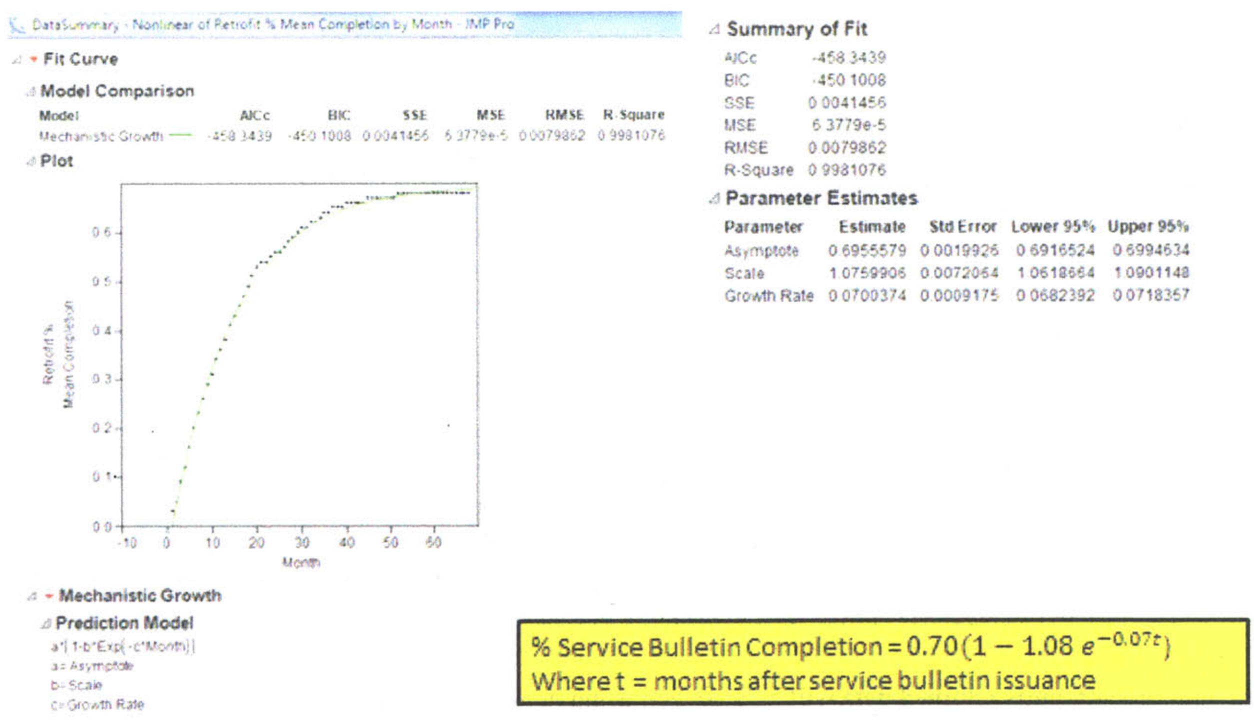

Figure 19: Retrofit SBs - % Completion Model

Equation 10 shows Retrofit % service bulletin completion model:

$$\% \, Service \ Bulletin \ Completion = 0.70(1 - 1.08 \, e^{-0.07t}) \tag{10}$$

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[19] JMP (pronounced "jump") is a computer program for statistics developed by the JMP business unit of SAS Institute. It links dynamic data visualization with robust statistics, in memory and on the desktop (http://www.jmp.com/software/).

R-squared for model fit = 99.8% which shows that 99.8% of the variability seen in the % cumulative units returned data is accounted by the model. R-squared or coefficient of determination is used to describe how well a regression line fits a set of data. It is explaining the variability in a data set that is accounted for by the statistical model. It provides a measure of how well future outcomes are likely to be predicted by the model. R-squared is a number between 0 and 1. An R-squared closed to 1 indicates that a regression line fits the data well, while an R-squared closed to 0 indicates a regression line does not fit the data well.

The average % service bulletin completion is about 70% and the growth rate is 0.07. One-sigma confidence interval is calculated for each period *t*.

Figure 20 shows One-Sigma upper confidence limit for retrofit service bulletin. It shows closed to 95% overall cumulative SB completion over the next 5 years.

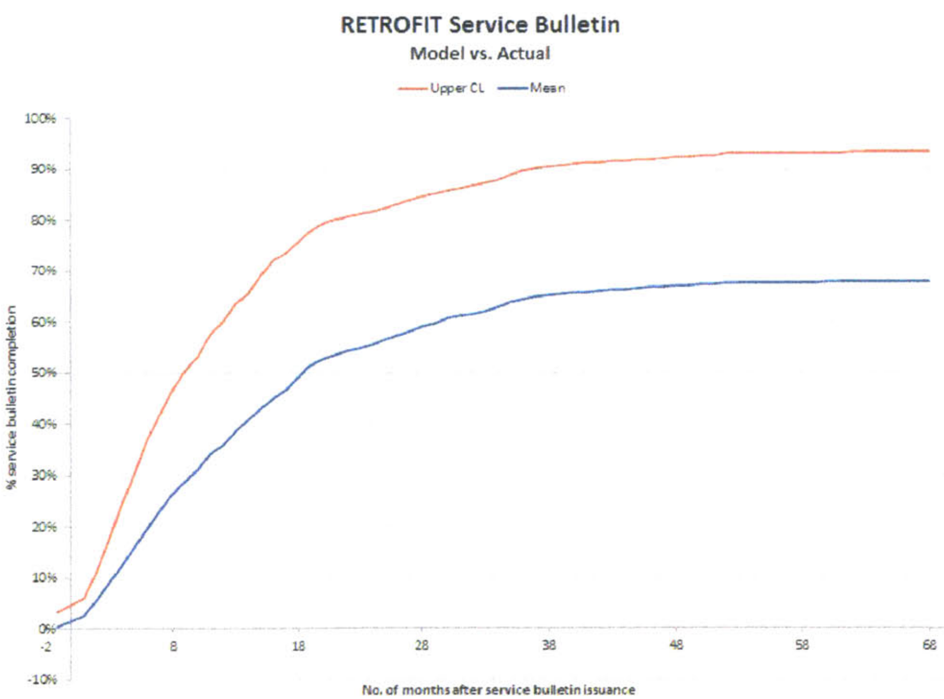


Figure 20: Retrofit % SB Completion with One-Sigma Upper Confidence Limit

6.2.4.2 *Attrition Service Bulletin*

Figure 18 shows only 20% of actual units returned for Attrition SB compared to the plan. The author was asking for explanation from UTC Aerospace Systems process experts why the number is low. Further segregation of data using SBS identifier was performed. Identifier such as free-of-charge, implementation period, compliance code, and SB type were used to screen the data. When the data is segregated by SB type (mechanical or electrical), the result looks more reasonable. From this point, Attrition SB is segregated into mechanical and electrical.

Non-linear regression with mechanistic growth model for fit is performed on both mechanical and electrical data using JMP software. Regression result is shown in Figure 21.

Equation 11 shows % completion model for *mechanical* service bulletin

$$\%\,Service\ Bulletin\ Completion_{mechanical} = 0.34(1 - 1.04\,e^{-0.03t}) \tag{11}$$

Equation 12 shows % completion model for *electrical* service bulletin.

$$\%\,Service\ Bulletin\ Completion_{electrical} = 0.42(1 - 0.98\,e^{-0.05t}) \tag{12}$$

R-squared for model fit = 99.7% for both data. The average % service bulletin completion is about 34% for mechanical with growth rate of 0.03, whereas it is about 42% for electrical with growth rate of 0.05.

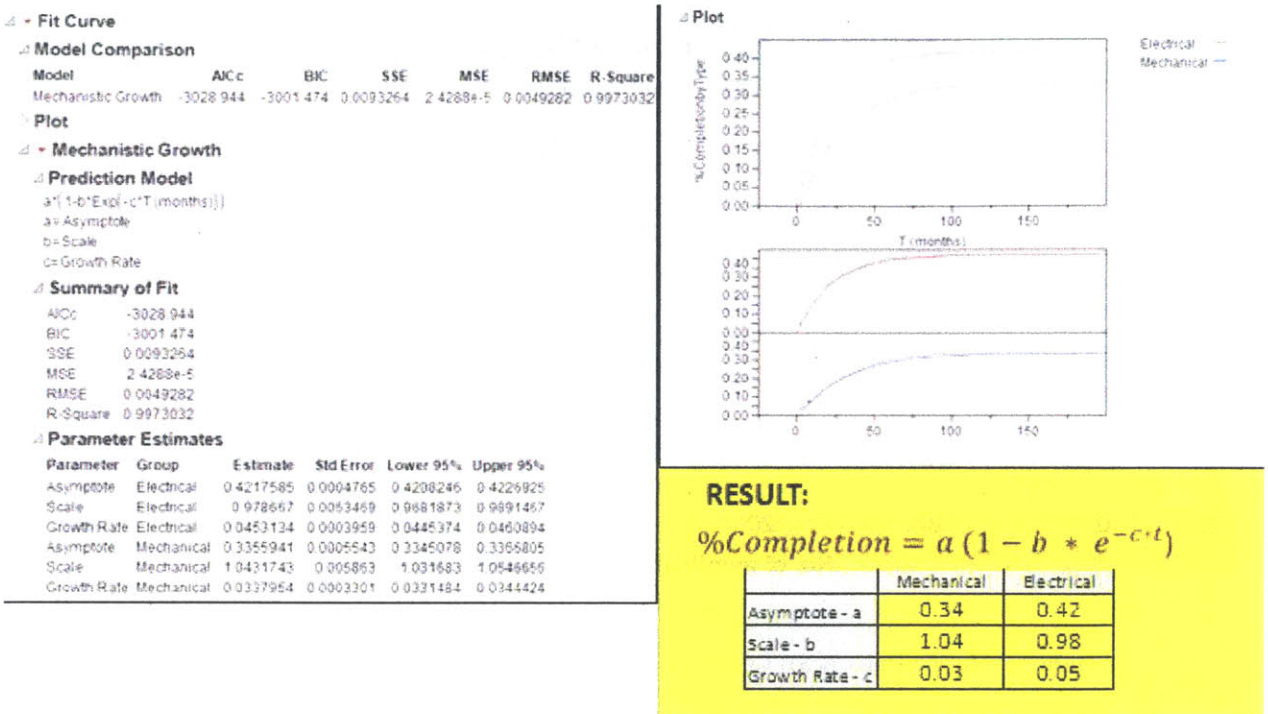


Figure 21: Attrition SBs - % Completion Model

One-sigma confidence interval is built for both service bulletin types. The one-sigma value is calculated for each period *t*.

Figure 22 shows One-Sigma upper confidence limit for *mechanical* service bulletin. It shows 60% overall cumulative SB completion over the next 5 years.

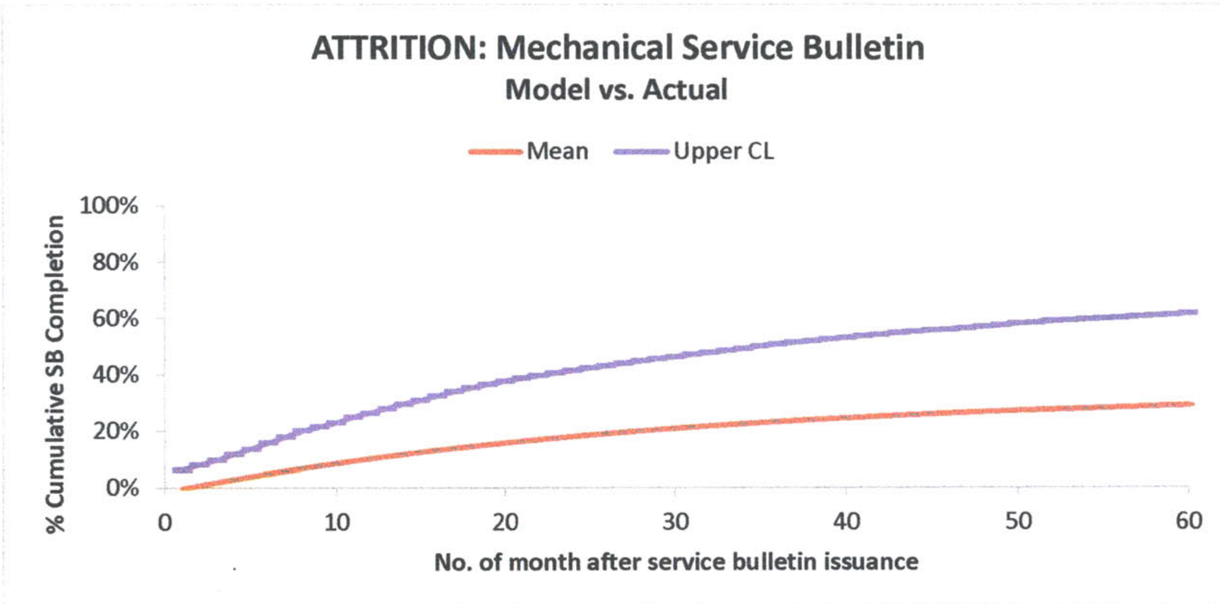


Figure 22: Mechanical - % SB Completion with One-Sigma Upper Confidence Limit

Figure 23 shows One-sigma upper confidence limit for *electrical* service bulletin. In this case, it shows 80% overall cumulative SB completion over the next 5 years.

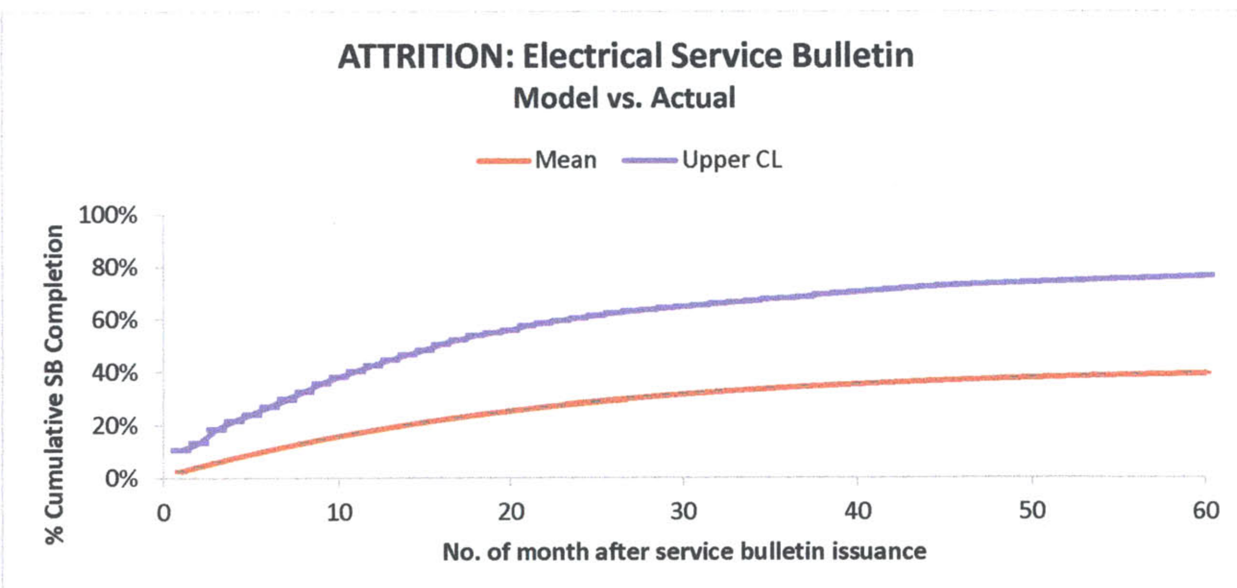


Figure 23: Electrical - % SB Completion with One-Sigma Upper Confidence Limit

6.2 Part Replacement Rate

Part replacement rate is intended to capture the actual part replacement rate. The initial approach to replacement rate model is to calculate Percent Replacement Rate for each new part number associated with released service bulletin as a function of the number of months after SB is released as shown in Figure 14.

Based on the author's effort to get to the source data for part replacement rate, it was decided not to pursue replacement rate modeling on 8/2/2012 project status review due to reasons listed below:

1. Material Replacement (MRL) database can only extract data from each individual end item part number. Note: Total end item part number > 1000
2. Many end item part number listed in SBS ended up to be old part numbers that got rolled-up. However, the change in the part number is not reflected in SBS
3. Out of the 97 sample part numbers extracted, initial data screening shows high replacement rate deviation than planned. This is due to the inclusion of standard parts in the dataset such as washers, shims, etc.

Due to these limitations, the author will only use the % cumulative units returned to make recommendation for service bulletin inventory position. This omission does not provide UTC Aerospace Systems with a complete inventory management piece since inventory is currently managed at a part level. If actual part replacement rate does not deviate by 20%, which is the one-sigma value for retrofit bulletin shown in Figure 20, from the forecast replacement rate, the omission of replacement rate data will not have much impact to the inventory plan. However, if the deviation is more than 20%, it will cause either out-of-stock or over-stock condition.

The author recommends UTC Aerospace Systems to enable extraction of part replacement rate data. This effort will enable the modeling and analysis of part replacement rate which in turn will complete the service bulletin inventory management activity. These recommendations are included in Section 8.

7 Units Returned Summary and Recommendation

Based on the data analysis and mathematical modeling presented in Section 6, the author proposes the following recommendations.

7.1 Retrofit SB

For SB identified as Retrofit Campaign SB, follow the plan managed and executed by Retrofit team. Reason: Retrofit team is in constant communication with customers and adjusting their plan accordingly. In addition, due to SBS limitation and lack of standard work for documenting units returned data related to SB activity, the Retrofit team plan is showing the most accurate source of information at the moment.

The historical data shows on average, about 70% of customers returning their units for rework. However, applying 1 upper confidence interval limit as a safety stock is recommended for UTC Aerospace Systems to support the campaign. Especially with Retrofit team's goal of having 100% campaign completion and perform better customers' management.

7.2 Attrition SB

For SB identified as Attrition SB, make a note if the modification work is related to mechanical or electrical work. Based on the analysis in Section 6, it shows that on average *mechanical* SB gets a lower units returned from customers by about 10% compared to *electrical* SB which needs to be accounted and noted for inventory planning (34% vs. 42%). It is also noted that the rate of units returned from customers are slower with *mechanical* SB compared to *electrical* SB (.03 *vs.* .05).

The author recommended an excel simulation tool described in Section 7.2.1 to be used to forecast the units returned from customers utilizing the model's parameters in Section 0. It is also recommended that an excel control chart be used to monitor actual units returned against the forecast. By performing this monitoring process, it will enable a real time adjustment to the inventory plan on a monthly basis. In addition, the forecast error calculation to be done and a necessary modification to the model and its parameters can be performed. Hence this is supporting the strategic forecasting framework shown in Figure 8.

7.2.1 Forecasting Simulation Tool

Figure 24 shows the forecasting tool that the author built to forecast units returned based on service bulletin type. The tool can be used by inventory planning group to estimate the amount of parts to be ordered in any given month after SB is released.

The yellow cells shown: Enter months after SB is published, Enter total population, etc. are the cells that required input. The grey cells are locked cells where automatic calculation is performed based on the model parameters set in Section 0. An example: A *Mechanical* service bulletin with 1000 units impacted. The planner wants to know how many units will be returned by the customers on the twelfth month after the SB is released. The calculation shows that units received up-to month 12 should be 102. And it is forecasted that about 8 units will be returned for month 12. An additional amount needs to be added to this number that should serve as a safety stock. The number recommended to be used is the one-sigma number.

Attrition Service Bulletin Units Returned Forecasting Tool

This simple forecasting tool is develop to provide a forecasted total units received until t-months after service bulletin is published (cell B11) -or- a forecasted units received at month t after service bulletin is published (cell B12)

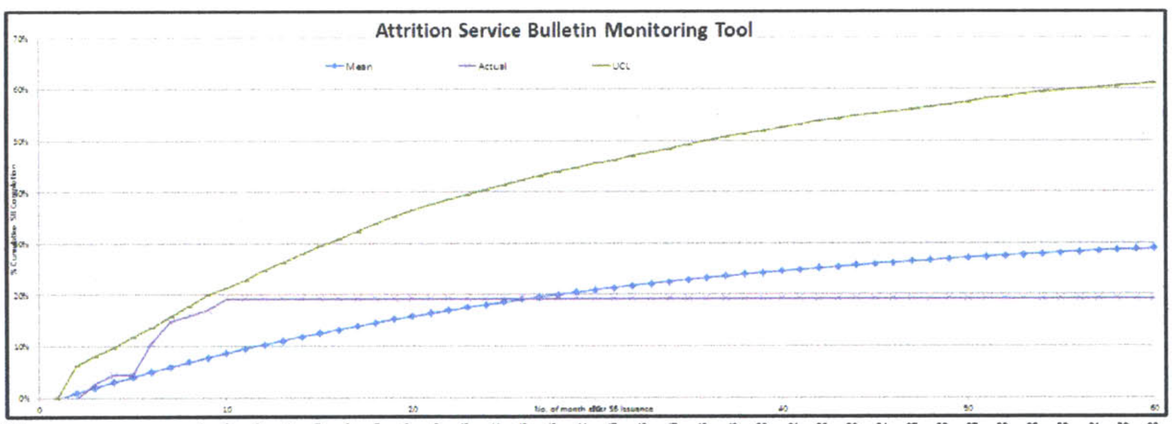
Specify the months of interest (cell B8),total population (cell B9)

Enter months after SB is published	12
Enter total population	1000
Enter Service Bulletin Type: "M" for Mechanical or "E" for Electrical	M
Total units received to date	102
Total units received only to the month specified in B2 cell	8

Figure 24: Attrition Service Bulletin Units Returned Forecasting Tool

7.2.2 Excel Control Chart for Process Monitoring

An Excel-based process monitoring tool can be utilized to monitor monthly units returned data as shown in Figure 25. The yellow cell (Enter the actual units received) is the cell that needs user input on a monthly basis. Based on the bulletin type, the mean and the upper control limit are automatically calculated based on the model parameters shown in Section 0. Once the units returned number is entered into the cell, the % cumulative units returned will be automatically calculated and it will be reflected in the chart. The planner needs to monitor the chart to ensure that it is below the upper control limit. If the units returned chart falls above the upper control limit, it should send a signal that inventory re-plan is needed. The leadership team needs to decide how many more units need to be ordered in the upcoming months to ensure shortages can be avoided. Otherwise, follow the forecast calculation on how many units should be ordered on a monthly basis based on the forecasting tool calculation shown in Section 7.2.1.



Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Mean	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	9%	10%	11%	12%	12%	13%	14%	15%
UCL	6%	8%	10%	12%	14%	16%	18%	20%	21%	23%	25%	26%	28%	30%	31%	32%	34%	35%
Service Bulletin Type (M/E)	M																	
Enter Actual Units Received	1	0	1	0	4	3	1	1	2									
Cumulative Units Received	1	1	2	2	6	9	10	11	13	13	13	13	13	13	13	13	13	13

Month	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Mean	15%	16%	16%	17%	17%	18%	19%	19%	20%	20%	20%	21%	21%	22%	22%	22%	23%	23%
UCL	36%	38%	39%	40%	41%	41%	42%	43%	44%	45%	46%	46%	47%	48%	48%	49%	50%	51%
Service Bulletin Type (M/E)																		
Enter Actual Units Received																		
Cumulative Units Received	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13

Figure 25: Attrition SB Units Returned Monitoring Tool

8 Discussion

Reflecting back to the main goals of the internship stated in Section 1.2.3 (Project Goals and Deliverables) -- which was to provide regular updates on service bulletin progress with the expectation that service bulletin inventory would be improved – the author believes this can be achieved by reducing the amount of error made in the original forecast made by technical team. Data shows that 80% of released service bulletin is currently identified as Attrition bulletins and this is where improvement opportunity can be made. Section 0 shows that *mechanical* service bulletin typically yields to 60% cumulative units returned compared to the planned, whereas the number goes up to 80% for *electrical* bulletin. The % number already accounts for one-sigma deviation in the historical data. This means that there is an opportunity to save about 30% inventory cost over the next 5 years which outperformed the original expectation of seeing $1M inventory values reduction.

Moreover, due to the limitation in extracting the part replacement rate, the current recommendation is only based on the units returned from customers. This recommendation does not complete the inventory management piece as service bulletin inventory also depends on part replacement rate. If the forecast of part replacement rate is different than the actual replacement rate, the actual inventory needed will be different than the forecasted inventory quantity. The author recommends UTC Aerospace Systems to enable data collection of actual part replacement rate in order to better manage service bulletin inventory.

In addition, it is important for UTC Aerospace Systems to start using some type of monitoring tools to evaluate actual returned to the forecast. This monitoring activity will create awareness and trigger communication across functional team.

Bibliography

Aero Legal Services: Reigel Law Firm, LTD. (2013). Service Bulletins: What Is An Aircraft Owner To Do? Retrieved 2/21, 2013, from http://www.aerolegalservices.com/Articles/ServiceBulletins-Owner.shtml

Caggiano, K.E., Jackson, P.L., Muckstadt, J.A., Rappold, J.A. (2007). Optimizing Service Parts Inventory in a Multiechelon, Multi-Item Supply Chain with Time-Based Customer Service-Level Agreements. *Operations Research*, 55 (2), 303-318.

Cohen, M.A., Agrawal, N., Agrawal, V. (2006). Winning in the Aftermarket. Harvard Business Review OnPoint 4311.

Fontaine, D., Martilla, K., Russell, L. GE Aviation Inventory Management. *Worcester Polytechnic Institute*. Project Number: MQP-JZ-1234. URL: http://www.wpi.edu/Pubs/E-project/Available/E-project-031311-183000/unrestricted/MQP-GE_Aviation-Inventory_Management[1].pdf

Gunasekaran, A., Patel, C., and Tirtiroglu, E. (2001). Performance measures and metrics in a supply chain environment. *International Journal of Operations & Production Management*, 21 (1/2), 71-87.

Jacoby, R.A. (2005). Supply Chain Management Viewpoint - Achieving High Performance through Capabilities: What's Required to Dominate in the Service Business.

Langenbrunner, J.R., Booker, J.M., Hemez, F.M., and Ross, T.J. (2009). An Uncertainty Inventory Demonstration – A Primary Step in Uncertainty Quantification. *11th Non-Deterministic Approaches Conference: May 4, 2009*. Report Number: LA-UR-09-01969.

Lean Manufacturing Tools. (2013). Waste of Inventory; causes, symptoms, examples, solutions. Retrieved 2/21, 2013, from http://leanmanufacturingtools.org/106/waste-of-inventory-causes-symptoms-examples-solutions/

United Technology Corporation. (2013). *United Technology Corporation Main Website*. Retrieved 2/21, 2013, from http://www.utc.com/Home

United Technology Corporation (2013). *United Technology Aerospace Systems Main Website*. Retrieved 2/21, 2013, from http://utcaerospacesystems.com/

United Technology Corporation (2013). *United Technology Aerospace Systems Customers*. Retrieved 2/21, 2013, from http://utcaerospacesystems.com/customers/

United Technologies Corporation 2012 Balance Sheet (Forbes, 2013). Retrieved 2/21, 2013, from http://finapps.forbes.com/finapps/jsp/finance/compinfo/FinancialIndustrial.jsp?tkr=utx&period=qtr

United Technologies Corporation Competitive Landscape: Financial Comparisons for Aerospace Products & Parts Manufacturing (Hoover.com, 2013). Retrieved2/21, 2013, from http://subscriber.hoovers.com/H/company360/competitiveLandscape.html?companyId=11559000000000

Rosenfield, Donald B. (1989). Disposal of Excess Inventory. *Operations Research*, 37(3), 404-409. URL: http://www.jstor.org/stable/171060

Silver, E. A., Pyke, D. F., & Peterson, R. (1998). Inventory Management and Production Planning and Scheduling. New York City: John Wiley & Sons, Inc.

Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E. (2004). Managing the supply chain: the definitive guide for the business professional, New York: McGraw-Hill.

Six Sigma Material. (2013). Six Sigma material: Inventory. Retrieved 02/21, 2013, from http://www.six-sigma-material.com/Inventory.html

Wessels, S.A. (2011). Improving Inventory and Distribution in an Aerospace Parts and Service Organization.