Development of a Tool for Forecasting a Warehouse Facility Footprint and Enabling Rapid Scenario Analysis

By

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ABSTRACT

Companies in every industry, including both manufacturers and service providers, must make decisions about their operational footprint - the amount of building space required for business needs such as storing inventory and equipment and providing work areas for employees. Changes to the existing footprint often involve buying, building, expanding, leasing or selling facilities. These are long lead time decisions, making it critical to accurately forecast these needs far in advance. The problem is that many companies do not know what facility footprint requirements will be years from now. This thesis addresses the problem by investigating factors that drive space requirements and estimating trends, resulting in a five year space forecast. An approach is provided for quantifying a proactive outlook, thereby enabling more confident decisions regarding the operational footprint of the future.

The thesis addresses how to adapt the forecast to create a valuable instrument that enables analysis of changing conditions and assumptions in a dynamic environment. This provides the ability to easily and intuitively compare the outcome of multiple changes with one another. It also displays the capacity to perform analysis of complex multivariable scenarios.

We explore in this thesis approaches for reducing facility size required to store inventory. These approaches include consolidation of warehouses, utilization of high bay storage and the identification and elimination of aging inventory.

This research was conducted at Raytheon Company, a US-based defense contractor, with a focus on predicting warehouse space required to store inventory to support their manufacturing operations. However, these concepts apply to any situation where costly investments must be made to enable capacity to meet demand. This includes expansion or contraction of manufacturing plants, retail stores and office buildings. A proactive approach enables more insightful decisions about capital investment, construction plans and lease terms.

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I. Introduction

The success of companies in every industry across all geographies depends to some extent on the ability to accurately predict the future. This is a challenge since none of us possess a crystal ball. Decisions are made based on imperfect and incomplete information. This challenge becomes even more difficult when making decisions that require a long lead time. If predicting what will happen next month is hard, then foretelling circumstances looking out several years can be especially problematic. However, when making decisions about how much building space will be required this is precisely what must be done. The impact of underestimating the facility needs can be disastrous because it can become a constraint that does not allow an operation to function properly. For this reason many companies simply err on the side of purchasing or building more space than they expect to need. But this is an expensive solution and one that is less and less acceptable given continually increasing competitive environments. Fortunately, it is possible to create a sound picture of what requirements will be several years from now.

Research supporting this thesis was conducted over a six month period with Raytheon Company, a large defense contractor that experienced difficulties from not predicting future warehouse capacity needs. Specifically, the study was completed in the Raytheon Space and Airborne Systems (SAS) Logistics group, a shared service organization that supports multiple business units. Details about Raytheon Company, the challenges they face and what has been done to address those challenges are contained in subsequent sections. Examples of applying the proposed methodologies at Raytheon are included throughout the thesis.

One can expand knowledge gained from the research application at Raytheon to the accurate prediction of operational space needs in a broader context, as these concepts apply to any situation where costly investments must be made to enable capacity to meet demand. A hypothesis that the forecast approach proactively accounts for future conditions in order to enable confident decisions about the future size of an operational footprint is explored. Another key portion of the proposed methodology is the addition of sensitivity analysis and complex scenario analysis. These enhancements allow for more rapid and insightful decisions about capital investment, construction plans, lease terms and other footprint design parameters.

This thesis also includes a section addressing the reduction of required facility size. Several tactics for achieving a reduced footprint, and as a result reduced costs, are proposed. This is aimed specifically at streamlining facilities for storing inventory (i.e. warehouses), but again the fundamental principles apply to various operational environments.

Recommendations for further steps for Raytheon Company are proposed. A few statements boiling down the essence of the thesis bring the work to a close.

The remainder of this section will discuss in detail the motivation for the thesis, summarize the key objectives of the thesis and outline the thesis hypotheses.

A. Motivation for Thesis

In July of 2008 SAS Logistics realized that required warehouse space exceeded available space by approximately 25% in the North Texas (NTX) region. As a result leadership identified an internal objective to determine a proactive forecasting process for assessing long term (five year) regional warehouse space needs.

One might ask how it could be that a company as stable and experienced as Raytheon could be caught off guard by their own need for warehouse space. A proactive and rigorous determination of space needs for a company is not as common as might be expected. Consider a common analogy regarding the 'boiled frog': if you put a frog in a pot of boiling water it will jump out immediately. However, if you place the frog in comfortable water and slowly heat it to boiling the frog will remain because it isn't aware of the incremental increase in water temperature. In this particular case, Raytheon was focused on more immediate objectives such as shipping quality product on schedule and developing the next era of innovative products. The warehouse shortage, like the frog's boiling water, only became an issue at an incremental rate: one pallet at a time. In the short run they responded by placing a pallet in an unused area that did not adhere to their material handling procedure, but only until they could find a better location for it. This happened again and again until finally material was stored in pedestrian and material handling aisles, trailers in the parking lot, and in hallways and under stairwells in office areas.

Similar situations are experienced at other operations companies. In the article *Is Your Fulfillment Center a Tight Squeeze* (Del Franco), operations consultant Bill Kuipers is quoted as saying that facilities exceeding 80-85% utilization are ready for expansion. "In a cramped or crowded facility people don't realize how much time is wasted in picking, replenishment and travel. By the time management realizes it's time to move, it's already too late." There is a good chance that something similar is happening right now in your organization. If footprint projection is not actively on the radar due to other competing priorities, then this situation is inevitable. The implications are nearly all negative.

For Raytheon, once the realization occurred, there was a huge effort to determine an immediate solution to alleviate the capacity constraint. The resulting solution was the leasing of an offsite warehouse. Although this provides near-term relief it also caused other problems. First, this scenario no doubt caused significant stress on the organization. While the response was impressive – a viable solution was put in place with relative speed – the people involved had to bend over backwards in order to make this a reality. While fully engaged in this transition the risk of missing other priorities increased substantially. This includes tactical execution.

Second, higher costs were absorbed than would have been incurred if a strategy would have been possible to devise and implement more proactively. For example, the process of transitioning material from existing storage spaces to the new space has not been lock step. One of the proposed benefits of the transition was to move inventory storage from more expensive to less expensive real estate. While this is occurring, it has happened more slowly than anticipated. Expense outflow from leased space begins as soon as the facility is acquired contractually. The new space was acquired and Raytheon began making payments in June 2009. However, facilities being exited were maintained for much longer. Modifications to the new facility were required, which took some time. Also, SAS Logistics was only approved initially by Raytheon executives to use the space for a portion of the inventory they manage, although the facility has several times more capacity available. In addition, realizing savings from exiting more costly facilities is predicated on several things. When exiting leased space, the entire leased portion of a facility normally must be emptied and made available to other lessees before payments stop. In this case much of the inventory was moved out of a leased facility, but some was left. The racking was still in place, it was just sparsely filled with remaining inventory for several months. Although the use for Raytheon was limited it was completely unusable for anyone else, therefore payments to the lessors continued. In the case of Raytheon-owned space, cost reduction was expected by moving from an official Raytheon site, where operating fees are extremely high, to a much lower-cost offsite leased warehouse. The reasoning makes intuitive sense in that the space, which is on a capacity constrained site, can be turned over to higher value operations such as manufacturing. However, until an operation moves into the vacated space, those savings are nonexistent. In fact the position is now worsened because the logistics organization is responsible for both the expensive Raytheon-owned space as well as the newly acquired space.

As discussed below in the *About Raytheon* section, Raytheon is a relatively bureaucratic organization. Internal politics are important and facilitate decision making. For this reason having proper approvals for capital expenditures is critical and takes time. At the time that the warehouse constraint issue was being addressed there is a key corporate-wide metric aimed at reducing the square footage of Raytheon facilities of all types. Clearly adding a facility is at odds with this objective, which was instituted because overall the company had excess building space. Even though the additional facility would reduce the cost of warehouse operations there was pressure to use existing space. However, space that is ideal for warehouse operations is much different than space required for offices or even manufacturing. For example, high bays are important so that inventory can be stored vertically, which dramatically increases utilization per square foot. Also, the level of security required to store preassembled parts is lower than that of finished goods, to which much value-add and confidential know-how has been added. Even information such as plans, drawings, contracts, customer information and financials, require a higher level of security than a box of parts that has limited value alone.

There are two positive aspects of this scenario. One is that Raytheon realized the issue before it caused them serious problems. Although they had to bend over backward to alleviate the problem quickly, shipments were not missed and no injuries occurred. Second, this issue will now be on their radar foreseeable future, probably making them one of the more proactive companies in this realm.

B. Key Objectives

The main goals of this thesis are to:

1. Create awareness that forecasting future footprint requirements is an important part of proactively running any organization that depends on the capacity-limited facilities,
2. Provide an approach that will improve the ability to analyze the impact of changing variables on long lead time decisions, and
3. Provide options for reducing material management space needed to support business priorities.

This challenge of operational space forecasting spans many companies across multiple industries; therefore this application is appropriate in numerous circumstances.

C. Hypotheses

We propose two hypotheses to be addressed by this thesis. The first focuses on employing techniques intended to improve confidence in long lead time decisions related to matching capacity to demand. The second hypothesis addresses expanding the forecast capability to create a tool that allows one to adjust levers that reflect change in the business environment and quantify the resulting outcome.

1. Hypothesis 1

The factors influencing facility space requirements can be understood and quantified well enough to reasonably predict future footprint requirements.

2. Hypothesis 2

An existing forecast, can be enhanced to include functionality that enables the rapid and intuitive understanding of how changing variables impact anticipated requirements.

II. About Raytheon

Raytheon Company, originally called the American Appliance Company, was founded in Cambridge, MA in 1922 by Laurence Marshall, Vannevar Bush and Charles Smith (Raytheon Company).

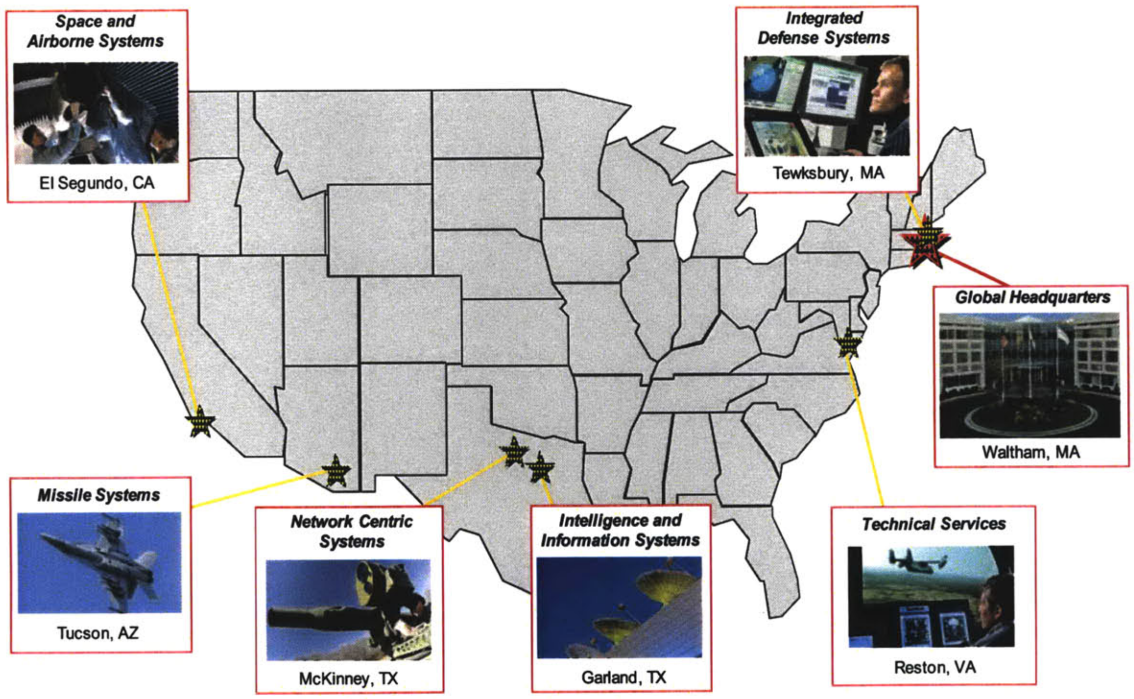
Raytheon's innovation was apparent from the start. Its first successful product was "a new kind of gaseous tube that would allow radios for the first time to be plugged into a wall socket and operate on electricity rather than batteries." Since this initial product development breakthrough, Raytheon has continued to create incredible new products, including "the first commercial microwave ovens, miniature tubes for hearing aids, the Fathometer depth sounder, the mass production of magnetron tubes, early shipboard radar, the first successful missile guidance system, a space communications system, mobile radio telephones, the first combat-proven air defense missile system and Terminal Doppler Weather Radar."

Today, more than 80 years after its founding, Raytheon is a major defense contractor headquartered in Waltham, MA with approximately 73,000 employees and $23.2 billion sales in 2008. The chart below provides information about Raytheon's largest business units.

Table 1: Summary description of major business units within Raytheon Company (Raytheon Company)

BUSINESS UNIT	MISSION	2008 REVENUE	EMPLOYEES
Integrated Defense Systems (IDS)	Leader in Joint Battlespace Integration providing affordable, integrated solutions to a strong international and domestic customer base, including the U.S. Missile Defense Agency, the U.S. Armed Forces and the Department of Homeland Security.	$5.2 billion	13,000
Intelligence & Information Systems (IIS)	Developer of leading-edge, mission-centric intelligence and information solutions to enable timely and accurate decisions.	$3.1 billion	9,200
Network Centric Systems (NCS)	Developer of world-class capabilities in networking, command and control, situational awareness and focused logistics.	$4.5 billion	12,400
Missile Systems (MS)	Designer, developer, and producer of missile systems for critical requirements, including air-to-air, strike, surface Navy air defense, land combat missiles, guided projectiles, exoatmospheric kill vehicles, and directed energy weapons.	$5.4 billion	12,500
Technical Services Company (TSC)	Provider of technical, scientific and professional services, as well as a full-spectrum of training services and outsourcing for defense, federal and commercial customers worldwide.	$2.6 billion	9,000
Space & Airborne Systems (SAS)	Provider of actionable information systems, including Sensor, Integrated Systems, Space and MSI solutions.	$4.4 billion	12,000

Figure 1: Locations of Raytheon Company corporate and major business unit headquarters (Raytheon Company)



The following subsections explain aspects of Raytheon's history and culture relevant to this thesis.

A. Culture

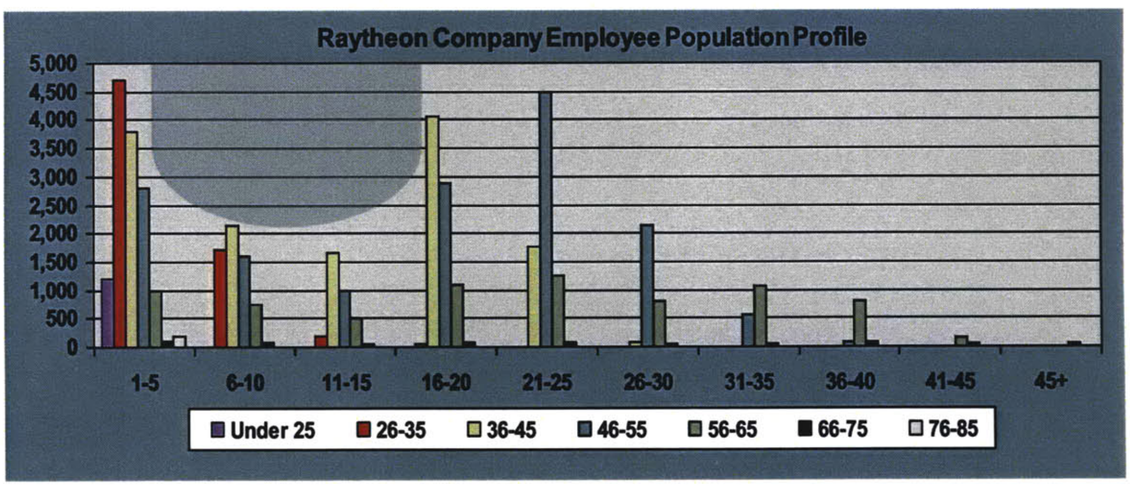
Raytheon, like most defense contractors, has a culture that is slow to change relative to companies in other industries. In part this stems from its close relationship with the United States government. Products are not only complex and technologically advanced, but also critical to the security of the U.S. and its allies. In order for governments to trust their business to contractors they must have confidence that their secrets will remain safe. This makes confidentiality of information a critical aspect of business success for Raytheon. In order to maintain this level of confidentiality, stringent business controls are required, which tend to lead to a conservative and slower-moving organization.

Raytheon is a proud company and deservedly so. The year following the release of "the tube" in 1925, Raytheon had sales exceeding one million dollars and has remained profitable ever since. For over eight decades success has been achieved by developing innovative products. This continued prosperity makes it easy to continue conducting business the way it has always done. Therefore a "don't fix it if it isn't broken" mindset is common and readily accepted. This certainly adds to the tendency to not alter operationally related business processes, possibly contributing to the capacity blind spot discussed in the Motivation for Thesis section.

The aging of Raytheon's workforce, shown in Table 2, is a critical concern for the company. Raytheon is an established and relatively stable company. Many of the employees are nearing retirement, well deserved after three or four decades in the industry. However the 90's were an economically tough period in the defense industry and therefore few new employees were hired during that timeframe. In recent years the industry has done well, resulting in renewed hiring. This creates a gap between a large group of very experienced and knowledgeable employees with a high degree of authority and a large group of fresh new faces that are learning quickly but not yet ready to take over leadership roles. To support this point, consider the following facts (Raytheon Company):

1. 50 percent of the current workforce is 45 plus years of age,
2. In 2008, 63 percent of the Raytheon workforce had less than 15 years of service, and
3. A gap exists for those with six to 15 years of experience.

Table 2: Histogram of Raytheon employee experience and ages (Raytheon Company)



This significant gap is a basis for concern. The more experienced group, in general, is more reluctant to change for multiple reasons, including those discussed above. The less experienced group, in general, is likely more open to change, but they do not yet have the authority or ability to create it. This situation adds to the change resistant and slow moving aspects of the culture that tend to inhibit it from adapting to new operationally related ideas. This will be an important theme as new methodologies and cross-business unit solutions are explored.

Additionally, a lot of corporate knowledge is captured only in the minds of experienced employees, who have begun to transition out of the business. There is a need to create processes in which to embed this knowledge and make it a sustainable part of the company.

B. Focus on Design and Development

Although Raytheon manufactures all of their own products, the focus of the company is more on development of new technologies rather than manufacturing and operations. Supporting this idea, the company goals, as stated by Chairman and CEO William H. Swanson, begin with the following (Raytheon Company):

"Customer: Be regarded as a Customer Focused company known for its technology and innovation."

This statement clearly articulates the core competency. On the other hand, the goal related to operations states only the desire to "Execute well and with predictability." The bar is set fairly low in terms of operational excellence.

Additionally, Raytheon summarizes their history as one of "Global Technology Leadership", further describing it in this way:

> *"Throughout its more than 80-year history, Raytheon Company has been a leader in developing defense technologies and in converting those technologies for use in commercial markets. From its early days as a maker of radio tubes, its adaptation of World War II radar technology to invent microwave cooking, and its development of the first guided missile, Raytheon has successfully built upon its pioneering tradition to become a global technology leader."*

However, it was superior manufacturing that launched Raytheon as a key defense contractor. During World War II Raytheon was able to streamline the manufacturing process for magnetron tubes (Raytheon Company). These tubes were the critical component of newly developed radar systems – which provided the Allied Forces with a key military advantage. Mass production of these parts was essential to the war and Raytheon was awarded a small supply contract. Due to superior ability to produce the tubes, "At the end of the war, Raytheon was producing 80 percent of all magnetrons, leaving Western Electric, RCA, GE and other giants far behind." Nevertheless, the company continues to see themselves primarily as a developer of new technology.

The takeaway is that significant opportunities for improvement exist in the operational functions, which is great news for those with a focus in operational excellence. A lack of cutting edge practices in the logistics arena is significant partially due to the enterprise focus on technological development. To combat this deficiency, Raytheon has in recent years recruited leaders with significant functional experience from other industries. An example is SAS Logistics Director Mike Hall, who is working to take Raytheon's logistics performance to a new level and as such provides the impetus for many of the concepts discussed in this paper.

C. Raytheon Six Sigma™

Raytheon utilizes an internally adapted version of Six Sigma as its continuous improvement approach. This is a good fit with the company's goals and culture since Six Sigma is an approach focused on defect elimination. Although traditionally applied as a rigorous statistical methodology, Raytheon's version focuses more on driving change than analytics. Any continuous improvement methodology successfully integrated into a company's manner of doing business can be a powerful instrument of change. Raytheon Six Sigma is one such instrument and can be leveraged to employ the new approaches proposed in subsequent sections, including opportunities to expand tools developed during the research for this thesis throughout the company, improve existing forecasting processes and reduce space required for warehousing operations.

D. Growth Via Acquisition

Over the course of 80+ years Raytheon has grown from a small startup to a huge multinational corporation. As is common in the defense industry, the main driver of that growth has been an aggressive strategy of acquiring complementary companies and divisions of companies.

The list of companies acquired include Beechcraft, E-Systems, Texas Instruments' Defense Systems and Electronics business and Hughes Aircraft's Defense Electronics business. The combination of these organizations creates one of the most powerful and respected defense companies in the world. As mentioned on Raytheon's corporate website, "All these businesses brought complementary skills and expertise, which have combined to make Raytheon a global leader in defense, homeland security and other government markets throughout the world." (Raytheon Company)

However, these acquisitions create challenges as well, with one of them being a company with significant organizational silos. Several of the companies acquired, instead of being completely integrated, simply became business units. Although the business units report up through Raytheon Company for financial reporting purposes they are often seemingly otherwise independent. The business units maintain many of the original business processes, information systems, products and cultures. Even specific sites tend to remain independent. An example is the McKinney, TX site which was acquired from Texas Instruments (TI). Many of the people that work at this site have been here for decades and thus were originally TI employees. In some of their minds the only thing that changed was the company name on their paycheck and badge.

To their credit, Raytheon is working hard to integrate aspects of the company. One massive initiative is the implementation of a common enterprise resource planning (ERP) system. The ERP system spans the entire company, thereby forcing alignment of reporting and some business processes. Other efforts are underway as well, but legacy culture and business practices are deeply engrained, thus complete alignment will take many years if it's possible at all.

In the meantime this makes the job of forecasting extremely difficult for a shared services organization like SAS Logistics whose capacity requirements are dependent upon the needs of businesses they support. Information from 8,000 different programs, many with a different forecasting process, must somehow be combined into an enterprise-level projection. We must build on alignment progress being made with the ERP initiative to determine a company-wide forecasting process. This would go a long way in improving long lead time decision making within the organization. Another area to leverage alignment is by translating forecasted needs into the operational space by instituting regional warehouses that house the material for all programs operating in that area, as proposed by SAS Director of Logistics Michael Hall and launched with efforts related to this thesis.

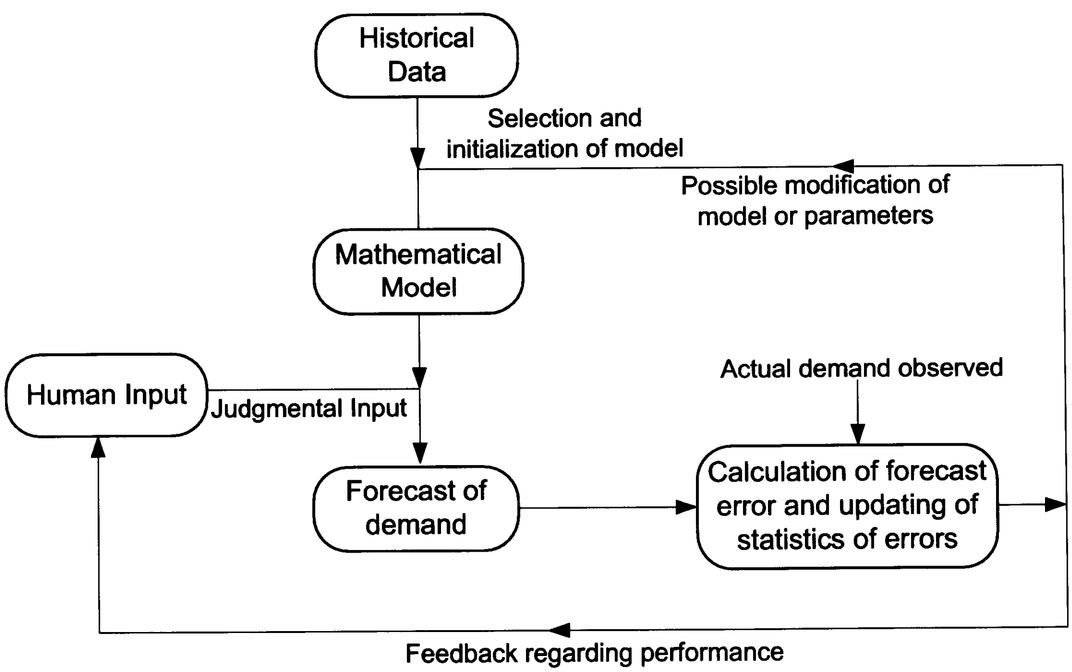
III. Forecasting Overview

Any reliable forecast should be based on sound fundamental forecasting techniques. This section provides an overview of commonly used techniques and discusses in what environment each is most appropriately used. It is not an in-depth guide to traditional forecasting methods. Detailed information on applying these techniques is addressed in a plethora of texts, such as Silver, Pyke and Peterson's *Inventory Management and Production Planning and Scheduling*.

A. Forecast Process

The basic purpose of a forecast is to provide information that is useful in making business decisions. In order for people to rely on a forecast for this purpose they must trust that the information is reliable. Key to reliability is the underlying process that is followed in order to derive the forecast. Figure 2 illustrates a basic forecast process framework.

Figure 2: A suggested forecasting framework (Silver, Pyke and Peterson)



1. Historical Data

Two basic types of input are used in developing forecasts. The first is quantitative information about the past. The concept is that the past often gives us clues about what we can expect of the future. This information about the past is usually in the form of historical data.

2. Human Input

The second type of information used to forecast is human input, which is often qualitative information about the future. Although historical data can provide insight about the future, it cannot be relied upon alone to make predictions. As investment firms often state in fine print, "Past performance is not a guarantee of future results." For this reason we must incorporate knowledge and intuition about how the future will differ from the past. This is often done by asking various experts for their input. For example, sales and marketing often keep tabs on how customer preferences change over time. Others have insight into technological progress. Yet others monitor legislative amendments and others external factors that ultimately impact future results.

In the book *Designing and Managing the Supply Chain* (Simchi-Levi, Kaminsky and Simchi-Levi), the balance between historical data and human input is addressed. In answer to the question, "How important is the past in estimating the future?" they state that "If the past is very important, time-series methods make sense. If significant systemwide changes render the past less important, judgment...may be indicated." As we will see in the case of Raytheon, contacts within each program rely heavily on relationships with customers to maintain an understanding of future demand. Due to the nature of future production, forecasts rely almost completely on human input.

3. Creating a Model

Once inputs have been determined and collected they must be combined and translated into meaningful output. Combination of the inputs will be addressed in subsection B. Translating often involves changing the units. For example, when forecasting space at Raytheon we want the output to be in terms of square footage. However, input data is in terms of production quantities. At a very basic level we adjust the production quantity forecast by the relationship that inventory levels change as quantities change, then use conversion rates to determine how that translates into floor space. A detailed example applied at Raytheon can be found in subsection B.

4. Repeatability

Forecasting is not a one-time action. The process must be repeatable so the forecast is updated to reflect new information. Normally the process is repeated at regular time intervals, such as monthly, quarterly or annually. The proper frequency will be a reflection of the time horizon of the forecast, stability of the forecast subject, and availability of new information. For example, if a forecast is largely based on a study that is released quarterly, it probably does not make sense for the process to be repeated monthly.

5. Improvement

A good process will not only include repeatability, but also improvement. Reviewing the accuracy of previous forecasts is a critical component of making these improvements. If we can quantify how actual figures compared with what was predicted we can try to understand what caused those deviations. Making changes to the forecasting process to mitigate these causes should result in improved forecast accuracy over time.

B. Raytheon Production Forecasting

It has been found that accurate forecasting in Raytheon's business environment is extremely difficult. There are several reasons for this. First, Raytheon specializes in complex systems designed for very specific uses and low volumes. Of course forecasts in low volume operations are usually much more difficult than those with higher volumes. Second, they have very few customers. In fact, their biggest customer – the United States government – accounts for a huge proportion of their business. For some "programs" within Raytheon, Uncle Sam is the only customer. The government is not only deciding how many of and when they need a particular product, but also whether they will purchase it at all and, if so, to which supplier they will 'award' the contract. The result of these decisions can result in an 'all or nothing' scenario for Raytheon. There may be an order for 100 super widgets on the table (a large quantity for the type of product that Raytheon manufactures), but the supplier decision means that they will likely be awarded either all 100 or none. An award of 'none' could result from one of two decisions: first, the decision could be not to award the contract at all, and second, the contract could be awarded to a competitor.

Raytheon addresses this by estimating a "PGO" and "PWIN" for each potential product volume. "PGO" represents the probability that the customer will go forward with the contract, thereby awarding it to some company. "PWIN" is the probability the Raytheon will receive the award given that it is awarded to someone. The result is almost certainty that the expected value of volume awarded is very different from the actual volume awarded. To illustrate, take the hypothetical order above for 100 super widgets. Assume that the probability of the customer moving forward with the contract is 80% (PGO = 80%). Also assume that the probability that Raytheon receives the award, given that it is awarded is 50% (PWIN = 50%). The expected value of what Raytheon estimates they will be awarded is:

$$Potential\ Volume * PGO * PWIN = 100 * 0.80 * 0.50 = 40\ units.$$

However, the actual award is likely to be either 100 or zero units. For companies whose production volumes depend on tens of thousands of decisions like this, the net expected value is very likely to be relatively accurate. However, since Raytheon's production lines are largely dedicated to a single program, this means that a single decision can dictate everything.

Compounding this is the fact that decisions regarding the operational footprint – such as whether an additional warehouse will be required two years from now – rely on these production forecasts and involve issues that can be extremely costly. They are costly if the forecast is inaccurate in either direction. If the forecast is too high then millions of dollars will be spent to create capacity that is not needed. Clearly this must be avoided if at all possible.

However, the forecast being too low can have an even worse result. This would result in not enough capacity to handle requirements. This can be simply disastrous. As mentioned above, this is what almost happened with Raytheon logistics recently as the warehousing space required in North Texas exceeded space available. They compensated in part by overfilling the warehouse, which meant storing inventory in hallways. This created congestion, which blocked traffic. It also made it harder to locate parts when needed since they were not placed in locations that translated to the material tracking system.

1. Existing Forecasting Processes

Prior to this effort there was not a process in place for forecasting warehouse space requirements. However, processes did exist for creating business unit production forecasts. These production forecasts are key inputs to predicting warehouse space. Forecasts were initially created at the program or product group level, and then were rolled up to the business unit level. The purposes of these forecasts were primarily to make long lead time decisions specific to the program and business unit related to part and material purchases, production capacity and staffing. These processes differed by program and business unit. Some details as well as inconsistencies regarding these processes are discussed in the following sections.

2. Inputs: Garbage In, Garbage Out

In any forecast, it is imperative to ensure inputs are reliable. Production forecasting processes varied depending on the business unit. In the Raytheon example we found several instances where the process was not working properly, resulting in forecasts that could not be trusted and were therefore worthless at best and misleading at worst. An example is the business unit forecasts, which are the critical input to the warehouse space forecast. When looking into this process it was discovered that people responsible for entering the data were doing it differently. The data being entered consisted of potential end-item quantities and probabilities that these quantities would be attained. The revelation was that about half of the data was being entered 'un-factored', with quantities and probabilities separated. However, the remainder of the quantities was 'factored', meaning the probabilities had already been applied, but they still had to enter a probability, which they did. This resulted in probabilities being double counted and lower calculated quantities than really expected. For example, if the hypothetical order above of 100 potential systems, a PGO = 80% and PWIN = 50%, 100 units should be entered into the quantity field and 40% (80% * 50%) into the probability field. The resulting expected value, as above, should be 40. However, in the factored instances the expected quantity of 40 was entered at well as the overall probability of 40. The model interpreted these as expected values of 16 instead of 40. Since the warehouse space forecast is based on this data this issue had to be addressed.

Once this problem was discovered all of the people that enter this particular information met to discuss the differences and determine a solution. It was determined that everyone would enter un-factored quantities. The problem was remedied in the following forecast cycle.

3. Apples Versus Oranges

SAS Logistics is a shared service organization that supports several business units. Each of these business units tend to operate with relative independence. This includes their forecasting processes, which are different. The differences are not only between NCS and SAS, which represent the majority of SAS Logistics space requirements, but also among the programs that make up each of these business units.

Presumably many programs (not just every business unit) determine their forecast numbers differently. It is impossible to know for certain because this all happens behind a secret curtain due to the sensitivity of the information. However, the understanding is that program forecasts are estimates that result from discussions with the program's customer contacts. These numbers, in some instances may be quantified directly by the customer. In other instances they might be educated guesses based on general conversations with the customer. All of this will vary based on the relationship between program and contact, the process they have set up for sharing information and how the program contact interprets the information. Differences between program forecasting processes can include:

- Time Horizon: Some programs produce a rigorous forecast that looks out five years, while others don't predict beyond 12 months. This can cause difficulties when gathering input for an enterprise level five-year forecast. If a program submits a production quantity for each quarter for a one year horizon followed by a quantity of zero for the next four years, it is difficult to determine if this is because they really expect to make nothing in the ensuing years or whether they just haven't projected out that far.
- Timing of Update: SAS and NCS both update forecasts quarterly, but SAS does so on a rigid schedule whereas NCS does on a less predictable schedule.
- Output: SAS output is available in form of volume, PGO and PWIN while NCS data is already in the form of expected value.
- Source: An individual manually puts together and updates the NCS forecast by talking independently to each program lead and compiling a report, whereas SAS program contacts enter their data into an online system, from which a report can be generated.

These differences are important when trying to accurately predict future production levels. The forecasts for each of these programs must be amalgamated in order to create an enterprise-wide forecast.

All that said, the production forecast owners for SAS and NCS, both of which are fairly new to their roles, are in contact with one another and making a concerted effort to better align their processes. This provides hope that the forecasting processes of these two businesses will improve and become more similar over time as they learn from each other.

4. Limited Historical Data

As mentioned above, historical data is normally important to determining a reliable forecast. Given the nature of the very low volumes accompanied with binary award decisions, historical data is less relevant than in normal circumstances. However, it would still be instructive to study, for example, how historical volume projections compare with actual production. It would also be helpful to analyze trends in the number of pallet positions over time and how those relate to production levels. However, historic values are hard to come by for several reasons. These include:

- SAP Conversion: Arguably the biggest reason for lack of historical data has to do with Raytheon's recent conversion from legacy information technology systems to SAP, the ERP system discussed above. In doing so, data was transferred from the legacy systems to the new system. However, date stamps transferred over as the date of the conversion, not the date of the original data.
- Forecast accuracy of production volumes is not tracked by the business units.
- When forecasts are updated they tend to overwrite the previous data, thereby making it impossible to go back and determine forecast accuracy.

IV. Determining a Facility Footprint Forecast

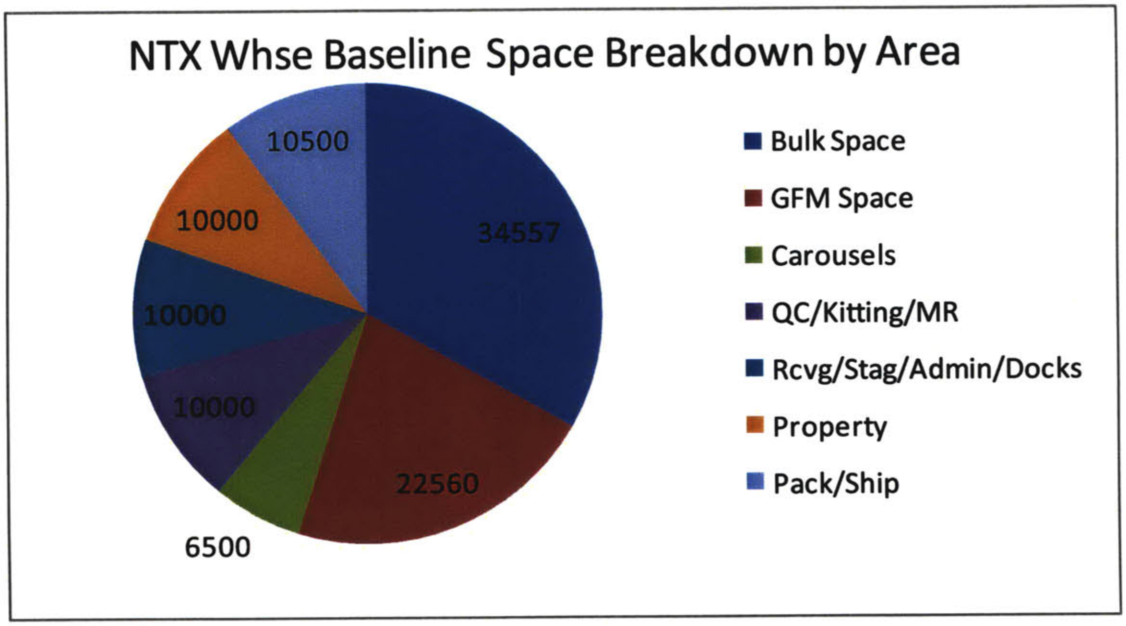
As stated in the text *Operations Strategy* (Beckman and Rosenfield), "Capacity decisions establish how much capacity the firm will carry in order to manage both short-term fluctuations in demand and longer-term growth opportunities. Facilities decisions are often closely related to capacity decisions, as firms add or close facilities in response to a need for more or less capacity." When forecasting facility space requirements we must understand the nature of the decisions that ultimately result in the size of the facility needed. In many businesses, inventory levels are set by those that manage the warehouses and their replenishment. In other businesses it is the manufacturing organization that makes these decisions while the logistics organization's role is tactically focused with the objective of handling that material in the most effective manner.

Raytheon is certainly in the latter category. Management of the programs, or manufacturing, makes all decisions regarding what to buy and when, as well as when they will use that material. The logistics function is to receive it when it arrives, store it securely, then quickly deliver it to the manufacturing area when requested. While logistics has very little influence on volume they nonetheless must estimate what these will be in order to ensure the infrastructure is in place to manage their role effectively.

A. Space Baseline

In order to determine the size of footprint required we began by working to understand existing allocation of warehousing space. To do this we first determine the areas in scope. For the scope of the Raytheon case, this basically comes down to those for which the SAS Logistics organization is responsible in the North Texas region. In total this represented just over 104,000 square feet of building space. The current breakdown of this space by area is shown in Table 3. The majority of materials stored in these warehouses are raw materials and components to be used by production. There is also a section called GFM that contains finished goods. Details about each of these areas are discussed in the following sections.

Table 3: SAS Logistics warehouse square footage allocation in North Texas (NTX) region

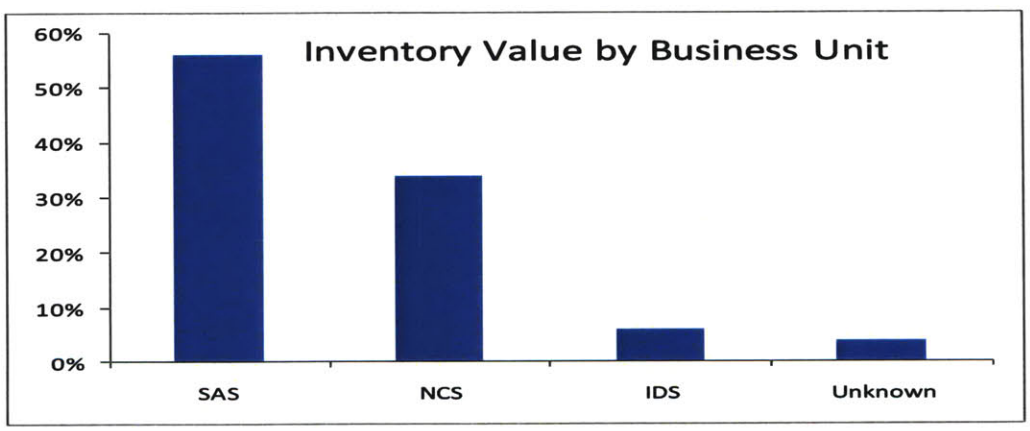


We now know our starting point. The next step is to understand the nature of each area and what affects the rate by which the space allocation increases or decreases over time. After significant searching it is clear that data was not available to quantitatively assess historical trends. Thus, this step was determined by questioning the people that managed each of these areas in order to understand the factors better. Following is a description of each area and a qualitative explanation of what affects space requirements.

1. Bulk Space

This area is dedicated to raw material and work in process inventory that has been received and is being stored until it is requested by manufacturing. The great majority of this inventory is palletized and stored on racks that are stacked five-high in the current warehouse. The volume of this inventory varies with production volumes. Whereas in normal cases the volume of inventory might change by a factor of the square root of the change in production, we assume a one to one correlation for our model. The main reason is due to industry procurement practices, which often call for all of the parts to support a given contract to be purchased shortly after the contract for the upcoming production period has been awarded and signed. This differs from a traditional environment where parts are purchased over time as they are needed. Therefore, we link expected bulk space allocation directly to production volumes. As we can see from the breakdown of inventory value in Table 4, the material managed by SAS Logistics is represented almost entirely by the SAS and NCS business units. Additionally, the small portion of material for the IDS business is included in the SAS production forecast. Therefore we only need to obtain production forecasts from SAS and NCS as inputs to our warehouse space forecast.

Table 4: Inventory value by business unit for SAS Logistics NTX region



The portion of inventory labeled as "unknown" represents items that were entered incorrectly upon receipt. We assume that this material is spread proportionally across the units identified.

2. GFM Space

We will use the terms GFM (Government Furnished Material) and CFI (Customer Furnished Inventory) interchangeably. This is inventory that is owned by the U.S. government or some other customer. Much of it consists of finished goods that have been completed and paid for, but which the customer is not ready to receive. In many if not all cases, the material is stored free of charge by Raytheon. The amount of inventory does change over time, but it is unclear by how much and how to predict these changes. It basically depends on when the customer decides they want the goods, which, to our knowledge, is unpredictable. A breakdown of dedicated GFM bin space by business unit and program is contained in Table 5. These figures represent a snapshot as of June 2009. This information is refreshed periodically and the space forecast is updated with the new information.

Table 5 : Bins (pallet locations) allocated to GFM by business unit and program

BU	Program	Total Bins
NCS	AAV	4
NCS	CITV	32
NCS	CIV	135
NCS	GS	60
NCS	HTI	159
NCS	IBAS	26
NCS	ITAS	316
NCS	ITSS	3
NCS	LRAS	1020
NCS	M1A1	8
NCS	OMNIBUS	12
NCS	TOW	5
SAS	AAS-44 PBL	16
SAS	AN/AAQ-26	14
SAS	APQ-158 SLEP REPAIR	8
SAS	APS	169
SAS	ATFLIR	55
SAS	CONVERSION	39
SAS	CV-22	37
SAS	EO	4
SAS	F16/22	60
SAS	IRADS	4
SAS	ISAR	8
SAS	JSF	2
SAS	MMA SDD	3
SAS	MTS	202
SAS	NAV/ATTK	18
SAS	SEAVUE	2
SAS	SURV	24
ALL	**TOTAL**	**2444**

3. Carousels

Semi-automated, high density storage of small parts for all areas. Plans are for these units to be moved from the previous central warehouse to the new warehouse. Space allocated (6,500 square feet) includes that necessary for a total of 20 new carousels double-stacked. These 20 carousels include significant excess capacity, which should be significant to handle small parts storage needs for many years to come. The expectation is that this equipment will be sufficient for the foreseeable future. Since floor space allocation will not change as utilization of the carousels changes, this figure will be static over time in our model.

4. Floor Level Operations

Floor level operations include receiving, kitting, staging, quality control, material review, and the docks for shipping and receiving. The purpose for these areas is fairly obvious. The layout of each is set and has been designed to accommodate variable levels of demand with staffing changes. Therefore space allocation for each of these areas is projected to be static over time. If the layout for one or more of these areas is going to be altered significantly, then the square footage allocation assumption in the model can easily be updated to reflect the change. Space in the new offsite warehouse has been allocated to each of these areas.

5. Pack/Ship

This is another floor-level operation, the purpose of which is to package parts, components and systems prior to shipment to the customer. Due to the conditions that these parts may undergo (severe heat, cold, humidity, vibration and extended storage periods), the packaging requirements are often extreme. Although this operation is under the responsibility of SAS Logistics, it will be physically separated from the other operations which have been moved to an offsite warehouse located in nearby Carrollton Texas. The reason is that this activity occurs post-manufacturing, which is all located at the McKinney site. Therefore the pack/ship operation remains in McKinney. For this reason pack/ship is omitted in analyses that are focused on managing capacity constraints at the central warehouse. However, from a layout perspective pack/ship behaves in much the same manner as the floor-level operations discussed above. Therefore we assume space allocation to be static over time. It is likely that this area will receive a layout update in the near future; however the impact this will have on square footage is unclear. If a new layout is created that differs significantly from the 10,500 square feet assumed, then the model should be updated to reflect the change.

6. Property

This term refers to capital equipment stored by SAS Logistics. This equipment is stored for very long periods, tending to move very seldom. Due to different storage processes and procedures it is separated physically from other types of inventory. We assume that the current level will remain static over time.

B. Predicting Future Bulk Space

We now need to convert our baseline into a forecast that will enable insight into the size of the required future warehouse footprint. The main unit used to make these decisions is square footage. Since most of the areas to which warehouse space is allocated are expected to remain static over time, the key to forecasting overall warehouse space is accurately predicting future square footage for bulk inventory. We begin knowing the total space allocated to bulk inventory: 34,557 square feet. In the ideal world we would simply divide this square footage by the total unit production forecast for each time period to determine the space required per time period. However, it turns out that this is too simplistic, so we must analyze this deeper.

LIST OF VARIABLES

TBS = Total bulk space (square feet)
PBS = Production bulk space (square feet), bulk space required for production-related material
NPP = Non production pallets (# of pallets), pallets stored in bulk area not related to production
SH = Stack height (# of vertical positions), levels of racking upon which pallets may be stacked
PRB = Pallets per rack bay (# of pallets)
ARB = Area per rack bay (square feet), including aisle allowance
CF = Cube Factor (square feet), floor space required per pallet of material
SF_i = Size Factor for product family i (ratio),1 / number of finished products that fit on single pallet
MF = Material Factor (ratio), space taken up by unassembled components relative to completed product
CQP_i = Current quarter production of product family i (units)
FQP_{ij} = Forecasted production of product family i during quarter j(units)

1. Size Factor

The systems being manufactured by the various programs are extremely different in size. In fact, completed units from the largest product family (program) are roughly 100 times the size of the smallest. This tells us that using overall averages could be extremely misleading. Therefore we will determine inventory space relative to each product family.

It is reasonable to assume that the sum of the space required to store the parts for a large product would be relative in size to the product itself. The same should hold true for products of various sizes. Therefore investigation was conducted to determine the factor of relative sizes for the main products for which SAS Logistics stores parts. Fortunately the number of products families turned out to be few in number: 18. The relative sizes of the various product families was determined (with a factor of 1 being equal to a product that fit one to a pallet) and is shown in Table 6.

Table 6: Size factor for each major product family managed by SAS Logistics in NTX

Size Factor	Product Family
1.000	CIV
1.500	IBAS
1.000	ITAS
1.000	LRAS3
0.500	HTI
1.000	CITV
0.250	RTS
0.250	TUSK
0.025	TWS II
0.250	DVE
2.500	ATFL
1.000	MTS A
1.000	MTS B
1.000	Q2
1.000	SR

2. Material Factor

We now know the relative size of the finished products for each product group. We need to translate this into an estimated size for the components being stored that are assembled into these final products. To do this we determine a Material Factor (MF).

Cube Factor (CF):

Baseline Assumptions
Stack Height (SH) = 5
Pallets per Rack Bay (PRB) = 2
Area per Rack Bay (ARB) = 94 square feet

$$Baseline\ CF = \frac{ARB}{SH * PRB} = \frac{94}{5 * 2} = 9.4$$

Production Bulk Space (PBS):

$$PBS = TBS - CF * NPP, where$$

NPP are materials on pallets supporting pack/ship (400), CCA (175) and QC processes (50), therefore

$$PBS = 34{,}557 - 9.4 * (400 + 175 + 50) = 28{,}682$$

Material Factor (MF):

In order to quantify this we must solve the following equation for MF:

$$MF * CF * \sum_{i}(SF * CQP) = PBS$$

Where SF and CQP for all i are:

Table 7: Size factor and current quarter production units (fictionalized) for major programs

i	SF	CQP
CIV	1.000	310
IBAS	1.500	65
ITAS	1.000	119
LRAS3	1.000	260
HTI	0.500	410
CITV	1.000	95
RTS	0.250	63
TUSK	0.250	1
TWS II	0.025	7500
DVE	0.250	330
ATFL	2.500	78
MTS A	1.000	47
MTS B	1.000	19
Q2	1.000	56
SR	1.000	28

From Table 7 we determine therefore $\sum_i (SFi * CQPi)$ = 1718, and can now compute the material factor.

Note: Current quarter production for product families shown above is fictionalized.

$MF * 9.4 * 1718 = 28{,}682$ → $MF = 28{,}682/(9.4 * 1718) = 1.78$

Therefore, the material factor is 1.78.

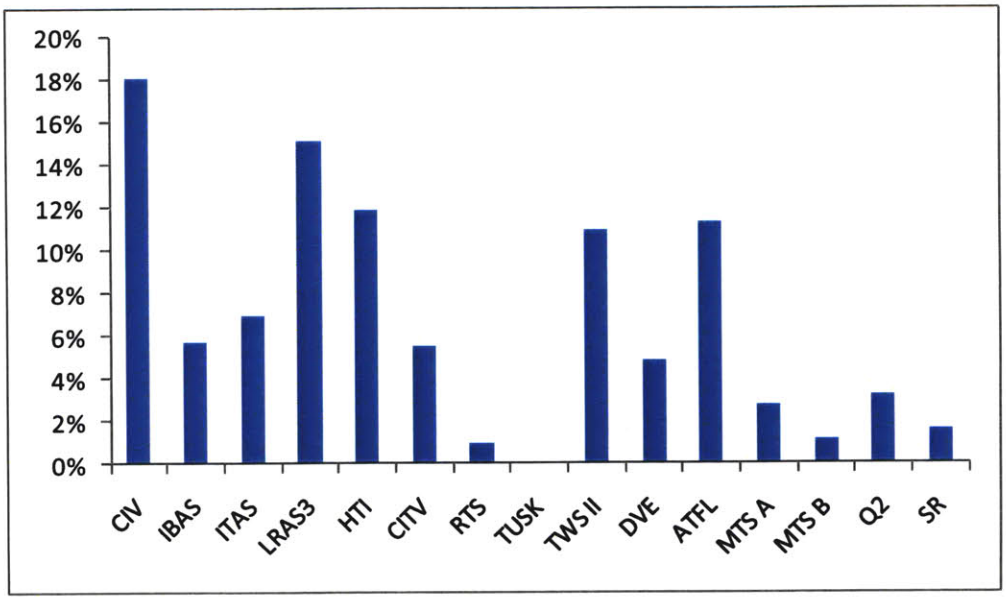
3. Bulk Space per Program

We can now estimate the current allocation of space for each product family by calculating:

$$PBSi = SFi * CQPi * MF$$

See Table 8 for the breakdown of space allocation by product family in relative terms.

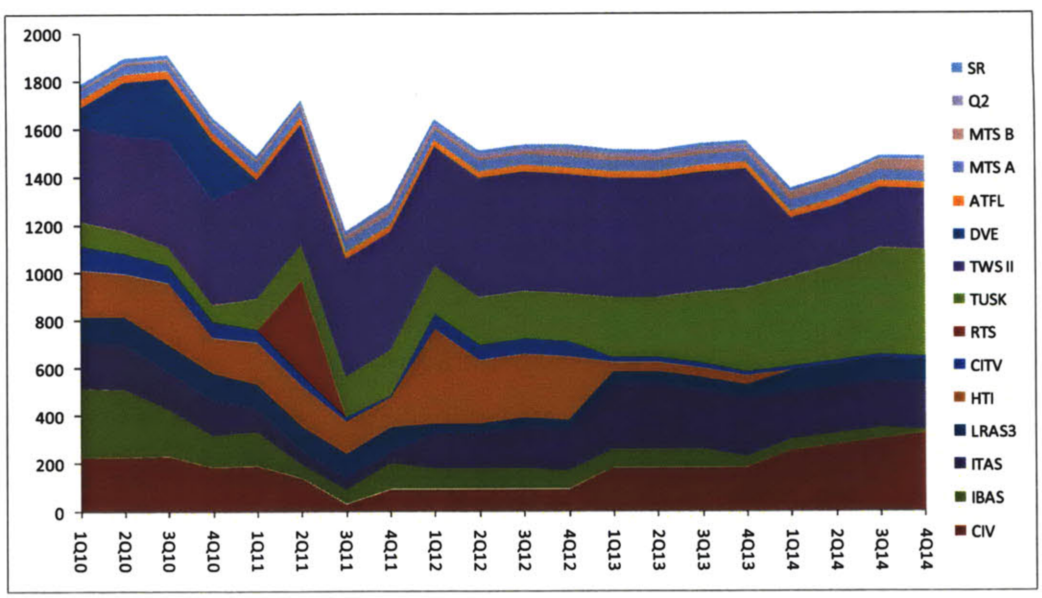
Table 8: Current bulk space allocation by product family (based on fictionalized CQP data)



4. Product Family Forecast

We now want to project forward to understand how the space allocation will change over time. We collect production forecasts for every product family for the desired five year horizon, as shown in Table 9.

Table 9: Quarter by quarter production forecast by product family (based on fictionalized data)



5. Bulk Space Forecast

With forecasted units per quarter for each product family available we can now determine the amount of bulk space required for the next five years. First we determine the Production Bulk Space (PBS) for each quarter. This is done by applying the Size Factor (SFi) and Material Factor (MF) to the Forecasted Quarterly Production (FQP_{ij}) all product families (i) for each quarter (j).

Thus, to determine total Production Bulk Space for the first quarter we calculate that

$$PBS_{1Q} = \sum_i (FQPi\ 1Q\ *\ SFi *\ MF * CF)$$

For example, if we project 290 IBAS systems for the first quarter of 2010, then space required to support IBAS during this quarter will be

$$PBS_{IBAS\ 1Q2010} = 290 * 1.5 * 1.78 * 9.4 = 3748 \text{ square feet}$$

We repeat this calculation for all product families to arrive at total PBS for first quarter of 2010. Now we must add space required for non-production pallets (NPP) to PBS in order to determine the Total Bulk Space (TBS) required for each quarter (j)

$$TBSj = PBSj + NPP * CF$$

We now repeat these calculations for every quarter in the forecast to determine the space forecast for the bulk area. To complete the overall five year warehouse footprint forecast in square feet we must combine the results from the bulk area to the static areas discusses previously. The output derived from fictionalized production forecasts is shown below in Table 10. A graphical representation of the same results can be seen in Table 11.

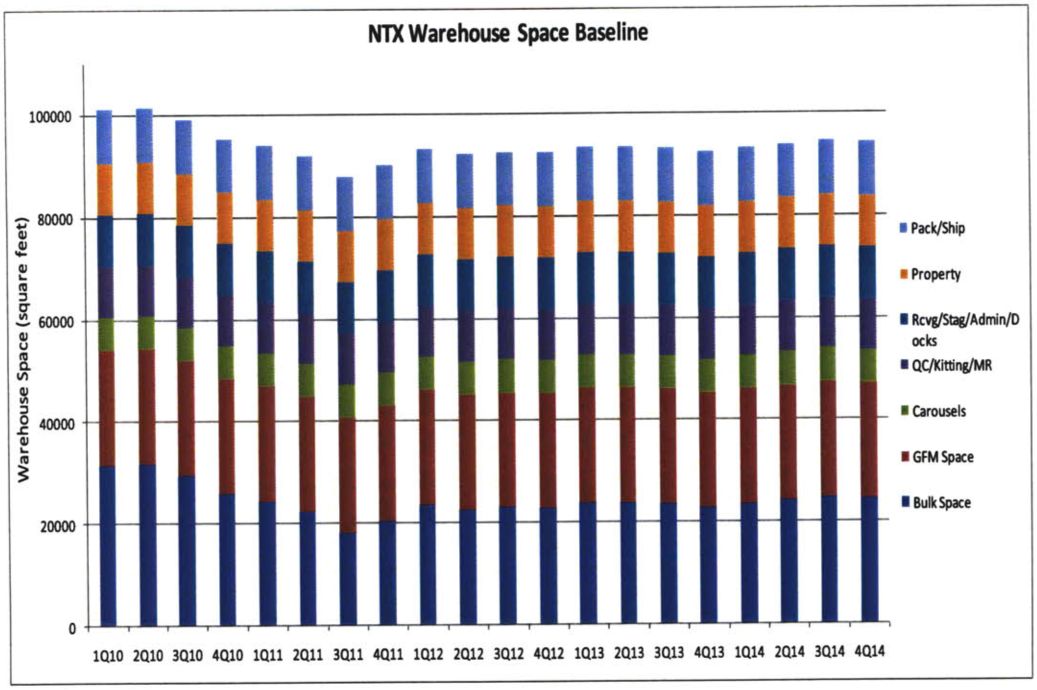
Table 10

NTX Warehouse Space Forecast Baseline

Quarter	1Q10	2Q10	3Q10	4Q10	1Q11	2Q11	3Q11	4Q11	1Q12	2Q12
Bulk Pallets	3353	3374	3143	2743	2583	2368	1930	2174	2515	2397
GFM Pallets	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Bulk Space	31517	31718	29547	25783	24281	22256	18140	20432	23637	22532
GFM Space	22560	22560	22560	22560	22560	22560	22560	22560	22560	22560
Carousels	6500	6500	6500	6500	6500	6500	6500	6500	6500	6500
QC/Kitting/MR	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Rcvg/Stag/Admin/Docks	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Property	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Pack/Ship	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500
Total NTX Whse Space	101077	101278	99107	95343	93841	91816	87700	89992	93197	92092
Capacity (85% Util)	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000

Quarter	3Q12	4Q12	1Q13	2Q13	3Q13	4Q13	1Q14	2Q14	3Q14	4Q14
Bulk Pallets	2440	2433	2531	2525	2507	2433	2513	2577	2653	2618
GFM Pallets	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Bulk Space	22934	22867	23787	23737	23561	22867	23620	24226	24938	24611
GFM Space	22560	22560	22560	22560	22560	22560	22560	22560	22560	22560
Carousels	6500	6500	6500	6500	6500	6500	6500	6500	6500	6500
QC/Kitting/MR	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Rcvg/Stag/Admin/Docks	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Property	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Pack/Ship	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500
Total NTX Whse Space	92494	92427	93347	93297	93121	92427	93180	93786	94498	94171
Capacity (85% Util)	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000

Table 11: Graphical view of NTX warehouse baseline space forecast



In order to know how good this forecast is, we need to track forecast accuracy. See section VII.B.2 on Future Steps and Areas of Focus for further discussion. In the meantime, it appears that the space required to store Raytheon's inventory in the North Texas region will be fairly steady over the next five years. Part of this is due to the relatively static space requirements of several of the components, such as floor level operations. We do see, however, that the amount of space dedicated to bulk inventory will increase and decrease with business demand.

V. Turning the Forecast into a Dynamic Decision-Making Tool

Having a reliable forecast to understand future requirements is extremely important. However, business conditions are in constant flux and the rate of change is ever increasing. Technology advances, legislation evolves, internal priorities change and probabilities of future production expectations are adjusted. As Charles Fine states in his book *Clockspeed*, "Technology and competition ... have driven us to an economy with unprecedented rapid clockspeeds." (Fine)

Because the factors that a forecast is using to estimate the future are changing, the forecast itself is not useful as a static tool. It must be constructed in a way that allows decision makers to easily update the assumptions in order to understand the implications of these changes.

When this study began, a rough warehouse space forecast had been created based on the best known information at the time. However, since that period several things had already changed. Firstly, the business units now had updated information regarding the estimates of future business. Secondly, the major business units had achieved improvements to their forecasting processes which resulted in more reliable transition of information into a quantifiable forecast. Thirdly, the facility footprint had changed radically. A new warehouse is now in operation and has the potential for consolidating material from several previous storage locations. This facility has more capacity and is different structurally than each of the other facilities, thereby changing the underlying assumptions for determining square footage requirements. Lastly, the logistics organization had further developed, clarified and communicated a "regional warehouse" strategy, which called for consolidation of all or most of the inventory into a single facility (the benefits and challenges of this strategy are discussed in the *Reducing Warehouse Footprint Requirements* section). One of the results of this was that SAS Logistics leaders were fielding many questions and requests from other organizations within Raytheon regarding whether SAS Logistics could manage their inventory.

A. Updating Forecast Inputs

The most obvious and critical aspect of keeping a forecast relevant is to ensure that the inputs are regularly updated. In the Raytheon example the critical inputs consisted of business unit forecasts. These forecasts, as expected, change over time.

1. Update Frequency

A key question to answer in structuring a forecast update procedure is how often updates should occur. It is generally preferable for updates to occur on a regular basis at predetermined time intervals. The choice of update frequency is important. If the frequency is too often, then excess resources are wasted producing something more often than it is useful. Additionally, excessively frequent updates can cause waste in the sense that results may bounce around, causing people to overreact to changes in output. However, issues can arise if updates are made too infrequently as well. Most dangerously, it could lead to finding out about significant changes that affect the forecast too late, leading to missed opportunities to make proactive decisions.

The length of these intervals can be determined based on various factors, many of which depend on the rate of change in the industry. In *Clockspeed* (Fine), several such factors are identified, including

- Capital equipment obsolescence rates (process clockspeed),
- Rate of new product launches (product clockspeed),
- Frequency of organizational restructurings (organizational clockspeed)

As Fine mentions, these factors all affect "the size of the time window for making decisions" within a business. Another critical factor is simply how often the inputs required for the forecast are updated. If updates to critical input happen on a monthly basis, then updating the forecast weekly might be unproductive. However, that being said, the forecast is by nature a long time horizon tool compared to a schedule or plan. Schedules are normally used to set very short-interval items such as what products will be manufactured on a given assembly line this hour or this shift. A plan is normally used to set medium interval items such as the volume of multiple product groups that will be made in a specific plant for the coming week or weeks. Forecasts, however, deal with a longer time horizon from a higher aspect such as a program. Since the time horizon considered is often measured in years, it does not make sense to update daily.

In the Raytheon case, determining the frequency for updating the warehouse space forecast was relatively straightforward. The key inputs were the business unit forecasts, which were updated quarterly. Therefore the warehouse forecast was also updated quarterly as the input forecasts became available.

2. Process for Updating Forecast

In order for the forecast to be useful not only today but for the future as well, a clear process must be put into place to ensure reliable updates. The keys to this process are to document and communicate what, when, who and how the process should happen. An example of this documentation is included below in Table 12.

Table 12: Example forecasting process update documentation

	Definition	Raytheon Example
What	Description of the expected results	Update SAS Logistics North Texas Regional Warehouse Forecast
When	Frequency and date 'anchor'	To be completed and distributed the last Friday of Raytheon fiscal calendar to the SAS Logistics Leadership Team
Who	Forecast owner	Bret Hanson, SAS Logistics senior engineer
How	Steps required to complete update	(simplified) 1. Obtain SAS BU forecast (source: Conexis) by running report of indenture level zero items in NTX region, 2. Paste report figures over existing figures in whse fcst tool SAS fcst tab, 3. Obtain NCS forecast from Adam Meissner, 4. Paste NCS forecast figures over existing figures in whse fcst tool NCS fcst tab.

Having a specific owner for this is absolutely critical. The absence of clear responsibility increases the chance that this procedure will fall through the cracks. It is also extremely important that this person know what to do and when. Often the initial owner is the person that originally created the forecast, in which case this person would be intimately familiar with the forecast and know how it should be updated. However, people eventually transition to new roles or leave the company for various reasons, often with limited notice. Therefore, the steps for updating the forecast and communicating results should still be well documented to ensure that if and when this person moves on that the knowledge is not lost. It is important for the customers of the process to be aware of these details as well, especially when updates will occur and how results will be communicated.

B. Customer Requirements

Once a process is in place to ensure that the forecast will be updated on a regular basis, attention can shift to adding functionality to turn the forecast into a dynamic decision-making tool. To do this we must understand what the customers of the tool would consider valuable. That is, what questions they would like to use this tool to answer.

In our case with Raytheon, the logistics organization was regularly attempting to answer questions regarding potential changes that might affect the future footprint requirements. Some of these questions were posed by the organization themselves as they worked to improve the logistics service. Other questions came from outside the organization – including executive inquiries and requests from other units. Some recurring questions include:

- Business unit D operates a small warehouse nearby with approximately 250 pallets of material. Can this be consolidated into the existing regional warehouse next quarter so we can free up space for manufacturing and lower operational costs?
- Can we handle 400 pallets of material from business unit E starting first quarter of next year for an indefinite period?
- Business unit F has a need to store an undisclosed material in huge wooden crates for 18 months beginning in the fourth quarter of this year. We can't tell you what it is, but it would require 4500 square feet of dedicated floor space during that time period.
- We have 30 trailers full of inventory and equipment stationed in the yard. We want to free up the trailers for transportation usage and house the material more securely. What will be the impact on moving this into an existing warehouse?
- Can we handle each of the previous requests? If not all of them, then which are feasible and when?
- The building currently utilized as storage area Q is needed for manufacturing expansion. What are the facility requirements if we move that inventory to a new facility? What if we also move the inventory from storage area R to the same new location?
- If we were forced to move from the current leased warehouse into a specific existing facility with different height and layout characteristics, what would be the impact on total space required?
- Looking out three to five years – is our current footprint optimal? Will we be capacity constrained and need to build or lease additional warehouse space? Will we have excess capacity?
- We want to make improvements that will reduce the overall footprint. Where should we focus we to get the most 'bang for our buck'?
- We understand that no forecast is perfect. What will be the impact to our forecast if certain inputs are different than expected?

C. Sensitivity Analysis Functionality

In terms of adapting the forecast into a tool that enables rapid answers to the questions cited above, we need to determine fundamentally how we are going to structure the logic. The decision is to create a tool with two fundamentally different sets of functionality. First, a sensitivity analysis portion was created based on logic that maintains independence between the various scenarios. This would allow users to compare multiple circumstances side-by-side on the same matrix and chart. Several things were done to enable this functionality. First, a template had to be set up that would serve as a palette for inputting the results of each of the different circumstances. Each circumstance or 'what-if' is represented by a separate row. Each row contains overall space requirements for a specific scenario and is independent from the other rows (Table 13).

Table 13: Template from forecasting tool for inputting what-if situation details

Sensitivity Results																				
Quarter	1Q10	2Q10	3Q10	4Q10	1Q11	2Q11	3Q11	4Q11	1Q12	2Q12	3Q12	4Q12	1Q13	2Q13	3Q13	4Q13	1Q14	2Q14	3Q14	4Q14
Baseline	104000	105000	100000	98000	96000	92000	90000	91000	90000	90000	90000	89000	86000	86000	85000	84000	82000	82000	80000	81000
Capacity	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000
What-If 1																				
What-If 2																				
What-If 3																				
What-If 4																				
What-If 5																				
What-If 6																				
What-If 8																				
What-If 8																				

This template structurally mirrors the timeline of the base forecast. It also includes the baseline forecast results so the various conditions can be compared not only with one another, but also with how they vary from current expectations.

In order to enable a more intuitive understanding of sensitivity analysis results, a chart template was created as well. This chart automatically updates when conditions are entered into the sensitivity analysis matrix. The chart provides a visual understanding of analysis results to complement the numerical output.

1. What-If Levers

In order to make conducting a sensitivity analysis as easy as possible for users, a control panel was created (Table 14). This control panel enabled the most common variables that Logistics analysts needed to adjust in order to answer questions posed to them. The panel was linked to the spreadsheet which calculates space requirements. Variables currently embedded in the control panel include Operations Space, Bulk Space, GFM Space, Property Space and Pallet Stack Height. These variables are all set at levels that represent current assumptions. Adjusting any of them will result in altered forecast output which is then compared with the baseline.

Table 14: Control panel from forecasting tool

What-If Levers	
Ops* Space	**Bulk Space**
100%	100%
GFM Space	**Property Space**
100%	100%
Pallet Stack Height	*Ops:QC/Kit/Rcvg/Sta g/MR/Docks/Pck-Shp
5	

Four of the five levers represent the biggest areas of warehouse space. Operations Space includes all floor-level operations in the warehouse, including quality control (QC), kitting, receiving, staging, material review, and pack/ship. Changing the Ops Space lever will adjust the overall square footage assumed for the combination of these areas. Since these are floor level operations, adjusting Pallet Stack Height does not change their footprint. Bulk, Property and GFM, however, are all stored in racks. Therefore adjusting any of these levers directly or adjusting stack height will change the footprint of these areas. For example, if we adjust the Bulk Space lever to 80 percent, it would represent the space required given that bulk area needs are 80 percent of current assumptions.

2. Using the Control Panel

Using a hypothetical example, consider a user that wants to know what would be the impact of moving from the current warehouse, which allows pallets to be stacked five high to one with a higher ceiling that allows pallets to be stacked six-high. The user would simply change the preset number in Pallet Stack Height section of the control panel from five to six. Space Required will automatically adjust in the tool. Only a portion of the warehouse square footage uses racks (namely bulk storage, GFM storage and approximately half of property storage), the tool is structured such that stack height adjusts only those areas. The user need only copy the new space required into the Sensitivity Analysis template. Numerical and graphical comparison of square footage required for the baseline versus the alternative is now available in the preset template section.

3. Sensitivity Analysis – Raytheon Example

In order to illustrate how a user might go about utilizing the sensitivity functionality aspect of the tool we will conduct an analysis based on a hypothetical set of conditions.

We begin with the tool set at current assumptions, which provides our baseline space requirements, which we copy and paste into the 'Baseline' portion of the template. We consider that the baseline is dependent upon the forecast of the different business units we're supporting. We know that these forecasts are unlikely to be perfect, so we want to know how much our square footage requirements will change if they increase or decrease. We think it is possible that the net BU forecasts could be over forecast by as much as 20 percent, so we want to model both of these conditions and compare to our baseline. Business unit forecasts are directly related to Bulk space requirements, so to quantify impact of this overage on square footage required we adjust the Bulk Space lever from 100 percent to 120 percent. Immediately the Total Warehouse Space line adjusts to represent the new square footage requirements. We copy the new data and paste it into the first line of the sensitivity analysis template. We also change the corresponding description from 'What-If 1' to 'Bulk increase (120% base)'.

Similarly, we believe it possible that BU volumes could be only 80% of forecast. To model this impact we change the 120 currently in the Bulk Space column to 80, paste the results in the next open row in the sensitivity template and change the description from 'What-If 2' to 'Bulk Decrease (80% base).

In order to model similar conditions for the GFM area we re-set the 'Bulk Space' lever to 100 and repeat the prior steps by adjusting the number in the GFM Space section.

Let us now assume that we have received questions about specifically what could be done to reduce to the amount of space that GFM requires. We look at the breakdown of GFM allocation by program and note that the LRAS program requires over 40% of total GFM space. We want to know what would be the impact to overall footprint requirements of eliminating GFM storage for this one program. The easiest way to quantify this impact would be to subtract the number of pallet positions (bins) occupied by the LRAS program in the GFM area (1020) from the total GFM pallet requirement on the sensitivity analysis sheet (2400). We can make this adjustment for any timeframe we wish, so for the purpose of this exercise we will use the entire forecast timeline.

Next let's assume that we're considering launching a lean initiative targeted at streamlining our floor operations. We have been told that this effort should reduce the space required for these operations to a minimum of 80% of current and could possibly achieve as much as a 50% reduction. In order to model these effects, we first change the Ops Space figure in the What-If Levers box from 100 to 80 percent. We pasted the results in the next open column and change the column description. Next we repeat for the 50% reduction and set the figure back to 100 to represent the original state.

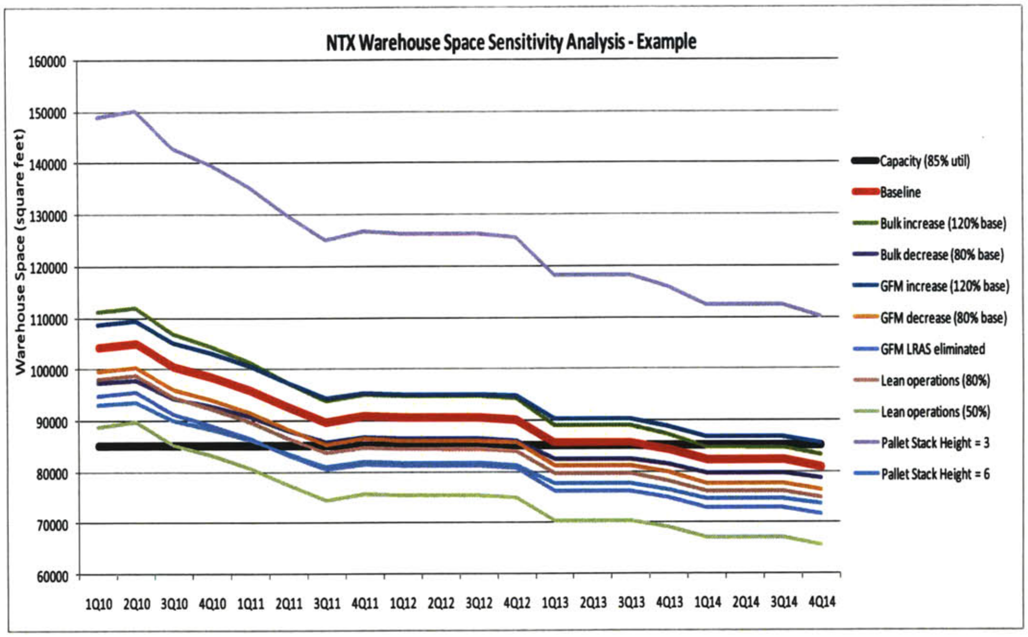
Finally, we want to know what would happen if we moved to a facility that is different structurally. First consideration would be an available warehouse down the road with higher ceilings that would allow us to build pallet racks six high. We change the Pallet Stack Height figure from five (the rack levels in our current facility) to six. We put the appropriate information in the template. Next we have received an executive request to consider utilizing an existing unused manufacturing facility for our warehouse to save money on the lease for the warehouse currently in use. However, the facility in question was not constructed as a warehouse and therefore does not have high bay ceilings. Considering the clearance allowed we determine that we would be able to build racks three high, so we adjust the Pallet Stack Height figure to three and record the output in the template.

We now have a sensitivity analysis that considers many different factors that we can weigh against each other. The output is in the form of a spreadsheet (Table 15) with resulting square footage for each consideration by quarter for the next five years. We also have a chart (Table 16) illustrating the results of each.

Table 15: Spreadsheet view of results from sensitivity analysis

Sensitivity Results																				
Quarter	1Q10	2Q10	3Q10	4Q10	1Q11	2Q11	3Q11	4Q11	1Q12	2Q12	3Q12	4Q12	1Q13	2Q13	3Q13	4Q13	1Q14	2Q14	3Q14	4Q14
Baseline	104117	104890	100563	98486	95945	92685	89745	90879	90576	90560	90576	90160	85678	85662	85662	84351	82250	82250	82250	80932
Bulk increase (120% base)	111029	111956	106764	104271	101222	97310	93782	95143	94779	94760	94779	94280	88901	88882	88882	87310	84788	84788	84788	83206
Bulk decrease (80% base)	97206	97824	94362	92701	90668	88060	85708	86615	86372	86360	86372	86040	82454	82441	82441	81393	79712	79712	79712	78657
GFM increase (120% base)	108629	109402	105075	102998	100457	97197	94257	95391	95088	95072	95088	94672	90190	90174	90174	88863	86762	86762	86762	85444
GFM decrease (80% base)	99605	100378	96051	93974	91433	88173	85233	86367	86064	86048	86064	85648	81166	81150	81150	79839	77738	77738	77738	76420
GFM LRAS eliminated	94717	95490	91163	89086	86545	83285	80345	81479	81176	81160	81176	80760	76278	76262	76262	74951	72850	72850	72850	71532
Lean operations (80%)	98017	98790	94463	92386	89845	86585	83645	84779	84476	84460	84476	84060	79578	79562	79562	78251	76150	76150	76150	74832
Lean operations (50%)	88867	89640	85313	83236	80695	77435	74495	75629	75326	75310	75326	74910	70428	70412	70412	69101	67000	67000	67000	65682
Pallet Stack Height = 3	148862	150150	142938	139476	135241	129808	124908	126799	126293	126266	126293	125600	118130	118103	118103	115919	112417	112417	112417	110219
Pallet Stack Height = 6	92931	93575	89969	88238	86121	83404	80954	81899	81646	81633	81646	81300	77565	77551	77551	76459	74708	74708	74708	73610

Table 16: Graphical view of results from sensitivity analysis



We can now easily see how each of these different circumstances differs from the baseline as well as how they compare with existing space available (capacity). We also see how they compare with one another and by how much. For example, we see that overall space required is relatively insensitive to changes in bulk inventory (i.e. business unit forecasts). We are slightly more sensitive to changes in GFM material volume and eliminating the largest program's usage of GFM storage would be a very significant reduction in space required. Clearly overall space is very sensitive to pallet stack height and changes to floor level operations. We can definitively tell senior management that moving warehouse operations to the unused manufacturing building would result in a massive impact to the amount of square footage required.

One way this aspect of the tool can be useful is to determine where to focus resources for improvement activities.

D. Scenario Analysis Functionality

The second basic aspect of functionality enabled in this tool is a scenario analysis portion, which is based on "AND" logic. This section allows users to create complex scenarios that include a combination of changes that might occur at different times but would have a cumulative impact.

To set this up, again a template is created for the user to input the details of the scenario. Also again, each row will represent a different change considered within the scenario. Unlike the scenario analysis, however, these changes will be dependent upon one another. Therefore, the first adjustment will modify the baseline. The second adjustment will further modify the modified baseline (as opposed to scenario analysis, where the second what-if would again modify the original baseline).

We must consider the customers of this tool in order to configure it in a useful manner. The logistics organization considers changes that are communicated to them in multiple ways. Firstly, changes might be communicated in terms of pallets required. Thus, a section is included which allows adjustments to be entered in terms of an increase or decrease in pallets. Secondly, potential changes might be communicated in terms of square footage required. For this reason another section is included which allows adjustments to be entered in terms of an increase or decrease in square footage. Lastly, changes might be couched in terms of modifications to the initial assumptions; therefore the What-If Levers applied in the sensitivity analysis are made available here too. The key to keep in mind is that all modifications, regardless of manner of input, build upon one another to yield a single, comprehensive result.

Let's consider the following set of requests fielded recently by the SAS logistics organization. The organization has a new warehouse in Carrolton, Texas that currently has excess capacity. They intend to utilize the facility as a regional warehouse, whereby as much of the storage requirements from the various satellite facilities in the area are consolidated into this single facility. The ideal scenario result would be one in which all of these options could be accommodated, however management believes that exceeding 85 percent space utilization would result in operational difficulties. Requests:

- 250 pallets of bulk inventory for the Forest manufacturing facility in Q2 of 2010.
- 8,000 square foot vibration testing operation in Q2 of 2010.
- 450 pallets of customer dispatch inventory for the Carson facility in Q3 of 2010.
- 100 pallets of bulk inventory from the Largo facility in Q3 of 2010.
- 400 pallets of bulk inventory from the Lemmon Ave facility in Q4 of 2010.
- 12,000 square feet of equipment in large wooden crates for unidentified purpose in Q4 of 2010 that will be depleted to zero at a rate of 2000 square feet per quarter.
- 250 pallets of bulk inventory for the IIS business in Q1 of 2011.
- 100 pallets of material for the Elcan facility in Q2 of 2011.

Entering each of these conditions into the template discussed above yields both a quantitative and graphical summary of the impact (Tables 17 and 18 respectively).

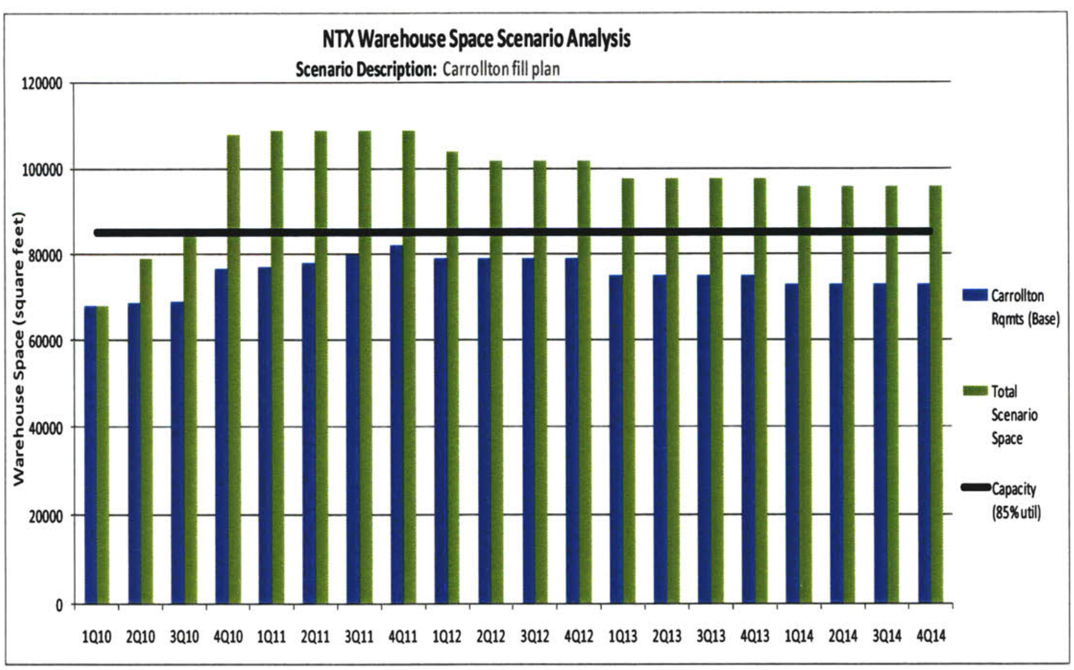
Table 17: Spreadsheet view of results from scenario analysis

NTX Warehouse Space Forecast Scenario Analysis

Quarter	1Q10	2Q10	3Q10	4Q10	1Q11	2Q11	3Q11	4Q11	1Q12	2Q12	3Q12	4Q12	1Q13	2Q13	3Q13	4Q13	1Q14	2Q14	3Q14	4Q14
Carrollton Rqmts (Base)	68000	68500	69000	76500	77000	78000	80000	82000	79000	79000	79000	79000	75000	75000	75000	75000	73000	73000	73000	73000
Capacity (85% util)	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000
SCENARIO																				
Pallet Adjustments																				
Forest Bulk		250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Carson Cust Disp			450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450
Lemmon Bulk				400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
Largo Bulk			100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
IIS Bulk					250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Elcan						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Net Pallet Input Incr/Decr	0	250	800	1200	1450	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550
Square Ft Adjustments																				
Vibration testing operation		8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000
Classified eqpt - wooden crates				12000	10000	8000	6000	4000	2000											
Adjustment 3																				
Adjustment 4																				
Adjustment 5																				
Adjustment 6																				
Net Sq Ft Input Incr/Decr	0	8000	8000	20000	18000	16000	14000	12000	10000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000
Scenario Space Change	0	10350	15520	31280	31630	30570	28570	26570	24570	22570	22570	22570	22570	22570	22570	22570	22570	22570	22570	22570
Total Scenario Space	68000	78850	84520	107780	108630	108570	108570	108570	103570	101570	101570	101570	97570	97570	97570	97570	95570	95570	95570	95570

The matrix and chart clearly demonstrate that we would far exceed capacity at 85 percent utilization if we were to accept each of these options.

Table 18: Graphical view of results from scenario analysis

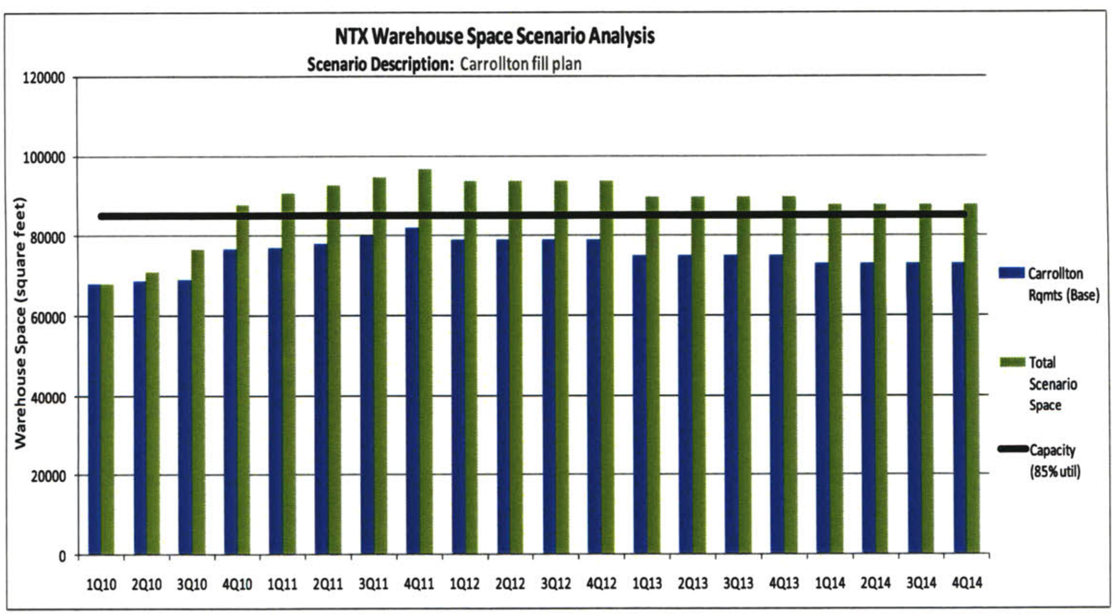


This leads us to another question – what can we do? If we go back to our model we can begin adjusting the different options to attempt to find a feasible solution. We determine that we will not accept the opportunity to store the wooden crates of classified material. Since the crates are too big to fit in our racks, it is probably more effective to store it in a facility that does not have high bays. We remove that square footage from our model, which still leaves us constrained. From both Table 17 and 18 we see that we exceed capacity beginning in Q4 2010 by over 10,000 square feet. We might determine that, similar to the crates of equipment, that the vibration testing operation is better suited for location within a normal manufacturing facility. In fact, we might suggest to the space allocation group that they consider putting both of these items in the empty manufacturing space that they asked us to consider moving our warehouse operations into (recall Pallet Stack Height of three what-if from the sensitivity analysis above). Removing both of these items from our model (Table 19) puts us much closer to capacity (Table 20). However, we still exceed capacity long term beginning in Q4 of 2010.

Table 19: Portion of template for scenario analysis showing elimination of excess storage options

Square Ft Adjustments																			
Vibration testing operation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Classified eqpt - wooden crates			0	0	0	0	0	0											

Table 20: Graphical view of adjusted results from scenario analysis



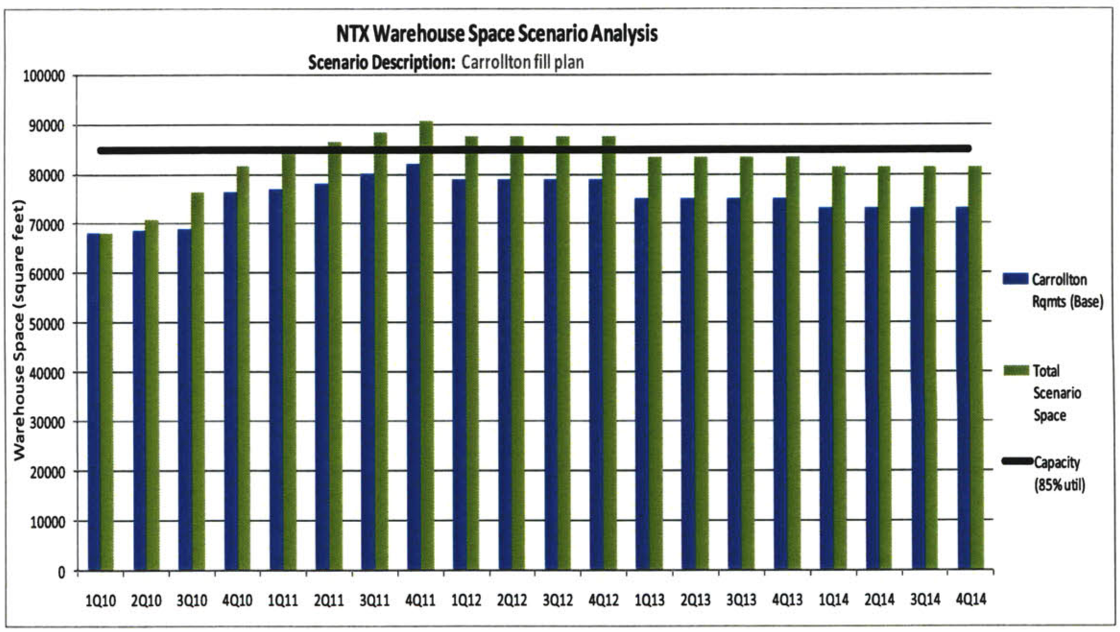
We're really motivated to consolidate as much of the potential inventory as possible into this facility. Every one of these options that we can accommodate has significant benefits because they each allow us to close down an existing smaller facility. Some of these are leased, so rent payments would be eliminated. Others are owned and can be turned over to manufacturing expansion and thus avoid building or leasing additional facilities.

Recall from the sensitivity analysis that our floor-level operations were sensitive to change. It is proposed that we create a team to begin studying these operations for opportunities to streamline activities and improve layout, thereby reducing floor space needed. In fact, recall that our conservative estimate would allow us to reduce operations space to 80 percent of current, resulting in a 6,100 elimination of square footage required. If we put a team in place now, they should easily be able to implement improvement by Q4 of this year. We therefore place a negative 6,100 in the Square Foot Adjustments row beginning Q4 of 2010 and label this "Lean Operations (80% base)", as shown in Table 21.

Table 21: Portion of template for scenario analysis showing adjustment for lean operations

Lean Operations (80% base)	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100

Table 22: Graphical view of further adjusted results from scenario analysis

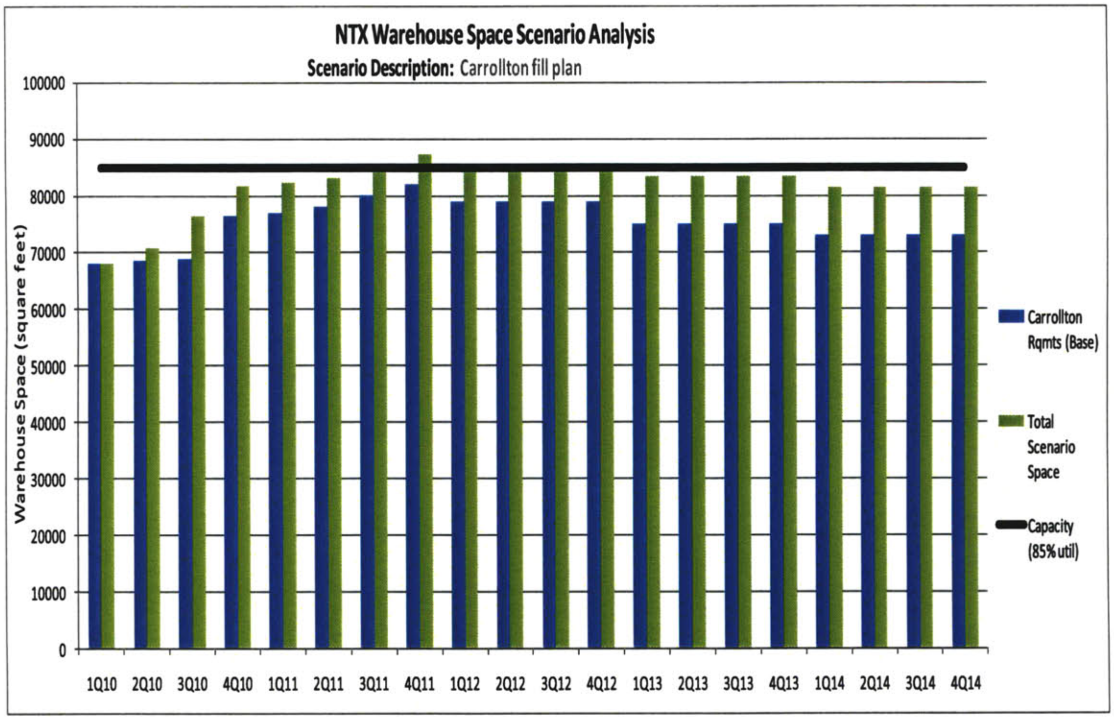


This change puts us even closer to meeting capacity available (Table 22). It also pushes the timing of our estimated constraint out by six months and alleviates the constraint long term with all remaining desired additions in place. We can now have a very fruitful conversation about what to do. Several options arise. One is to proceed with consolidation and deal with the temporarily higher capacity utilization that we consider ideal. If we want to be more conservative we might delay the last two consolidation options (IIS and Elcan) until 2013 (Table 23), which would result in a constraint only during Q4 of 2011 and only by a small margin (2180 square feet), as illustrated by Table 24.

Table 23: Portion of template for scenario analysis showing timing adjustment (postponement of IIS and Elcan)

Quarter	1Q10	2Q10	3Q10	4Q10	1Q11	2Q11	3Q11	4Q11	1Q12	2Q12	3Q12	4Q12	1Q13	2Q13	3Q13	4Q13	1Q14	2Q14	3Q14	4Q14
IIS Bulk					0	0	0	0	0	0	0	0	250	250	250	250	250	250	250	250
Elcan						0	0	0	0	0	0	0	100	100	100	100	100	100	100	100

Table 24: Graphical view of further adjusted results from scenario analysis (postponement of IIS and Elcan)



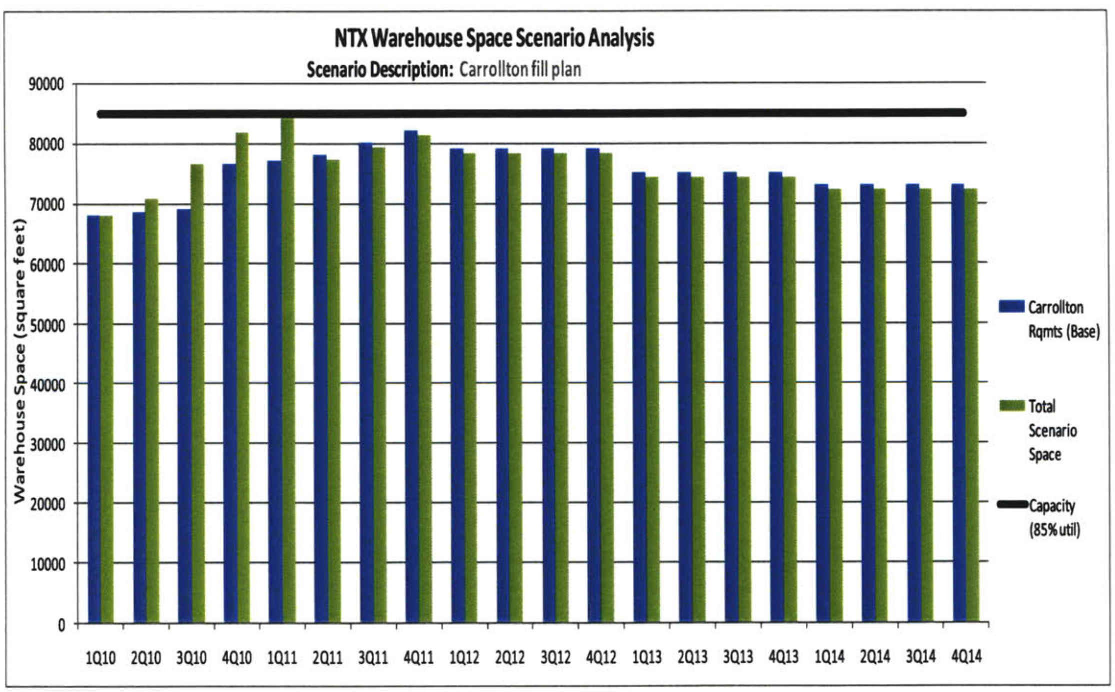
Another option to be considered is a more aggressive approach and assumptions regarding the lean operations. Assuming a 50 percent reduction in space required for floor-level operations would reduce space by another 9,150 square feet (Table 25). This allows us to consolidate all of the palletized options into the warehouse while still maintaining a safe capacity utilization margin (Table 26).

Table 25: Final spreadsheet view of scenario analysis after adjustments to mitigate capacity constraint

NTX Warehouse Space Forecast Scenario Analysis

Quarter	1Q10	2Q10	3Q10	4Q10	1Q11	2Q11	3Q11	4Q11	1Q12	2Q12	3Q12	4Q12	1Q13	2Q13	3Q13	4Q13	1Q14	2Q14	3Q14	4Q14
Carrollton Rqmts (Base)	68000	68500	69000	76500	77000	78000	80000	82000	79000	79000	79000	79000	75000	75000	75000	75000	73000	73000	73000	73000
Capacity (85% util)	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000
SCENARIO																				
Pallet Adjustments																				
Forest Bulk		250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Carson Cust Disp			450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450
Lemmon Bulk				400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
Largo Bulk			100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
IIS Bulk					250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Elcan						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Net Pallet Input Incr/Decr	0	250	800	1200	1450	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550
Square Ft Adjustments																				
Vibration testing operation		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Classified eqpt - wooden crates				0	0	0	0	0	0											
Lean Operations (80% base)				-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100	-6100
Lean Operations (50% base)						-9150	-9150	-9150	-9150	-9150	-9150	-9150	-9150	-9150	-9150	-9150	-9150	-9150	-9150	-9150
Adjustment 5																				
Adjustment 6																				
Net Sq Ft Input Incr/Decr	0	0	0	-6100	-6100	-15250	-15250	-15250	-15250	-15250	-15250	-15250	-15250	-15250	-15250	-15250	-15250	-15250	-15250	-15250
Scenario Space Change	0	2350	7520	5180	7530	-680	-680	-680	-680	-680	-680	-680	-680	-680	-680	-680	-680	-680	-680	-680
Total Scenario Space	68000	70850	76520	81680	84530	77320	79320	81320	78320	78320	78320	78320	74320	74320	74320	74320	72320	72320	72320	72320

Table 26: Final graphical view of scenario analysis after adjustments to mitigate capacity constraint



The key point is that this tool now allows the logistics organization to make informed decisions about their warehousing footprint and the tradeoffs to be made. It will also help them to have more informed discussions with other organizations about whether and when they can provide them with logistics services. Finally, it will allow better communication and more solid justification of decisions with executives that are concerned with minimizing the overall footprint.

E. Comparison of Complex Scenarios

Finally, these two aspects of tool functionality can be used together to compare the impact of multiple complex scenarios with one another as well as the initial baseline. This can be accomplished by modeling a complex scenario with multiple variables in the scenario analysis section using the 'and' logic. Once this has been accomplished and the resulting forecast determined, the results can be fed into the sensitivity analysis as a single entry. The user can then return to the scenario analysis section and model yet another complex scenario and feed it into the sensitivity analysis section. This can be repeated until a dozen complex scenarios are set up in the sensitivity analysis section. In this way, users can compare multiple complex scenarios on the same chart and matrix with relative ease and quickly understand how they contrast.

VI. Reducing Warehouse Footprint Requirements

In this chapter we will address approaches to be applied in order to reduce the overall square footage necessary to manage and store inventory required for supporting operations. Again, Raytheon's SAS Logistics North Texas region activity will be used as a basis for discussion. We consider several aspects of what this group has done well that can be adopted by other companies. Since no company is perfect we also consider opportunities that Raytheon has for further improvement.

A. Structural Design

It is very beneficial to ensure that materials are stored in a facility that is specifically designed for warehousing purposes.

- Vertical Storage: As discussed in *Warehouse & Distribution Science* (Bartholdi III and Hackman), "Pallets that can be stacked high allow many pallet positions per square foot of floor space. Conversely, pallets that are unusually heavy or fragile or that have uneven top surfaces cannot be stacked very high and so render unusable all the space above. This waste may be avoided by installing pallet rack, so that pallets may be stored independently of each other." Using a structure with high bays enables the installation of these vertical racks, which enables achievement of a high storage density. In the case of the facility in question this allows pallets to be stacked five high. Recall our sensitivity analysis that demonstrated square footage to be extremely sensitive to stack height. This impact is extreme when considering material currently stored non-vertically, such as that in hallways and under stairwells.

Figure 3: Picture of vertical pallet racks (Moran)

- Layout: Using a facility that was originally designed as a warehouse can enable more efficient operations due to an open layout enabling customization to current needs and dock doors on both sides of facility which improve flow.
- Safety: Moving out of non-warehouse storage has significant safety implications. In a normal warehouse the personnel are trained to handle inventory in a safe manner. This includes the use of hard-toed shoes as well as floor markings that distinguish between areas intended for walking versus material transport versus material storage. The normal office worker is not accustomed to nor trained to operate safely.
- Inventory Control: The inventory tracking system in a warehouse is a carefully designed set of processes and procedures that allow employees to know what parts are where. Entry to

and exit from the area are also controlled to ensure that people are not walking off with material without following the proper processes. Clearly this all breaks down when inventory is stored in locations other than originally intended.

B. Warehouse Consolidation

One of the biggest moves that SAS Logistics has made recently is to transition from a dispersed warehouse footprint to a more centralized regional footprint. Historically a central warehouse for the North Texas region did exist; however, capacity was extremely limited. Thus, various satellite facilities were sprinkled throughout the region, each supporting specific parts of the business. This scattered footprint likely is the result of the many acquisitions that went into making Raytheon what it is today.

When the organization recently decided to open a new facility to accommodate burgeoning demand for storage, they decided not only to address the immediate need, but to obtain a facility with enough capacity to consolidate some of the satellite storage into the "regional" warehouse. This move resulted in several key advantages, but also some disadvantages.

Advantages

- Variability Dampening: Better stability due to consolidation of inventory from various facilities into a single location. In the case of various product lines with weakly correlated or negatively correlated demand, the benefit of minimizing variability can be enormous. When the demand for a specific product line increases, it will clearly require more warehouse space. Meanwhile another product line might be facing decreased demand during the same period, resulting in less need for storage space. If these inventories are stored separately then the result is one underutilized and one over-utilized warehouse. However, if the inventory is consolidated into a single warehouse then the capacity requirements offset and demand is met with much less overall space assuming that inventory is allocated to location on an availability basis and not "hard" allocated or reserved. However, beware of product lines whose demand is highly positively correlated. If this is the case, then demand profiles will move in the same direction – both will be high at the same time and vice versa. The combination of common parts shared by multiple product families into a single location can further improve this advantage, but there are very few common parts across the businesses serve by SAS Logistics.

- Process Consistency: When operations are in a single location it is much easier to apply processes and procedures consistently. It is simply more coherent when all of the people are under one roof with materials entering and leaving via single sets of doors. In the article *Designing Distribution for Profit* (Moran), warehouse manager Patrick O'Keefe is quoted describing the benefits of consolidating of six warehouses into a single regional facility "The operation consolidated all the inventory information onto one warehouse management system. Orders were getting filled on time, more completely, more accurately and with fewer exceptions. As a result, customer service was greatly improved."

Disadvantages

- Decreased Service Level: If a warehouse is located near a specific manufacturing center being supported, then lead time should be minimal due to the short distance travelled. Material will likely travel further in a consolidated scenario, thereby increasing lead time. Another factor on service level is priority: in the dedicated setting priorities of what material to handle first should be clear – they are set by the business being supported. However, when supporting multiple businesses the prioritization will be less obvious. Each business will consider their priorities most important, but somehow the shared service organization must further prioritize the priorities of the businesses. This may mean that urgently needed material for business 'A' will wait in line while business 'B's urgent need is processed. Another factor to consider is level of complexity. As consolidation is achieved, a specific facility obviously handles a higher volume of inventory and different characteristics. This creates a higher level of complexity, making flawless execution more difficult. It is difficult to determine how big is too big, but certainly a threshold exists where issues from added complexity will outweigh benefits of consolidation.

- Increased transportation costs. If, for example, a warehouse exists for each manufacturing facility, then the location, size and function of each dedicated warehouse can be optimized for the needs of each business unit. However, in the case of a consolidated warehouse supporting multiple business units, the location, size and function of the warehouse will be determined upon the combined business being supported. One obvious result of this is that warehouses supporting specific business units will likely be closer to point of use (suppliers, manufacturing, customers).

- Out of User's Sight: As mentioned, consolidation by definition is likely to be further from customers. One of the complaints the logistics organization received from their internal customers when relocating to an offsite consolidated warehouse was that they would no longer be able to come down and see their inventory easily. The customers were accustomed to their material being within walking distance and felt secure knowing they could go see and touch it at any time. Interestingly, this change may ultimately prove to be a benefit. By removing the material from customers they are forced to pay more attention to the processes for requesting material, whereas before there was a tendency to ignore this because the thought was, "the material is right here, so I don't really need to plan for when I need it." Also, having non-warehouse personnel down on the facility floor can tend to impede operations via extra congestion. There is also the tendency to think, "I really need this part right now, but if I follow the procedures I won't get it for a few hours. It won't hurt anything if I just take one without saying anything." Eliminating this risk could be good for inventory accuracy.

C. Consolidating Locations Within a Warehouse

Storage density can be increased by storing like parts in the same location. As we can see from Table 27, thousands of part numbers are scattered amongst multiple locations within a single facility. In fact, a total of 573 different part numbers are stored in 10 or more different locations. This often happens because when parts are received, the procedure is to look for any available space, place the parts in it and move on. The likelihood that this space will be one shared by the same part number is slim.

Table 27: Part numbers stored in multiple locations

# Locs	2	3	4	5	6	7	8	9	10	11	12	13-20	21-50	51-387
# PNs	5902	2445	1262	634	418	245	185	156	93	90	69	226	83	12

It is difficult to determine how much of an impact this will have for several reasons. One is that multiple part numbers are often stored together in a single bin, therefore some of these locations will already be full for that reason. Another is that some of these parts are large and therefore few fit in a single location, therefore requiring them to be spread out.

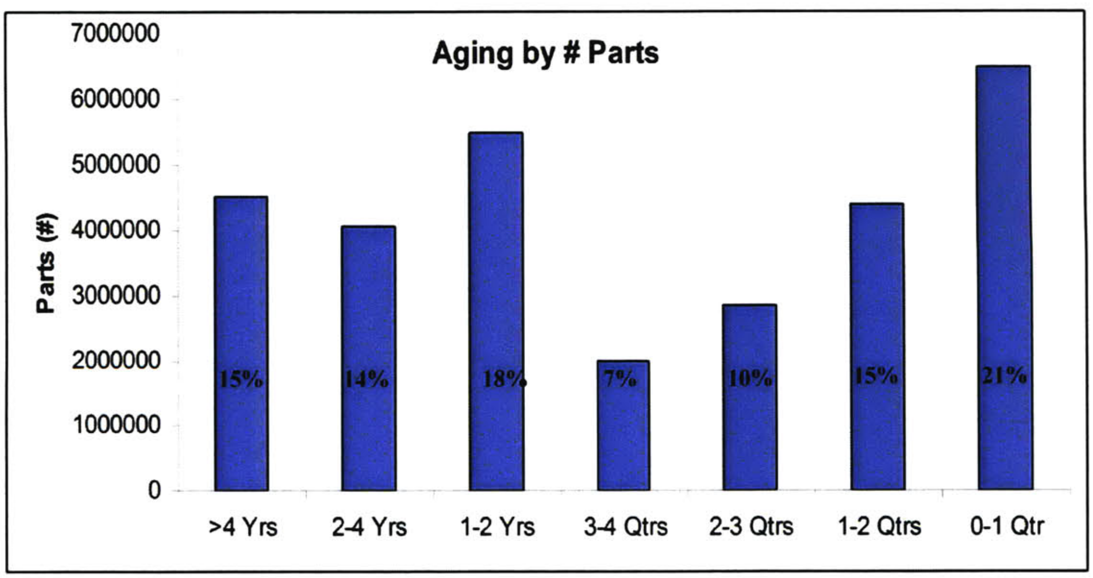
D. Inventory Aging

If not carefully managed, inventory levels can build over time due to an increase of excess and obsolete material. This happens because the primary objectives for most warehouses are to effectively and efficiently receive and store material, and then deliver it when requested. It is often not anyone's responsibility to figure out what to do with material that is never requested.

This is further complicated, as is often the case, when decisions about what to order, and therefore what and how much to store, are made by people not running the warehouse. This is the case for SAS Logistics. In most cases they do not have authority to get rid of excess material. This authority lies with managers who are not measured on warehouse footprint or effectiveness.

That said, what the logistic organization can do is to show compelling data to those with the proper authority. By just looking at the aging profile of bulk material (Table 28) we have a compelling case. We see that nearly half of the material stored has been there for over a year. Of the total a full 15% is greater than four years old. When digging deeper into the available data we see that some of these parts date back to the early 1980's. Considering that these are technical products with extremely high quality requirements, it seems that there are significant opportunities to reduce the inventory of these older parts.

Table 28: Aging profile of bulk material in SAS Logistics NTX region



Minimizing aging inventory not only reduces space required, it can also impact productivity. In the article *5 Ways to Find Hidden Warehouse Space*, Larry Shemesh points out that "Every time your warehouse employees move past these slow and no-move SKUs, that unnecessary travel time results in increased labor costs."

Unfortunately, data is not available for GFM without looking at the paperwork attached to each piece. I suspect the aging profile for items in these categories is even more skewed if for no other reason than the lack of data makes the problem difficult to see.

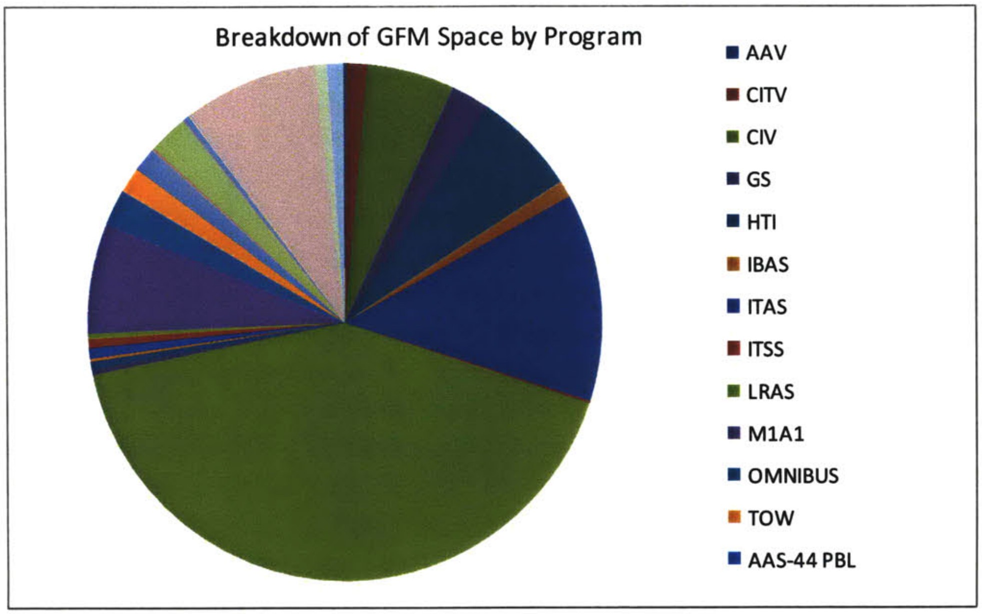
E. GFM Storage Elimination

As discussed previously, GFM represents material, much of which is finished goods, stored by Raytheon for the customer. In all cases which we are aware this service is not charged to the customer. The space required to store this material is roughly 22,000 square feet, over 20% of the total. This presents an opportunity to either lower cost, increase revenue or both. Raytheon could either discontinue offering this storage completely, or consider charging for the service.

Not only does this have an impact on the warehouse space required, but the nature of the product is cause for concern as well. Many of these items are completed high-value defense systems that are critical to national protection. The security required to ensure these systems are stored securely is much higher than that required to store raw materials and parts.

However, changing this practice is not a decision that can be made lightly. We must fully understand why Raytheon is providing this service. Is it required contractually? How much does it weigh into the customer's decision about whether to award projects to the company? If we look at the big picture, we might find that the cost required for this storage is well worth the benefits derived.

Table 29



As mentioned in the sensitivity analysis section, a full 40 percent of GFM space is consumed by the LRAS program (Table 29). For this reason it might be worth digging into this program to understand the details behind this practice. If results are favorable, then investigating the other programs listed likely would be a worthwhile effort.

F. Aligning Incentives with Desired Results

Ultimately, the incentives for those making the decisions that influence the factors driving space requirements are largely responsible for the ultimate amount of space required. If those incentives drive behavior that is not in line with reducing building space required, then achieving these improvements will be extremely difficult.

For instance, in the Raytheon case, many incentives encourage behaviors that end up requiring much more space than is really necessary.

1. Customer Contracts

Many of the contracts that Raytheon's customers enforce are 'milestone contracts'. This type of contract stipulates that the customer will pay Raytheon when certain milestones are achieved. While this is not inherently bad, the nature of the milestones included can be. Consider the common material procurements milestone. In this case Raytheon will receive a milestone payment when they have purchased all of the material required to manufacture the products. These contracts are often multiyear, for example (hypothetically) requiring the delivery of 10 XYZ systems per quarter for the next 12 quarters with a $1 million milestone payment once all materials have been purchased. Now consider the individual responsible for procuring these materials. What is he/she likely to do? The correct answer to minimize warehouse space requirements would be to order the materials when they will be needed over the course of the contract. From an overall business perspective, however, that would mean delaying the $1 million payment for almost three years. Any logical businessperson would consider the time value of money and clearly prefer to earn the $1 million now. In that case we would immediately procure all of the material for the contract today and store it until it is needed.

2. Definition of Metrics

It is important not only to have the proper metrics, but also to ensure that they are defined properly. Like many companies, Raytheon is attempting to control costs by reducing their operational footprint. One of the key internal metrics for the business is square footage and targets have been set to decrease this metric. The way the square footage is measured, however, can encourage unintended behavior. For example, warehouse space is included in the total, as it should be, but trailers are not. SAS Logistics has historically stored a significant portion of inventory and equipment in trailers that are placed out in the yard on company property. SAS Logistics Director Mike Hall considers this to be poor business practice and thus has mandated that all of these trailers be emptied and the contents stored in a different manner, such as within a warehouse.

Mr. Hall's perspective is sound. There are several reasons why storage in trailers can be considered poor practice, including:

- Increased Risk of Theft: It is much easier to steal the contents of a trailer that is set out in a large parking lot away from buildings than it is to get something out of a warehouse with tight security and plenty of people around.
- Increased Risk of Damage: Items stored in a properly constructed building are simply better protected from environmental effects, such as water, wind, heat and cold.
- Inefficient loading and unloading: If you want something in the back, the entire trailer must be unloaded to get it out, and then re-loaded.
- Out of Sight Out of Mind: Material in a trailer out in the yard easily becomes "out-of sight" and therefore out-of-mind, so it is easily forgotten about.

VII. Conclusion

A. Key Takeaways

Determining an optimal operational facility footprint consists of making long lead time decisions, such as expanding, contracting, adding or eliminating buildings. Being wrong about the necessary footprint can be extremely costly to the business. Valuable insight can be gained by understanding what impacts the footprint required, quantifying these factors and estimating how they might change over time. The result is a forecast that provides information about the future that was not available beforehand, greatly improving confidence in the decisions required. This forecast can then be adapted to enable the quantification of different situations as variables change in a dynamic environment. Constructed properly we can provide leadership with an understanding of the effects of these changing variables.

B. Future Steps and Areas of Focus

Raytheon has made significant progress in understanding the facility footprint required to effectively provide warehousing services now and in the future. However, there are plenty of areas where continuous improvement efforts would reap a favorable return on investment. Some ideas for where to go from here are discussed below.

1. Extending to Other Regions

The warehouse space forecast created for the North Texas region could be extrapolated to other regions quite easily. The first step should be to extend to those regions that are heavily manufacturing driven like the North Texas region. In these cases the basic assumptions about what drives the space requirements should be very similar. However, in regions with a different focus, such as the South California region, which is very research and development heavy, the drivers for square footage requirements should be revisited.

2. Improving the Existing Tool

We hope that the tool delivered provides a relatively accurate picture of the warehouse footprint requirements over the next five years. However, forecasts inevitably have errors. Errors could result from inaccurate inputs, invalid assumptions or simply unforeseen conditions. For this reason, the tool provided should be considered a first pass that will be improved upon. A key to enabling and encouraging improvement is to measure forecast accuracy. The tool has been set up with the ability to calculate forecast accuracy. In order for this to happen it will require tracking actual levels of production and space requirements. Once forecast accuracy is calculated, one should dig into the causes of the inaccuracy and determine what can be done differently to ensure they are reduced or eliminated. The result should be an improved ability to predict future requirements.

3. Corporate-Wide Production Forecasting

I believe that enormous benefits would be gained from implementing a forecasting process for Raytheon that is the same across all businesses. One advantage would be to ensure that all areas are leveraging industry practices for forecasting instead of leaving it up to each group to figure it out. Another would be simply to have consistency in terms of process, timing, input and output. This would be particularly helpful to shared services organizations like SAS Logistics that must operate across multiple businesses. It would also decrease the learning curve for employees whose changing roles take them to different parts of the organization. Given the strong organizational silos within the company this effort would have to be supported at a very high level in order to be successful.

4. Lean Warehouse Operations

Raytheon has a strong continuous improvement program with many people that are talented at analyzing and streamlining business processes. Focusing some of these resources on mapping all of the warehouse operations processes would be insightful. It is extremely likely that this would result in the identification of wasteful steps and activities that could be eliminated or modified. This could have the benefit of reducing space and cost while improving cycle time and quality.

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IX. Appendix

A. Raytheon Vision, Values and Goals (Raytheon Company)

Vision: To be the most admired defense and aerospace systems supplier through world-class people and technology

Strategy:

- Focus on key strategic pursuits, Technology and Mission Assurance to protect and grow our position in four core defense markets (Sensing, Effects, C3I and Mission Support)
- Leverage our domain knowledge in these core defense markets, as well as in Mission Systems Integration, Homeland Security, and Information Assurance/Information Operations.
- Expand international business by broadening focus and expanding adjacent markets.
- Continue to be a Customer Focused company based on performance, relationships and solutions.

Goals:

Growth: Grow revenue faster than the market. Build on good performance in improving cash flow. Execute well and with predictability.

People: Retain and attract world-class talent while providing superior opportunities for employee development. Treat all employees with respect. Leverage our diversity efforts as a competitive advantage, continuing Raytheon's leadership in diversity.

Productivity: Improve ROIC for Raytheon Company. Take Raytheon Six SigmaTM to the next level, further engaging customers and partners. Deliver great value and predictability through the Integrated Product Development System, Earned Value Management System and Capability Maturity Model Integration.

Values:

People:

- Treat people with respect and dignity.
- Welcome diversity and diverse opinions.
- Help our fellow employees improve their skills.
- Recognize and reward accomplishment.
- Foster teamwork, innovation, collaboration and embrace change.

Integrity

- Be honest, forthright and trustworthy.
- Use straight talk; no hidden agendas.
- Respect ethics, law and regulation.

Commitment

- Honor commitments to customers, shareholders, the community and each other.
- Accept personal responsibility to meet commitments; be accountable.

Excellence

- Improve performance continually.
- Stress quality, productivity, growth, best practices and measurement.
- Always strive to be the best.