Algorithmic approach to warehouse consolidation and optimization

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Master of Science in Engineering

By

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ABSTRACT

Algorithmic approach to warehouse consolidation and optimization

Sonny Henry Nguyen

This thesis presents a new methodology for warehouse consolidation to optimize the capacity, throughput, and overall efficiency of the warehouse. The application of the methodology allows an organization to become more competitive by reducing real estate and inventory holding costs. The algorithms use various quantitative techniques including statistical inference and integer programming, and apply them to material handling and facilities layout issues. The proposed methodology is independent of the warehouse management system in use. It was implemented by a Fortune 500 company, and resulted in significant cost, capacity and productivity improvements.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

This report describes an algorithm for Optimization Practitioners to consolidate warehouses and improve operation efficiency. Consolidation of several warehouses can occur for a variety of reasons. Through a series of mergers and acquisition a company may be left with several warehouses from different legacy companies. Business leaders may want to consolidate warehouses to reduce redundant labor cost, real estate, and enable better control of requirements and standards. Consolidation of warehouses also provides an opportunity to standardize the processes and optimize operations. In an environment where real estate is becoming increasingly more expensive, optimizing the usage of real estate is necessary for companies to remain competitive. This thesis proposes an algorithm that focuses on the consolidation of warehouses and utilizing the methods to optimize the warehouse production to gain a competitive advantage.

The first step in consolidation is to ask if the business leaders of the company want to consolidate to reduce cost and increase efficiency. Work cannot go further without key management support for such activity because it requires a commitment of expenditures in order to execute. However, the algorithm builds a business case to execute with minimal expenditures while optimizing capacity and production. Once the decision to consolidate is made the next question is to ask if consolidation can occur with the current storage method. Utilizing quantitative analysis to explore alternatives will lead to decisions regarding optimum storage methods. Specifically, carousels will be examined as they can increase capacity and productivity. To fully analyze storage requirements a system to randomly infer the part dimensions needs to be developed. A statistical system such as Microsoft Excel or Minitab is used to fit the population of products. After defining the different part dimensions, the number of carousels needed can be extrapolated. After deciding on carousels, the optimum size, shape, and capacity of carousels is determined using Microsoft Excel or any optimization program such as Lindo. Lastly the new configuration is used to develop a process that will improve the production rate of the system.

The algorithm can be presented to business leaders as a proposal to 1) increase real estate utilization, 2) reduce operating cost, and 3) improve production activity by consolidating. This thesis will present the algorithm and how it is used in a Fortune 500 company's decision to consolidate warehouses to stay competitive because of mergers and acquisitions. This algorithm can be used in any business sector that require the storage of products.

CHAPTER 2

OBJECTIVE

The objective of this project is to propose an algorithm to consolidate warehouses that optimize storage capacity, reduce operating costs, and improve production activity. This new approach is relevant to any companies that store products for production usage. This thesis validates the algorithm by applying to an aerospace and defense company.

The following are the objectives of this Master's thesis:

1) Develop an algorithm - Algorithmic approach to warehouse consolidation and optimization - which:
    1. Provides a business proposal for consolidation
    2. Employs statistical analysis and optimization tools to execute the vision of consolidation while providing optimal storage capacity and production with minimal cost
    3. Increases the awareness of quantitative analysis to make decisions
2) Test the algorithm
3) Report Results
4) Recommend additional research

CHAPTER 3

LITERATURE REVIEW

Introduction

As industries mature and grow, the most efficient and profitable companies begin to purchase, combine, and merge with other companies. The main reason for the activities is to become competitive and be the premier provider of their respective industry. However, not many companies can become the premier provider for their respective industry because mergers and acquisitions cause process and infrastructure inefficiencies. These inefficiencies are caused by poor communication, duplicate processes and work, duplicate systems, different culture and visions to name a few. Companies should actively exercise mergers and acquisitions despite the inefficiencies because the company can grow and by doing so can develop better technology, ideas, and services. This can provide a competitive advantage, but in order to gain this competitive advantage it must quickly make the inefficiencies efficient.

In order to make this happen a company needs to consolidate work, process, and warehouses. The literature review will look at different improvement and optimization methods in order to help make the consolidation of warehouses happen. This literature review consists of four major research areas; Warehouse Facilities Layout, Storage Optimization, Statistical Sampling Inferences, and Linear Programming Optimization

Warehouse Facilities Layout

Research has been conducted to optimize a facility layout within the warehouse to improve the capacity and efficiency of the operations. Several of these studies used Linear Programming methodology and facilities layout to make this happen. The research ranges from an 1870's puzzling technique (Gue and Kim, 2007) to a heuristic model for layout (Larson, and Kusiak March, 1997).

The primer for the research is to utilize floor space more efficiently. A comprehensive study shows that an effective warehouse layout can be just as beneficial and efficient as spending money on automations and an elaborate Warehouse Management System (WMS) (Napolitano, 2003). Another study discovered multiple factors affect the layout and throughput such as quantity, layout type, storage assignment, picking route, etc. (Roodbergen and Vis, 2006). The warehouse layout is just the beginning as others have studied the impact of warehouse layout to transportation efficiencies. The interdependencies between the two are apparent and both need to be optimized in order to improve overall performance (Bartholdi and Gue, 2004).

Effective warehouse layout is apparent to improve warehouse process efficiency and is evident from extensive academic research.

Storage Optimization

Storage optimization is utilizing real estate as efficient as possible. There are several different techniques to make this happen. Faculties Planning 2nd Edition discussed a myriad of different techniques to store different products in different environment. Most of the discussions surround using Linear Programming techniques (Tompkins et al., 1996). There is even a study developing an algorithm to house multi-item inventory using mixed integers with non linear programming to efficiently store products on aisle (Hariga and Jackson, 1996).

Effective use of storage is possible through the use of different extensive academic research. The information is available and one can find this in any academic arena.

Sampling Statistical Inference

The science of statistical sampling is widely used to infer characteristics of a mathematically derived sample of a population. Companies do this to minimize cost and in turn provide a best “guessimate” of the outcome. Doing this can provide a good guess without conducting a study of the entire population. Conducting a study of the entire population can be infeasible to measure in a timely manner (Devore and Nicholas, 1999). This is essential when one needs to consolidate warehouses and decides to use carousels or to buy different size totes to get the most optimal amount of each size. In order to capture the size characteristics of a part one needs to use a set of random samples and make sure the information is unbiased to the results.

A method to find the number of samples if the population is known and determine part size to infer the characteristics of a population is found using an equation called the Normal Approximation to the Binomial. This equation uses the Binomial distribution methodology in order to mirror the behavior of a Normal distribution (Scheaffer et al., 2006). Other random sampling techniques can be used but this equation will give you the best estimate of a number to randomly sample.

Linear Programming Optimization

Linear Programming (LP) is a technique from a scientific field called Operations Research. Linear Programming is used to optimize a particular objective, either minimization or maximization. It uses linear algebra to make this happen by developing an objective equation and setting it to one or more constraint equations. The constraint equations will bind the objective equation to optimally provide a result (Winston, 1994).

The LP technique is used in the industry in several different applications ranging from automotive and services to aerospace and defense. The usage of LP in warehouse applications has been popular to improve the pick throughput and optimization of product class storage (Hsieh and Tsai, 2006). There has been a study to store products in very high density areas to improve the pick efficiency (Gue et al., 2006). There are also methods using LP to minimize products shipped for combat to efficiently ship for missions (Gue, 2001). Linear Programming techniques are used to not only improve capacity usage but also for process efficiencies for the layout of cross dock and warehouse activities (Bartholdi and Gue, 2000). In fact, LP techniques are even used to determine warehouse order scheduling and traffic flow (Gademann and Van de Velde, 2005).

It is apparent that Optimization Practitioners use Linear Programming extensively in different applications for different purposes. The power of LP is evident. LP usage in warehouse optimization is overwhelming throughout the research.

Conclusion

Extensive research of warehouse process and capacity optimization has been conducted. However, a study to develop an algorithm to consolidate warehouses has yet to be developed. By combining different types of optimization and improvement ideas, one can develop an algorithm to consolidate warehouses; not only consolidate warehouses but improve the process productivity as well.

CHAPTER 4
DESIGN METHODOLOGY

The methodology of this research consists of the following steps:

1) Work with company's leaders to define the potential and issues to consolidating warehouses. This will be the start the algorithm.

   Perform a literature review to determine common methods of consolidation and research the topics of 1) Warehouse Facilities Layout 2) Storage Optimization 3) Statistical Sampling Inference 4) Linear Programming Optimization.
2) Develop an algorithm to consolidate warehouses.
3) Test the algorithm at a company.
4) Analyze consolidation results to show improvements.
5) Define areas for future research, and algorithm improvement.

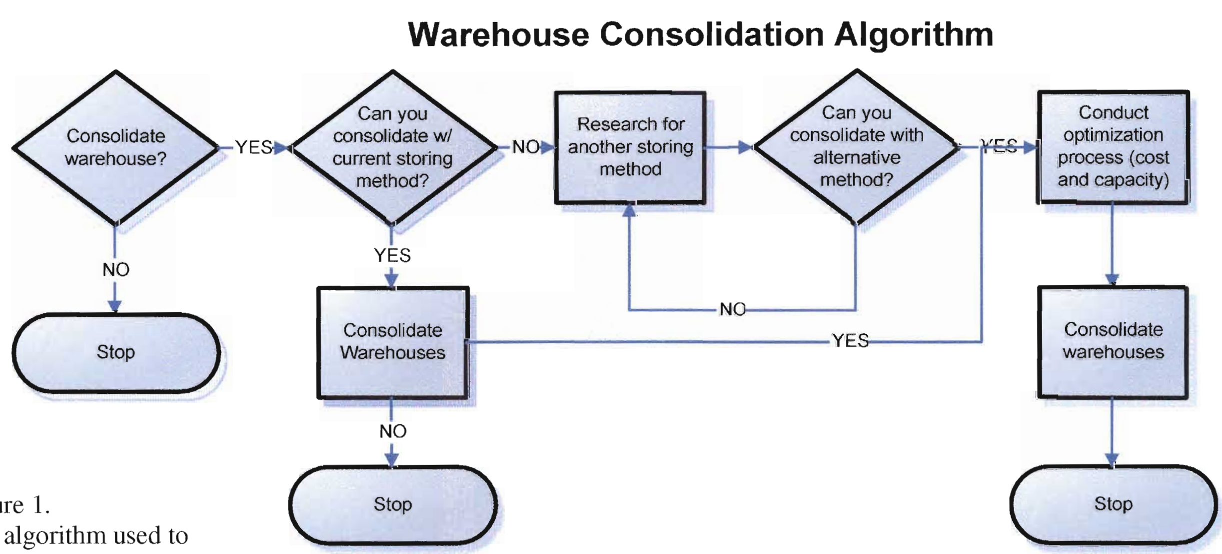


Figure 1.
The algorithm used to consolidate warehouse.

ALGORITHM STEPS

1. The first step of the algorithm is to work with the company's leaders to determine if consolidation of warehouses is a strategic project. Without leadership support to expend resources the algorithm ends.

2. The next step in the algorithm is to analyze the current state to understand if consolidation can happen with the current warehouse storage method. If the analysis suggests that consolidation can happen, then skip Step 3 and conduct optimization process in Step 4. The following equation is used to conduct this analysis:

$$\text{Average parts per square feet} = \frac{\sum_{\text{Sum of all unique part numbers}} X_i}{\sum_{\text{Sum of all warehouse square footage}} Y_i}$$

Equation 1.

P/SF (Average parts per square feet) = this equation determines how many parts are stored on average per square foot.

Where,
P/SF = Average parts per square feet
X_i = *Unique part numbers*
Y_i = *Square footage*
i = *The number of different warehouses in the area*

3. If analysis from Step 2 suggests that consolidation can not happen then move to the next step in the algorithm and search for other alternative methods for storage to enable consolidation. The process is iterative until an alternative storage method to enable consolidation is discovered. If an alternative method is not found the algorithm ends and consolidation cannot happen. The following equations are used to conduct this analysis:

Equation 2.

Lf (Location per part) = this equation determines through time due to parts separation; how many different locations are used per part.

$$Lf = \frac{Lt}{Ut}$$

Where,
Lf = Locations per part
Lt = Total number of possible locations
Ut = Total unique parts in the system

Equation 3.

Ln (Locations needed for a carousel) = this equation determines the number of locations needed per carousels dependent of the Population (Nt).

$$Ln = Nt * (1 - Pb) * (1 - Ps) * (1 + Pg) * (Lf) * (1 + Pe)$$

Where,
Ln = Total number of carousels bin needed
Nt = Number of part numbers
Pb = Percentage of bulk item
Ps = Percentage of special storage
Pg = Percentage growth factor
Lf = Average number of locations/ part number
Pe = Average percentage buffer capacity on carousels

Equation 4.

Cn_i (Total carousels needed) = this equation determines the total number of carousels needed to house the parts expected to be consolidate.

$$\sum Cn_{\mathrm{i}} = \sum \left(\frac{Ln_{\mathrm{i}}}{Ca}\right)$$

Where,
Cni = Total carousels needed
Lni = Locations needed
Ca = Standard number of locations per carousel
i = The index of different warehouses

Equation 5.
*n (the sample size) = this equation determines the sample size needed to infer the characteristic part sizes of a population. It is also known as The Normal Approximation to the Binomial (**Scheaffer et al., 2006**):*

$$n = \frac{Npq}{(N-1)*\left(\frac{B^2}{4}\right) + pq}$$

Where,

n= number of parts needed in the sample
N= number of parts in the population
p= proportion of parts having a particular size characteristic
q= proportion of parts not having that particular size characteristic
B= bound on the error of estimation (i.e., the margin of error)

Equation 6.
*Pi (percentage for a certain standard tote size) = this equation determines the percentage of a standard tote size in a sample population (**Scheaffer et al., 2006**):*

$$Pi = \frac{Ci}{n}$$

Where,

P = percentage for i
C = the count of the parts for i
n = the sample size
i = the different type of standard tote size

Equation 7.
*ME(Pi) (margin of error for a percentage of a certain standard tote size) = this equation determines the margin of error for a percentage of a standard tote size in a sample population (**Scheaffer et al., 2006**):*

$$ME(Pi) = 1.96 * \sqrt{\frac{Pi * qi}{n}}$$

Where,

ME(Pi) = the margin of error for the percentage of type i
Pi = proportion of parts having a particular size characteristic i
qi = proportion of parts not having that particular size characteristic i

n = the sample size
i = the different type of standard tote size

Equation 8.
Lnj (Number of tote type locations needed) = this equation determines the number of different tote types needed per carousel

Lnj (round down to the nearest integer) = SCj * LSj * PPj

Where,
Lnj = Number of carousel locations required for tote type j
SCj = Shelves/ Carriers
LSj = Locations/ Shelf
PPj = Percentage of he parts population
j = index of tote size

4. Once an alternative method is found to consolidate the warehouses, the next step is to develop an optimization solution in respect to cost, capacity, and process. The optimization of the process can be determined through Value Stream mapping (Rother and Shook, 1999) and a simulation of the future warehouse as well as visual controls to streamline the put away and picking process using a warehouse management system. A Linear Programming method is used to minimize cost while maximizing capacity (Winston, 1994). The following equation is used:

Equation 9.

*Minimize Z = (Cost of Carousel 1) * X1 + (Cost of Carousel 2) * X2*

Where the cost of x1 is $42,000 for a 40 carriers carousel and x2 is $63,000 for 50 carriers carousel for the case study.

Constrain by:
1) *Capacity*
   *(Number of Carriers 1)*X1+ (Number of Carriers 2)*X2 = Minimum number of carriers needed*
2) *Cost*
   *(Cost Carousel 1)*X1 + (Cost Carousel 2)*X2 ≤ Budget amount in $*

Where the number of carriers is constrained to equal 284 carriers and the budget amount is equal to or less than $363,000 in the case study.

5. The final step in the algorithm is to consolidate the warehouse using the findings from the equations.

CHAPTER 5

TEST THE ALGORITHM

INTRODUCTION

Raytheon is among the leaders in electronics, radars, sensing, and space systems of the aerospace and defense industry. Raytheon has six major business units throughout the country; Space and Airborne System (SAS), Integrated Defense Systems (IDS), Raytheon Missile Systems (RMS), Network Centric Systems (NCS), Information & Intelligence Systems (IIS) and Raytheon Technical Service Consolidate (RTSC). Raytheon Space and Airborne Systems (SAS) is a $4 billion business unit within Raytheon, and has launched programs like APG-79 Radars for F/18A Super Hornets, classified sensors and systems for space and reconnaissance. SAS has realized the advantage that comes from effective supply chain management, and has recently reorganized to better align its organization structure with customer expectations. An organization chart shown in **Figure 2** describes a small portion of the reporting structure for SAS Supply Chain Management based in El Segundo, California.

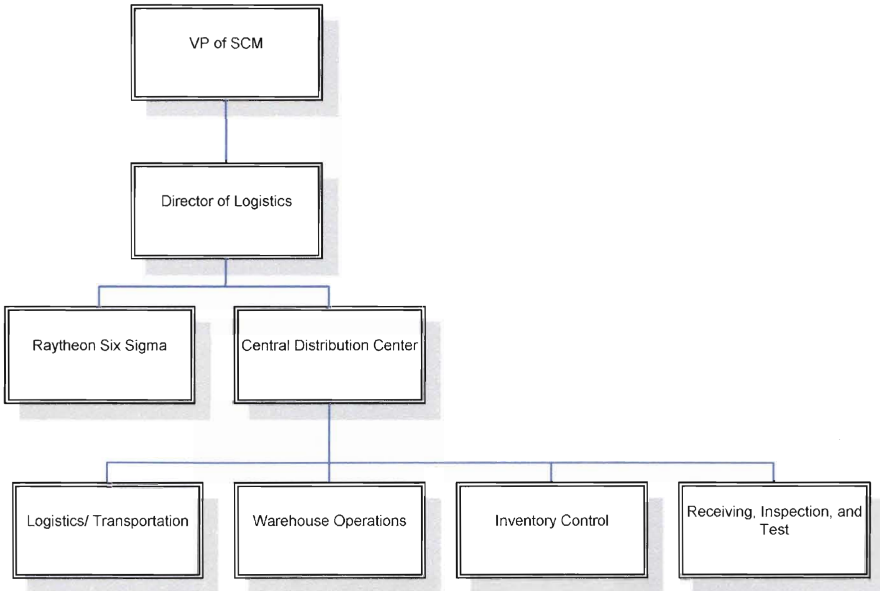


Figure 2.
An organization chart of the company's Supply Chain Management business.

Dealing with recent mergers and acquisitions, SAS has to overcome several inefficiencies in order to meet Raytheon's vision. A new process, system, and culture needs to be developed in order to become competitive. Within the last decade the warehouse facility has gone through three name changes, several layoffs, and a myriad of processes and systems mandation. Lack of identity and multiple layoffs caused a decrease in morale and empathy for improvements and growth. The facility was originally Hughes Aircraft and Systems, it then merged with General Motor (GM), and was finally purchased by Raytheon. Raytheon also bought E-System and Texas Instruments (TI) during this time. All four companies were combined to create a business unit within Raytheon call Space and Airborne System (SAS) illustrated in **Figure 3**. Combining different cultures, processes, and systems that are accomplishing the same tasks is challenging. It leads to confusion, redundancy, layoffs, and ultimately frustration and anxiety. A great case example is the warehouse locations in El Segundo.

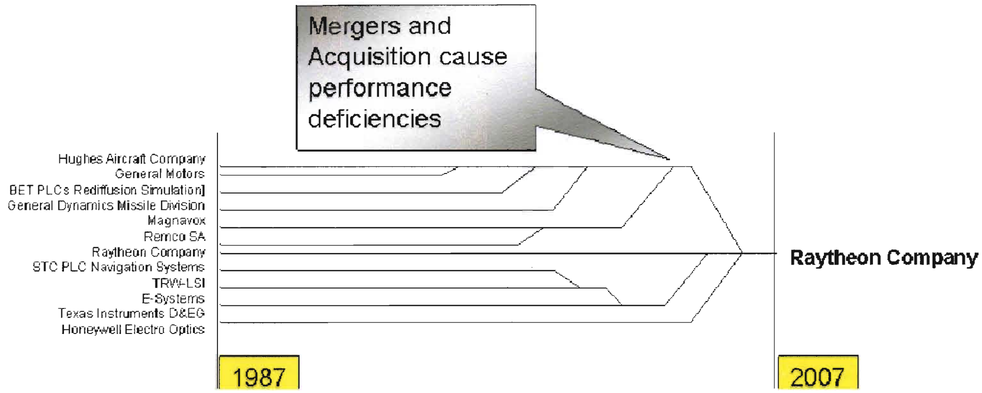


Figure 3.
Modified chart of Raytheon's mergers and acquisitions within the last 20 years from Aerospace and Defense Magazine (October 2007)

THE CURRENT STATE

The warehouse is not optimally organized due to the mergers and legacy systems shown in **Figure 4**. It consists of four main areas. The first area is utilized to stage Research and Development or Engineering products. These products are highly unpredictable in customer demand because engineers and scientists do not know what they need until they experiment with them. This area provides challenges for the warehouse process to support these activities. The second area is used to stage Production or Operations related products. These are products that should provide a daily or weekly demand. Unfortunately, due to the challenges of producing products from Development to Production, the demand varies as well. The next area is known as the Frozen Zone. The reason for the title is because products in this area have no demand, old technology, or are staged in case a need arrives. Some of these products date back to when Hughes Systems owned the products in the 80's. The reason for keeping these parts is because they are expensive to procure and the possibilities of using the products still exist. The fourth area is known as the Bulk/ Government Furnish Products (GFP).

This area is allocated for bulk items, products that require pallets or folk lift to manage. Similar to the two areas separated for Engineering and Operations usage, the bulk area products are segregated. It also has a portion where products are returned and stored from the government, hence the term GFP. The other warehouses located in several different areas of El Segundo configure storage in a similar manner.

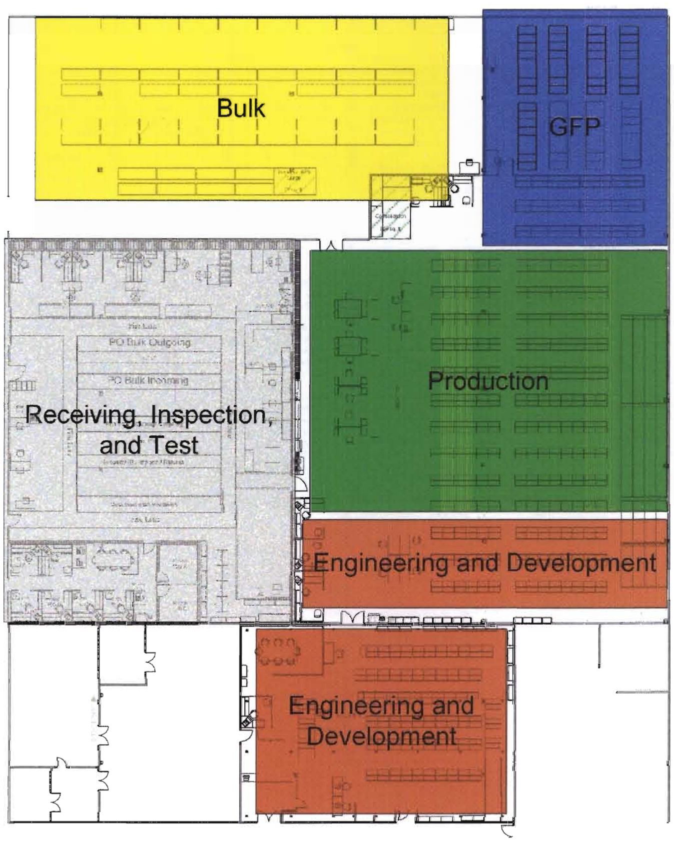


Figure 4.
The main warehouse layout is allocated to the following four areas (Engineering, Production, GFP, and Bulk)

The Issue

Although the main warehouse that was toured houses most of the products for the company, it only holds approximately 37% of the total products. The rest are scattered throughout the El Segundo corridor and even in other local cities. Since the warehouse process is highly unpredictable, the programs that purchased the products decide to build and facilitate the products next to the end users. Through time, these "point of use" areas grew into a "mini-warehouse," producing the same services and output as the central warehouse. The redundancy of efforts for eight mini-warehouses increase cost of capital for equipments, square area, and labor. It also does not position the company for growth due to limited real estate. These mini-warehouses utilize real estate that could be utilized for production or engineering development. In order to stay competitive and reach Raytheon's vision, all warehouses needed to be consolidated into one single location to optimally improve usage of capital equipments, square footage, and eliminate redundant labor. **Figure 5** illustrates the vision.

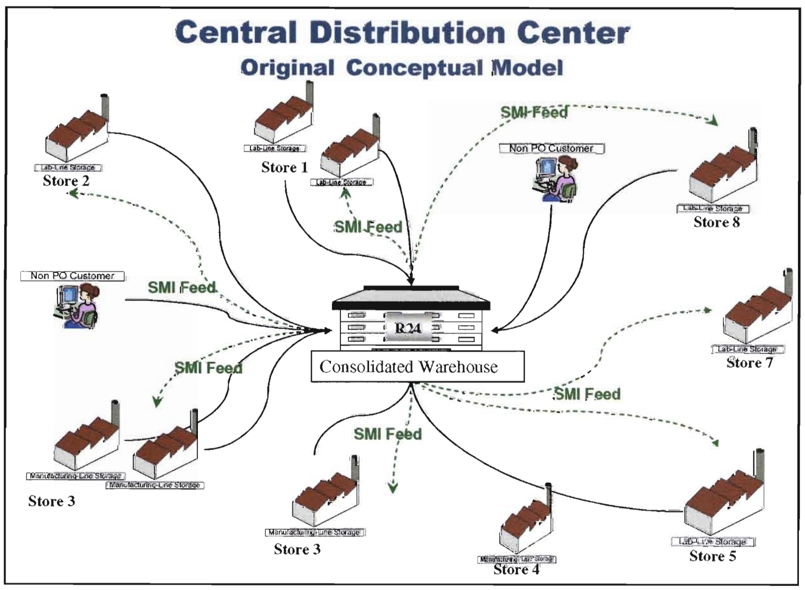


Figure 5.
Conceptual idea of warehouse consolidation and routing services using SMI (supplier manage inventory)

This is the first step in the algorithm: determining strategically to consolidate warehouses. One cannot move on to the next step if the company's leaders are not willing to spend the resources and the algorithm end shown in **Figure 6**. The first step to accomplish the vision is to understand the current state of how the products are stored, how much, and where.

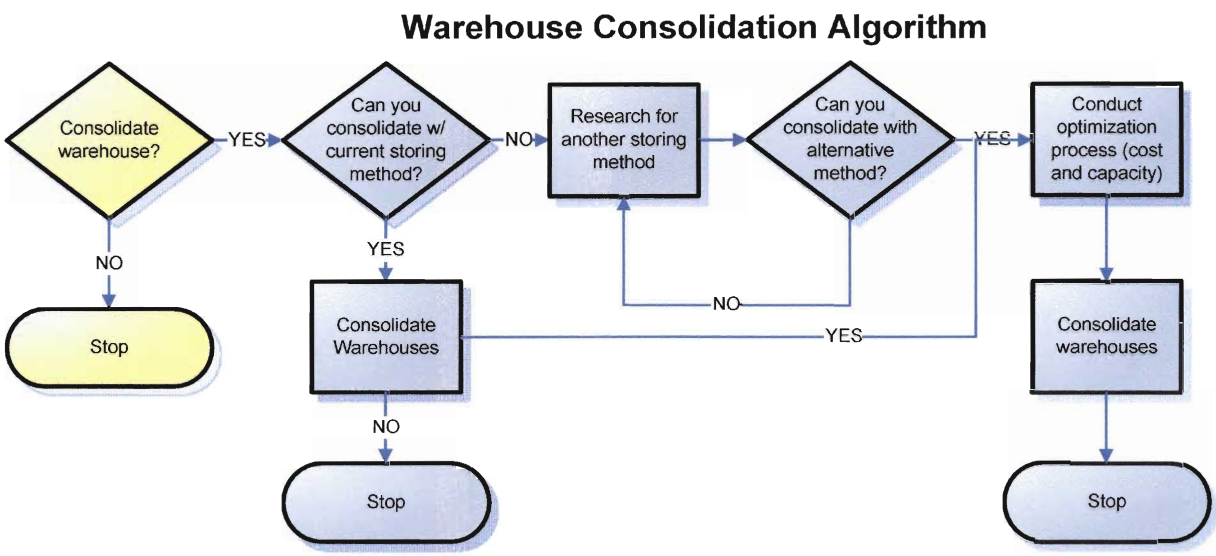
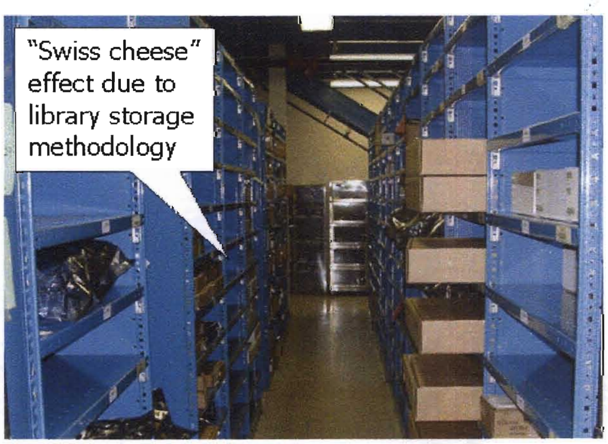


Figure 6.
Figure 6 shows the first step in the algorithm.

Current warehouse storage method

Since the warehouse is stored by categories the products are segregated. R24 is the name of the location of the main warehouse in California. The products are stored by Programs and the part numbers are stored alpha-numeric from left to right and top to bottom on book shelves configured within totes similar to **Picture 1**.



Picture 1.
Current storing method causes inefficient utilization of space.

The storage concept is similar to a conventional library book storage system. In order to put away the products a store clerk would go down the aisle and look for the Program and part number to find its location and store the products. Unfortunately, if the product is new the clerk will have to create a new tote bin with its Program and part number and shift the rest of the totes toward the right and down the shelves to make room for the new item (**Figure 7**). This can be very time consuming if several new products arrive at the same time as anticipated for growth in Raytheon SAS business.

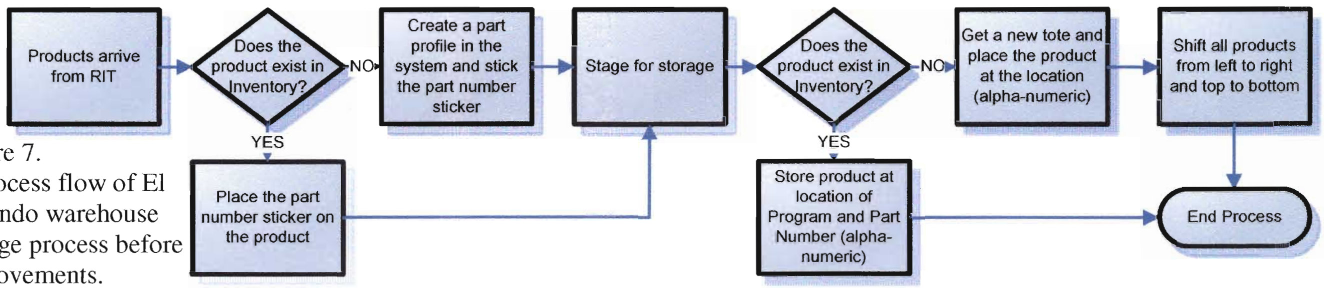


Figure 7.
A process flow of El Segundo warehouse storage process before improvements.

Not only is the put away process cumbersome but the storage of the products is not optimal. Most products are stored within a tote or left in original packaging on the shelf. In a typical aisle there are several different size totes housing products and products that do not fit in a tote lying on the side shown in **Picture 2**.

Picture 2.
Picture 2 shows a picture of a current tote inefficiently storing a product.

For instance, if a product is a resistor with a dimension of 1" x 1" x 1" it can be in a tote that is much bigger than its actual size which uses valuable storage capacity. This is a likely scenario throughout the warehouse because the first time a package arrives; it can be configured to optimally fit the size of a tote. However, over time the consumption of the products will shrink the dimension into a scenario where the product's size does not justify the storage capacity.

Another disadvantage of storing products in this fashion is the inability to store the product randomly. Since the products are stored alpha-numerically and segregated by Programs, the flexibility of storing products randomly is not possible. If a solution could be found to store parts randomly it will eliminate the cumbersome process of adding extra products and will utilize the space more efficiently. Also storing products randomly improves the efficiency of the warehouse throughput (Manzini et al., 2006). Visual data were collected to understand how much of the warehouse is occupied with parts shown in **Figure 8**. Qualitative estimation shows approximately 80% of the available shelves are occupied. Due to the current storage conditions, the shelves are occupied by products from designated Programs and part numbers but can have empty “air space.” Similar to swiss cheese, there are holes in the shelving compartment.

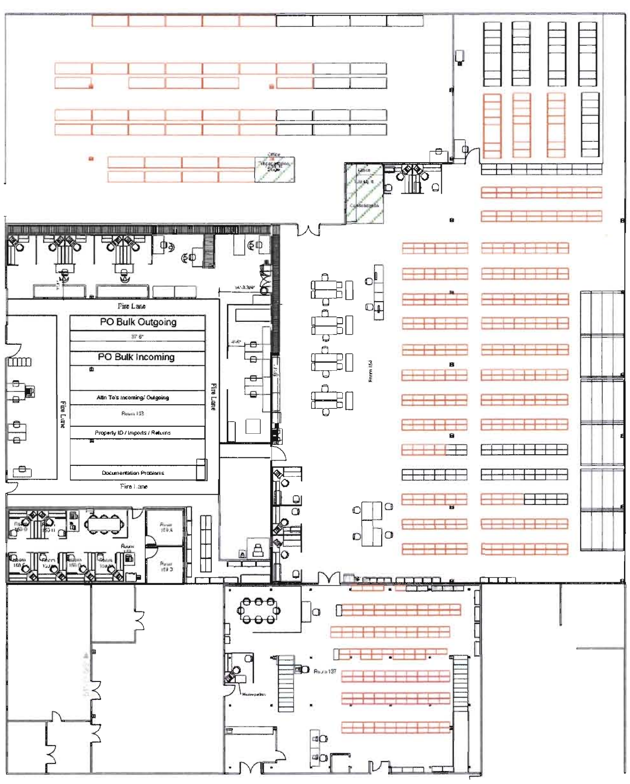


Figure 8.
Warehouse layout with qualitative data of storage consumed in red.

Quantitative Analysis I

Analysis of total space required with current storage method

The next step in the algorithm is to understand if consolidation can happen with the current storing method and condition. **Figure 9** shows the preliminary area for the R24 Central Warehouse where the mini-warehouses will be consolidated has a total of 22,750 square feet with 38,717 part numbers already stored in this footage. This compares to the current area data of the eight mini-warehouses cumulating 20,751 square feet with 65,750 part numbers. Taking the summation of unique part numbers divided by the summation of the square footage in the warehouse provides the number of unique part numbers per square foot which is also shown in **Figure 9**. Currently, the capacity usage of square footage is 2.40 unique part numbers for every square foot by calculating the summation of all unique part numbers divided by the summation of total square footage consume as shown in **Equation 1**:

$$\text{Average parts per square feet} = \frac{\sum X_i}{\sum Y_i} = 2.40$$

Equation 1.

Where,
X_i = Unique part numbers
Y_i = Square footage
i = The number of different warehouses in the area

Warehouse name	Square Footage	Line Items	Line item per square footage
Main Central*	22,750	38,717	1.70
Warehouse 1	2,651	7,372	2.78
Warehouse 2	3,200	13,213	4.13
Warehouse 3	575	147	0.26
Warehouse 4	1,200	5,776	4.81
Warehouse 5	2,623	6,389	2.44
Warehouse 6	1,625	6,440	3.96
Warehouse 7	3,777	12,998	3.44
Warehouse 8	5,100	13,415	2.63
Grand Total	43,501	104,467	2.40
Total warehouses to consolidate	20,751	65,750	
Consolidation Occurs w/ 20% growth	22,750	125,361	5.51

Figure 9.
The figure shows the impact of capacity if consolidation of warehouses occurs. In red are the line items per square footage in the current condition and in green if consolidation occurs. This is a factor of more than 2X the storage efficiency.

However, if one consolidates the mini-warehouses one would get 4.59 unique part numbers per square foot using the same equation. Therefore, the goal is to double the current capacity of the central warehouse in order to house all the products. One has to find enough space for an extra 20,751 square feet and more than double the number of line items. In addition, the company is growing rapidly and needs to account for 20% growth in the next 5 years. This accounts for a total of 125,360 line items in the current square footage of 22,750. That is more than 3 times the current line items in R24 Central Warehouse! This answers the decision block on the algorithm if we can consolidate with current storing method. If yes, then consolidation can be conducted. In this case study we cannot due to the findings and will move to the next step of the algorithm: research for another storing method shown in **Figure 10**.

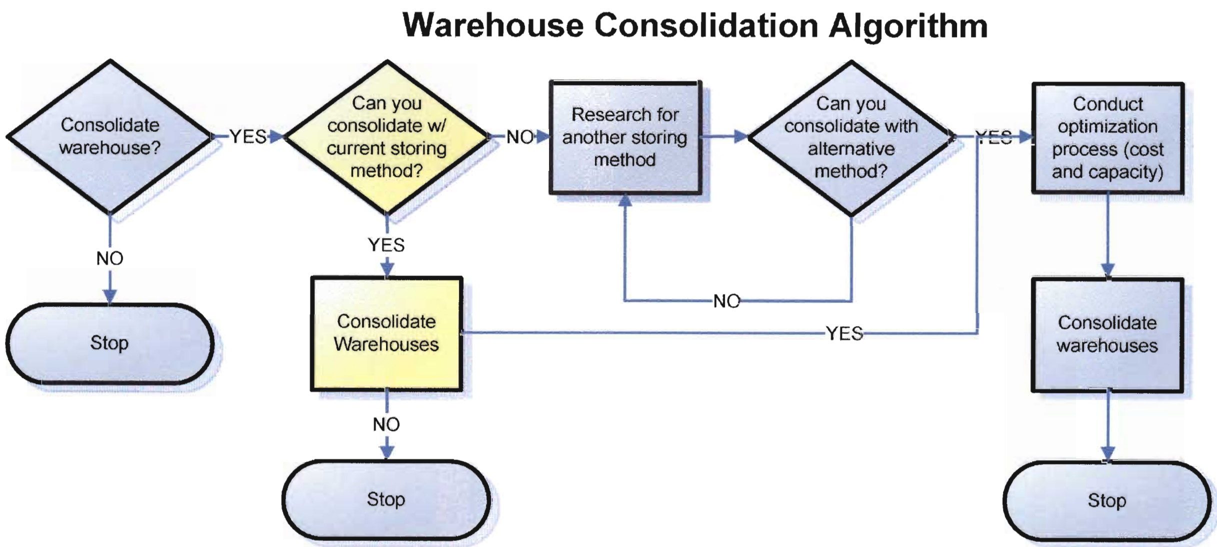


Figure 10.
Figure 10 shows the next step in the algorithm.

Researching for another storage method

After deciding that the current storage method cannot enable warehouse consolidation the next step in the algorithm is to search for an alternative storing method. It was discovered that the typical industry's solution to capacity constraints for storage is to implement carousels. Carousels can be horizontal or vertical in design and are typically the most flexible storage device to configure into a warehouse. Horizontal carousels are a system of horizontally rotating shelves whereas vertical carousels rotate vertically, move on command, and are driven by a Warehouse Management System (WMS). A carousel brings the product to the store clerk, instead of the clerk searching for the products, reducing the travel time throughout the warehouse. The paradigm shift of the concept of the products coming to you instead of you coming to the product was a refreshing idea to a culture that has worked in the latter process for 30 years. Most WMS are designed with a barcode system providing accuracy and traceability of the products, reducing the possibility of human error when reading alpha-numeric part numbers. The new system coupled with carousel and barcoding technology provides shorter cycle time to locate a product and an increase in accuracy of the products thus increasing order picking throughput significantly over traditional methods. Most importantly it was the answer to the issue of providing three times more capacity in the R24 Central Warehouse due to vertical usage, part sizing, and partition capability.

A Raytheon site in Texas which was purchased from Texas Instruments has an active carousels system. Unfortunately, during the tour the author realized that the storage capability is not optimal because it did not have the partition schemes typical in the industry. Barcode technology, the concept of bringing the products to the store clerk, and random storage exist but due to inadequate funds a study was never conducted to design the most optimal partition scheme to house the products at the Texas site.

Evaluating another storage method

The Texas put away process starts with the products coming from Receiving Inspection and Test (RIT) similar to El Segundo's process, but once it completes the RIT process each product is assigned a barcode from the WMS known as Warehouse Automation Control (WAC) system. The product with the barcode is assigned to a recycle tote from the carousels that best fit the product. If the product is too big for any of the totes it is assigned to the bulk process for storage. Once the barcode is assigned to the product and the tote separately it is transported to the carousels with several other totes at the end of the first shift. Each carousel workstation consists of two carousels called a Pod. The products are randomly assigned to a carousel Pod to be put away. The store clerk rotates the carousel until one sees an empty location or an upside down tote. The upside down tote signifies an empty location. The upside down tote's barcode is discarded and transported to the RIT area for reuse. The process is described in a process flow format in **Figure 11**.

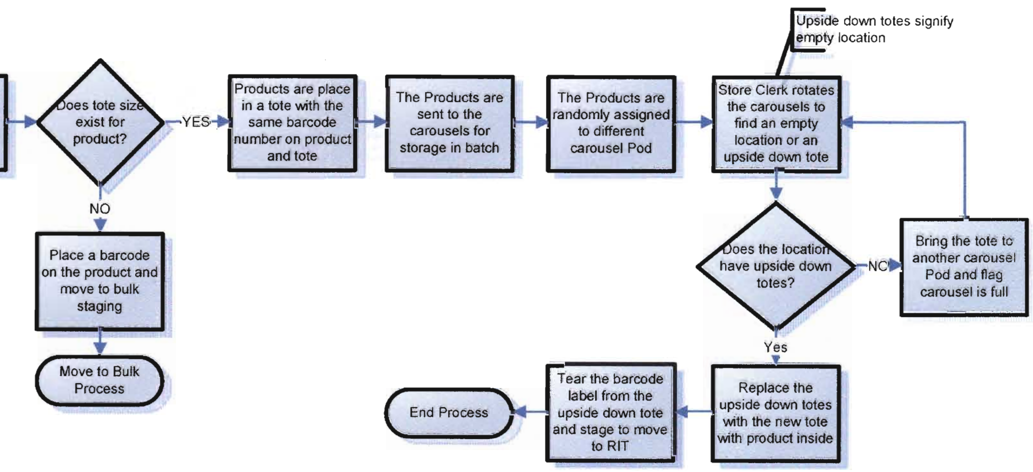


Figure 11.
A figure of the process for Texas warehouse storing.

Quantitative Analysis II

Data analysis of another storing method

The next step is to analyze the current carousel capacity data to understand how many horizontal carousels were needed to house all products in El Segundo. Before describing the data, some carousels terminology needs to be define shown on **Figure 12** and a pictorial schematic with the terminology shown in **Picture 3**.

Terminology	Definition
Carousel	The entire mechanism housing the product
Carrier	A rack that travels around the carousel
Shelf	A single shelf on the carrier
Totes	A box that houses the products
Partition	One or more dividers inside a tote
Pods	A set of 2 carousels

Figure 12.
A table for carousel's terminologies used in this report.

Picture 3.
A picture of a typical carousel configuration at Texas Raytheon.

Data was gathered regarding the carousels such as height, number of carriers, number of totes configuration. Referring back to the total of line items in El Segundo of 104,467 and coupled with the carousel configurations and dimensions, a spreadsheet can be used to determine the amount of carousels needed. First, one needs to understand how many parts can actually be in the carousel because some products have environmental needs and others are just too large to be housed in a carousel. Estimation is used for products that are too large for the carousels and environmental needs by using a percentage factor of 3% for bulk and 20% for nitrogen induced products. Estimation is necessary because there is no part profile data for the parts. This estimation was generated by subject matter experts within the warehouse. SAS within Raytheon is growing at a rapid pace of 20% per year. This growth must be planned into the space and part requirements. Not storing products randomly through time creates inefficiency in capacity; counting the total locations possible and dividing that by the number of unique parts on record provides a factor of inefficiency. For a sample warehouse in El Segundo the total possible locations is 3,408 with a total of 2,403 unique parts which equates to a ratio of 1.4 locations per part. This can be determined in **Equation 2**:

Equation 2. $$Lf = \frac{Lt}{Ut}$$

Where,

Lf = Locations per part
Lt = Total number of possible locations
Ut = Total unique parts in the system

This factor is used to quantify the number of parts in a system divided by the potential location a carousel will have because over time the same part number can be stored in another location and will occupy more than one carousel location. Another factor is an industry standard for carousels; to be most efficient the carrying capacity is at 90%. Therefore, a factor of 90% is used to provide the needed required space for the optimal throughput rate. **Figure 13** shows the analysis from the excel spreadsheet for the Production Inventory products. Similar calculation is needed for Engineering and other warehouses to find the total carousels.

Horizontal Carousel storage locations (also called bin boxes or line items) required:	
Unique part numbers	34,503
Percentage that is bulk	3%
Unique carousel part numbers without bulk	33468
Percentage that requires special storage (environmental, sensitive, etc.)	20%
Unique carousel part numbers w/o bulk and environmental need	26774
Potential growth factor	20%
Horizontal carousel part numbers with growth	32129
Storage locations per part number through time factor	1.4
Horizontal carousel storage unique locations needed	44981
Utilization factor (for efficient location of empty bin boxes when stocking)	90%
Total horizontal carousel storage locations needed	49,479

Figure 13.
Calculation process to determine the number of storage locations needed.

Equation 3 is used to find the number of locations needed for each warehouse to understand how many carousels are needed in total to consolidate:

$$Ln = Nt * (1 – Pb) * (1 – Ps) * (1+ Pg) * (Lf) * (1 + Pe)$$

Where,
Ln = Total number of carousel bins needed
Nt = Number of part numbers
Pb = Percentage of bulk items
Ps = Percentage of special storage
Pg = Percentage growth factor
Lf = Average number of locations/ part number
Pe = Average percentage buffer capacity on carousels

The total number of storage locations necessary for Production Inventory is 49,479. Using the configuration of the carousels in Texas, the necessary carousels can be determined by calculating the number of storage locations on each shelf, carrier, and finally each carousel. **Figure 14** shows Texas totes configuration for a carrier which equates to 78 total possible locations per carrier. Extrapolating the number of totes to the number of carriers will give the total number of totes or locations a single carousel would provide. The calculation consists of 78 totes per carrier multiplied by 58 carriers equating to 4524 total possible locations for a carousel. Knowing the amount of possible locations, one can determine the number of carousels by simply dividing the number of parts locations needed by the number of locations available in a carousel shown below for one sample of **Equation 4**:

$$Cn = Ln / Ca$$

Ln = Locations needed for a carousel
Ca = Available locations per carousel
Cn = Carousels needed for Production Inventory

For the example of Production Inventory numbers equated to:

49,479 needed locations / 4524 available locations = 11 carousels needed

Horizontal Carousel capacity information:

Average bin box configuration per carrier:

tote height:	2.75"	2.75"	2.75"	2.75"	5"	5"	5"	5"	**Total**
*tote width:	3.25"	6.5"	9.75"	13"	3.25"	6.5"	9.75"	13"	**per carrier**
# totes /carrier:	52	8	4	2	6	3	2	1	**78**

*Note - each shelf is 20" wide - therefore, as an example, 6 of the bin boxes that are 3.25" wide could fit on one shelf.

Horizontal Carousel storage locations available:

# Carriers	58	(based on Texas actuals)
Total horizontal carousel storage locations available	**4524**	(# totes/ carrier * # of carriers on a carousel)

Figure 14.
A typical storage configuration for one carrier at Texas to determine total locations available with one carousel.

This calculation is only for products used for Production or in the Inventory Control System (ICS). The ICS system consists of products in the R24 Central Warehouse and other mini-warehouses. Similar calculations need to be developed for Engineering products in the Engineering Control System (ECS) and other mini-warehouse from another system for classified products. Summing the total for all four systems provides a total of 24 carousels shown in **Figure 15**. The 24 carousels were found by **Equation 4**:

Equation 4.

$$\sum Cn_i = \sum \left(\frac{Ln_i}{Ca}\right)$$

Where,
Cni = Total carousels needed
Lni = Locations needed
Ca = Standard number of locations per carousel
i = The index of different warehouses

This is the number of carousels needed in El Segundo in order to consolidate all the mini-warehouses into one central location.

Total Carousels needed using Texas configuration					
Warehouse	Production and other stores	Engineer and other stores	F Stores	J Stores	Grand Total
Total horizontal carousel storage locations needed	49,479	22,071	17,000	14,309	102,858
Total horizontal carousel storage locations available	4524	4524	4524	4524	4524
Carousels needed	11	5	4	4	24

Figure 15.
Total carousels needed from Texas carousel configuration for all products in El Segundo.

Unfortunately, the current layout of R24 Central Warehouse containing 22,750 square feet is too small to fit 24 horizontal carousels. Also, the cost of 24 carousels does not justify the return in investment for consolidating the warehouses. Another solution needs to be provided in order to execute. The alternative storage method does not enable warehouse consolidation either. Therefore, the next step on the algorithm is to find another storage method shown on **Figure 16**.

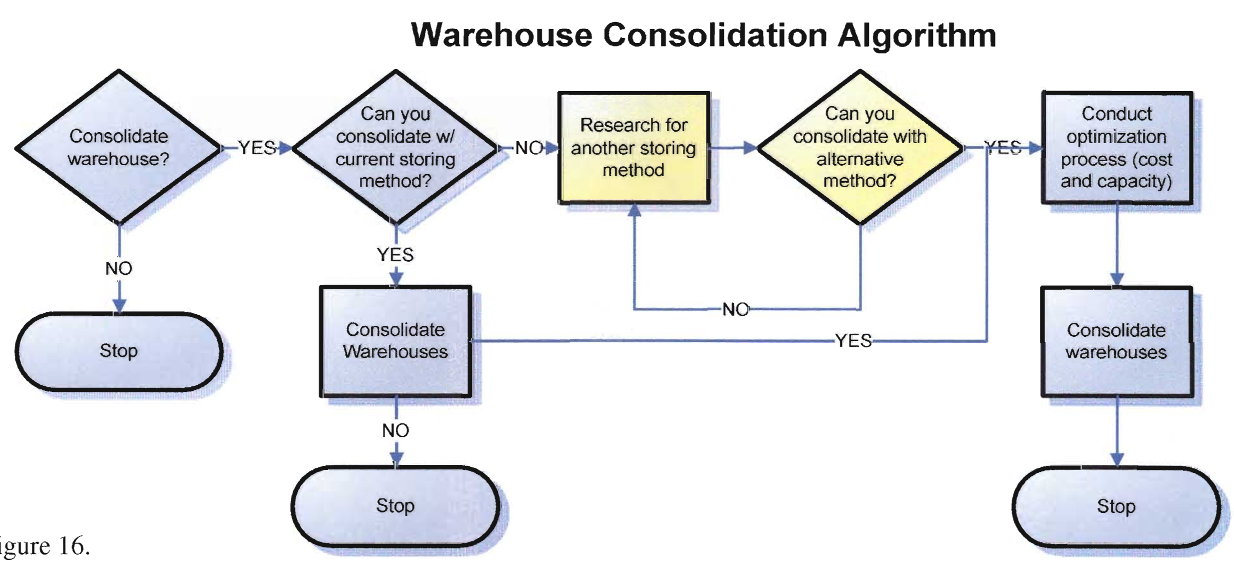


Figure 16.
Figure 16 shows a step in the algorithm where the alternative storage method does not enable warehouse consolidation.

Fortunately, during the author's research outside the company, other companies have developed partitioning schemes to optimize the capacity per tote, shelf, and carrier. By adding one partition to the totes it will provide two locations for one tote, this will double the capacity. Likewise, the more partitions placed in the tote the more capacity one will get from the carousel. However, one cannot add too many partitions unless a good study is used as to the size of the products. Conducting a study to measure all 104,467 products is unreasonable, time consuming, and costly. Therefore, a Random Sampling to infer the product's size from the population is used. This is an analysis to understand if another storage method will enable warehouse consolidation on the algorithm.

Quantitative Analysis III

Random sampling to infer partition size

By random sampling the population of the products one can estimate the size and characteristics of the products with a degree of confidence with unbiased data. "The advantages of using random sampling are: 1) it helps to reduce or eliminate bias in the manner in which the sampled items are chosen and 2) it enables us to make precise statements about the extent to which conclusions drawn from a sample can be applied to the entire population" (Devore and Nicholas, 1999). An approach to random sampling to infer the population by using the Normal Approximation to the Binomial taken from the following reference Elementary Survey Sampling (Scheaffer et al, 2006):

Equation 5.
$$n = \frac{Npq}{(N-1)*\left(\frac{B^2}{4}\right) + pq}$$

Where,

n= number of parts needed in the sample
N= number of parts in the population
p= proportion of parts having a particular size characteristic
q= proportion of parts not having that particular size characteristic
B= bound on the error of estimation (i.e., the margin of error)

The first step is to estimate the proportion of the parts in the population having a particular size characteristic. Since this quantity is unknown, the standard process is to start with the assumption that p= 0.50. This means that half of the parts in the population will have a particular size characteristic and the rest of the parts will have some other size characteristics. Setting the margin of error, B, to be .05 (5%) and q to be 0.50 will provide a first cut at the estimation. Conducting this method will yield the following results for the case study with the population size N=83,053 shown in **Figure 17.**

CONFIDENCE INTERVALS FOR SAMPLES			
n =	398.09	n category =	199.04
p =	0.5		
q =	0.5		
N =	83,053		
B =	0.05		

Figure 17.
An equation to understand the number of sample parts needed using the Normal Approximation to Binomial equation.

This means that one needs to select 399 samples to have a good confidence that the study will yield an estimated proportion having a margin of error of 5%. In order to make sure this equation is accurate for the population, each part category needs to have at least 5 sampled parts in the final sample.

Tote Size Name	A	B	C	D	E	F	G
Tote size dimensions (L, W, H) inches	4 x 4 x 4	4 x 6 x 4	6 x 8 x 4	8 x 12 x 4	12 x 12 x 4	12 x 24 x 4	24 x 24 x 4
Number of locations per shelf	36 loc	24 loc	12 loc	6 loc	4 loc	2 loc	1 loc
Count of parts that fit in tote size	214	264	136	204	146	105	18
Percentage of parts that fit in tote size	19.2%	23.7%	12.2%	18.3%	13.1%	9.4%	1.6%
Margin of error	+/- 2.4 %	+/- 2.6 %	+/- 2.0 %	+/- 2.3 %	+/- 2.0 %	+/- 1.7 %	+/- 0.76 %

Figure 18.
Total of 1,087 parts categorized into lot size locations from A to G.

Figure 18 shows the final results and size characteristics for a 1,113 part sample. Only 1,087 of the parts sampled were used because the rest did not fit a standard lot size tote. The smallest parts count from this sample is 18, which is well over 5. If there is a sample size of less than 5 than the inference of a binomial distribution does not follow a normal distribution and the equation is inaccurate for this study. For example, tote A is calculated by taking the count of parts that fit in tote A dimensions and dividing by the sample population (n) like **Equation 6**:

Equation 6. $$Pi = \frac{Ci}{n}$$

Where,

P = percentage for *i*
C = the count of the parts for *i*
n = the sample size
i = the different type of standard tote size

The margin of error can also be calculated by using **Equation 7**:

Equation 7. $ME(Pi) = 1.96 * \sqrt{\frac{Pi * qi}{n}}$

Where,

ME(Pi) = the margin of error for the percentage of type i
Pi = proportion of parts having a particular size characteristic i
qi = proportion of parts not having that particular size characteristic i
n = the sample size
i = the different type of standard tote size

In the case study another random sampling equation was used to infer the population that yielded the sampling of 1087 parts. The Normal Approximation to the Binomial equation yielded 399 part numbers to sample. Therefore, the study provided a sound result.

Once the sample size is found and the confidence interval is acceptable, a random sampling plan must be developed. In order to randomly measure the products to reduce bias a random number generator from Minitab is used. This gives a set of randomly generated numbers for the sample size with four digits for each warehouse. This is shown in **Figure 19** on column label Location (RN).

Location (RN)	Part #	Length	Width	Depth
2469	655655	14.00	12.00	2.50
1794	3267279	25.00	23.00	1.00
0306	5182932	8.00	7.00	2.00
0792	5200977	9.00	6.00	3.00
2585	6385875	6.75	6.50	3.25
2312	6477158.00	9.50	8.50	0.50
1311	8655385	11.00	9.50	2.00
0059	JCA812-100	12.00	4.50	1.25
2097	119552-200	23.00	9.00	3.50
2612	12103C334KAT2A	11.00	8.50	1.00
0816	226K010CRSB0000	10.50	9.00	0.75
1248	5002636-001C	9.00	6.50	0.50
1915	5137502-005	10.50	8.50	0.50
2358	6380234-002	15.50	14.00	1.00

Figure 19.
An excerpt of random sampling data with length, width, and depth in inches.

The four digits are used to systematically identify the storage location of the shelving to randomly measure the products:

- The first 2 digits are the aisle going from the front of the warehouse to the back (from 00 to 43)
- The next 2 digits are for the number of racks going from the front to back (00 to 14)
- The next single digit is from the front of the four digits number and is use for the number of shelves from top to bottom (0 to 8)
- The next 2 digits are the second and third digit of the four digits number and is use for the number of totes going from left to right (00 – 15)

For example, random number 1276 will be configured as so:

- The first 2 digits are 12, therefore it is the thirteenth aisle from the front to back of the warehouse (**12**76)
- The next 2 digits are 76, therefore you must travel the rack 5 times to surpass 15 sets of rack (00 – 14) then travel 1 more racks to get to 76 (12**76**)
- The next digit is the rotating number to the first digit which is 1. Therefore, the shelf is the second from the top. (**1**276)
- The next digit is 2 (the second digit). Therefore, the products to measure is in the second tote or if the product is not in the tote then the second product from left to right (1**2**76)

Figure 20 illustrate the location of the part to measure with the random number 1276.

Figure 20.
The location of the part to measure using random sample 1276 in the warehouse.

The author used this approach to systematically select random parts to measure. The round table approach to correlate the random numbers to the warehouse configuration is not the correct method because this may cause statistical errors. The correct method is to determine the warehouse configuration first in order to correlate it to the random numbers. In this example four digits were used but the number should be seven total digits. Therefore, each warehouse layout is different and determining the number of digits will be different.

Data inference to determine partition population size

After measuring and grouping all sample parts in all the stores to different group sizes, the next step is to infer it into different tote sizes. Before analyzing the part's characteristics a carousel vendor provided some standard tote sizes from the vendor's 20 years of experience in carousel installation. The vendor estimated that 70% of the parts will be in a tote size of 4" X 4" X 4" shown in **Figure 21**. The vendor also provided the carriers specifics such as the depth and width of the shelf at 24". The height can be adjusted between a minimum of 4" to the entire height of the carrier. The author decided to hold the constraint of the height to be 4" due to the fact that approximately 96% of the parts have either a Length, Width, or Height that is 4".

Average bin box configuration per rack/carrier:

Tote Type	A	B	C	D
bin box height:	4"	4"	4"	4"
bin box depth:	24"	24"	24"	24"
*bin box width:	4"	4"	4"	8"
# bin box sub slots	6	4	2	3
Total Cubic Inches	64	96	192	256
% Mix of Totes*	70%	10%	10%	10%

***Based on observations made in R24 by a carousel vendor**

Figure 21.
A Pareto Chart showing where the majority of the part sizes are grouped.

Constraining the height to 4” allowed the author to calculate the percentage of each part size by counting the Length and Width that fit in a 4”, 6”, 8”, 12” and 24” configuration. The number of carousels can now be determined by the percentages of part sizes through extrapolation of the data.

Quantitative Analysis IV

Data extrapolation to determine number of carousels

Once the percentage of sample size is characterized into standard tote sizes, the next process is to extrapolate the data to fit in a standard shelf on a standard carrier. The standard carousel has a width and depth of 24” with the height constraint to 4” and provides 16 shelves on one carrier. Calculating using the equation below and rounding down will provide the number of locations per carrier needed to house the products with that size configuration. For example, tote type A is calculated by using **Equation 8**:

Equation 8.

Lnj (round down to the nearest integer) = SCj * LSj * PPj

Where,
Lnj = Number of carousel locations required for tote type j
SCj = Shelves/ Carriers
LSj = Locations/ Shelf
PPj = Percentage of he parts population
j = index of tote size

For tote type A you get:

(16 shelves/ carriers) * (36 locations/ shelf) * (19.2% of the parts population) = 110 tote type A needed per carousel (round down to nearest integer)

The total number of locations per carrier can be calculated by summing the total locations per carrier for each tote type and then multiplying by the number of carriers on a carousel. This will provide the total locations available on a carousel as shown in **Figure**

22. There are two types of carousels available. One carousel has 50 carriers with a total length of 60 feet while another carousel has only 40 carriers but is only 48 feet long. The calculations shown in **Figure 22** are for 50 carriers. Forty carriers will lead to 10,178 total locations compared to 12,724 with 50 carriers.

Tote Type	A	B	C	D	E	F	G
Tote Size (W x D x H)	4 x 4 x 4	4 x 6 x 4	6 x 8 x 4	8 x 12 x 4	12 x 12 x 4	12 x 24 x 4	24 x 24 x 4
Count	214	264	136	204	146	105	18
Percent Mix of Totes	19.2%	23.7%	12.2%	18.3%	13.1%	9.4%	1.6%
Locations/Tote	6	4	3	2	2	1	1
Locations/Shelf	36	24	12	6	4	2	1
Locations/Carrier	110	91	23	17	8	3	0.26
Total Storage Locations/Carrier	252						
Locations/Carousel	5537	4554	1173	879	419	150	12
Total Storage Locations/Carousel	12724						

Figure 22.
Calculations of each tote types to determine the number of storage locations per carousel.

The sampling suggested that we will obtain 12,724 locations per carousels compared to the Texas calculations of 4,524 total locations per carousel without partitioning. That's a total of more than 8,000 extra locations per carousel!

The next step after determining the number of locations per carousel is refer to an earlier calculation the total unique locations needed for current capacity and growth (See Figure 15). Taking the data for all products in the R24 Central Warehouse and all other mini-warehouses gives a total of 71,550 locations needed not including products from the secret area to be taken later. To find the total number of carousels needed to house all production and engineering products one simply divides the number of unique locations needed by the number of storage locations per carousel using **Equation 4** from earlier. This example will yield:

71,550 locations needed/ 12,724 locations per carousel = 5.6 carousels

Therefore, one would need 5.6 or 6 carousels to consolidate all production and engineering products into one area using a 50 carriers carousel shown in **Figure 23**. Similar calculations are conducted to determine the number of carousels needed for a 40 ft carousel which is 7 carousels. Doing similar calculations for J and F Stores products yield 1 and 2 carousels needed respectively for a total of 9 carousels needed if we mix all products or 10 carousels if one round up and leave all products segregated summarized in **Figure 24**. Ten carousels is a more economic and feasible solution than 24 carousels calculated earlier using the Texas carousel storage method without partition configuration.

50-Carrier Carousel	
Total Carrier/Carousel	50
Carrier Height	97
Carrier Width	24.5
Carrier Depth	24
Shelf Height	4
Shelf Height w/Clearance	6.0625
Total Shelf/Carrier	16

Tote Type	A	B	C	D	E	F	G
Tote Size (W x D x H)	4 x 4 x 4	4 x 6 x 4	6 x 8 x 4	8 x 12 x 4	12 x 12 x 4	12 x 24 x 4	24 x 24 x 4
Count	214	264	136	204	146	105	18
Percent Mix of Totes	19.2%	23.7%	12.2%	18.3%	13.1%	9.4%	1.6%
Locations/Tote	6	4	3	2	2	1	1
Locations/Shelf	36	24	12	6	4	2	1
Locations/Carrier	110	91	23	17	8	3	0.26
Total Storage Locations/Carrier	252						
Locations/Carousel	5537	4554	1173	879	419	150	12
Total Storage Locations/Carousel	12724						

# of Carriers Needed:

**Total carrier storage locations needed	71,550
Total carrier storage locations available	252
Total carriers needed	**283.6**

# of Carousels Needed:

**Total horizontal carousel storage locations needed	71,550
Total horizontal carousel storage locations available	12,724
Total carousels needed	**5.6**

Figure 23.
Calculations method to determine number of carousels needed using partition and random sampling.

	Carriers Needed	Carousels Needed from calculations	Carousels Needed to procure
F Stores	74.9	1.5	2.0
J Stores	99.1	1.9	2.0
**Rest of Stores	283.6	5.6	6.0
Total	457.6	9.0	10.0
**All Production and Engineering products from ECS and ICS			

NOTE: Results calculated from using ICS Inventory data with stock on hand and orders already given

Figure 24.
Total number of carousels needed to consolidate.

Now the total number of carousels needed to consolidate is known for all the parts, the next question is which exact carousels should be used? There are two types of horizontal carousels. A 40 carriers carousel with 48 foot in length and a 50 carriers carousel with a 60 feet in length are available. To complicate the decision a 48 feet carousel costs $42,000 and a 60 foot carousel costs $63,000. How would one determine the mix of carousels to determine the optimal mix of carousels to provide the least amount of cost while ensuring enough locations to consolidate? The next step is to develop a Linear Programming equation from the scientific field of Operations Research to determine the right mix of carousels. One also needs to develop a process that will optimize the process for parts storage and distribution. This is the next step in the algorithm once the number of carousels needed is determined shown on **Figure 25**.

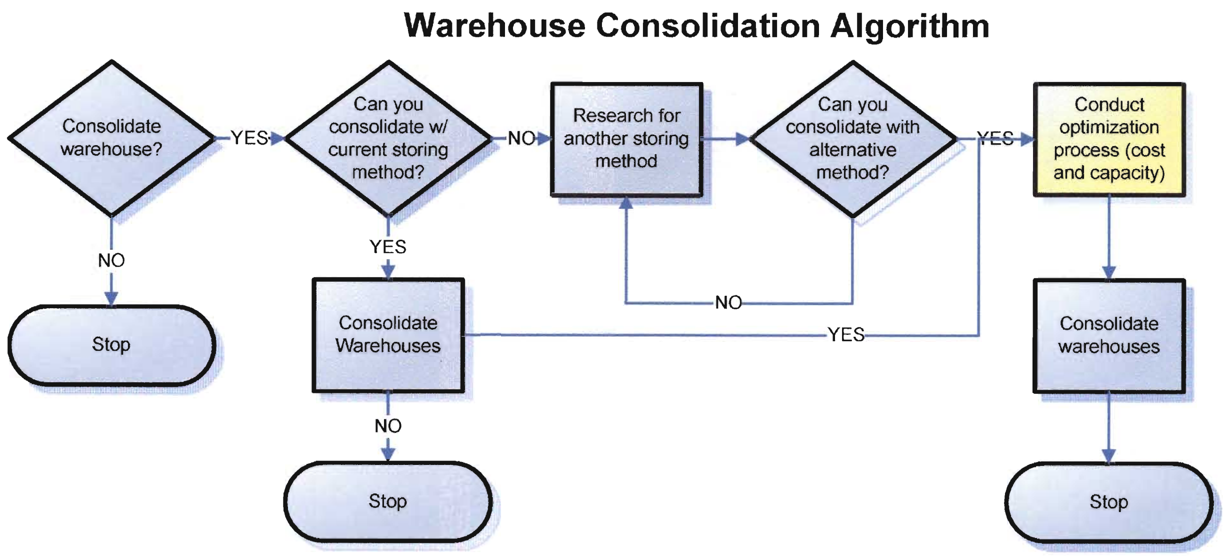


Figure 25.
The alternative method enables consolidation and the next step in the algorithm is to conduct an optimization process to optimize capacity and process.

Quantitative Analysis V

Optimal carousels equation

The Linear Program solution technique will be used to determine the mix of carousels needed to meet the budget of $363,000. There need to be enough carousels to consolidate all Production and Engineering products. J and F Stores products will be consolidated later due to cost constraint for the fiscal year and the time table of systems migration of these stores into a single Warehouse Management System (WMS). The first step in a Linear Program problem is to determine the Objective Function (Z). In this case one wants to minimize the cost of purchasing two different types of carousels. The two different type of carousels are defined to be the Decision Variables where X1 is the number of 48 foot carousels and X2 is the number of 60 foot carousels. This will derive the Objective Function to be and shown in **Figure 26** by using **Equation 9**:

Equation 9. Minimize Z = 42,000 * X1 + 63,000 * X2

Where the cost of x1 is \$42,000 with 40 carriers and x2 is \$63,000 with 50 carriers

Objective Function:	Minimize cost of purchasing carousels		
	Minimize Z = 42000x1 + 63000x2		
Decision Variables:	Amount of 48 ft. & 60 ft. carousels		
	x1	=	# of 48 ft. carousels
	x2	=	# of 60 ft. carousels

Figure 26.
The Objective Function and Decision Variables.

The next step is to determine the constraints. The constraints are as follows and shown in **Figure 27**:

- The number of carriers needs to be no less than 284 from the calculation from **Figure 24** for Production and Engineering products
- The cost shall not exceed \$363,000
- The number of carousels is 6 from **Figure 24**

Constraints:	Carriers Needed	=	284
	40x1 + 50x2	=	284
	Carousels	=	6
	x1 + x2	=	6
	Maximum Spending	=	\$363,000
	42000x1 + 63000x2	≤	\$363,000

Figure 27.
The constraints for the Objective Function.

The Linear Program Equation is developed using a Microsoft add on called Excel Solver to determine the optimal mix of carousels. The output is shown in **Figure 28**. The Linear Program Equation derives that the optimal mix of carousels to obtain at least 284 carriers while keeping the cost under \$363,000 is five 60 feet carousels and one 48 feet carousel. The entire spreadsheet is shown in **Figure 29**.

48 ft.	60 ft.	Carriers Obtained	Optimal Cost
1	5	290	$357,000

Target Cell

Cost = Z = 42000x1 + 63000x2

Figure 28.
The Linear Program Equation with Microsoft Solver derived numbers.

Although the equation states that the optimal mix of carousels are five 60 foot and one 48 foot, due to aesthetic and expected growth the author decided to procure six 60 feet carousels for Production and Engineering products in El Segundo. The author convinced the team to procure six 60 foot horizontal carousels, but another concern arrives: How will a store clerk know which standard tote type is needed for which parts as it arrives from Receiving? The author decided to develop a tote template to create an efficient flow of products to store in the carousels.

OPTIMAL CAROUSELS OPERATIONS RESEARCH PROBLEM

Objective Function: Minimize cost of purchasing carousels
Minimize Z = 42000x1 + 63000x2

Decision Variables: Amount of 48 ft. & 60 ft. carousels
x1 = # of 48 ft. carousels
x2 = # of 60 ft. carousels

Input Data:

	Carousel 48 ft.	Carousel 60 ft.
Purchasing Cost	$42,000	$63,000
Total Carriers	40	50

Purchasing Plan:

	48 ft.	60 ft.	Carriers Obtained	Optimal Cost
Amount of carousels to purchase	1	5	290	$357,000

Target Cell
Cost = Z = 42000x1 + 63000x2

Constraints:		
Carriers Needed	=	284
40x1 + 50x2	=	284
Carousels	=	6
x1 + x2	=	6
6	=	6
Maximum Spending	=	$363,000
42000x1 + 63000x2	≤	$363,000

Figure 29.
The Operations Research spreadsheet.

Quantitative Analysis VI

Improving Storage Process Flow

Referring back to the current warehouse storage configuration, the process was cumbersome and time consuming due to lengthy operator travel time in order to store the products. Also, due to the "library" storage concept of the parts, new products are painfully stored by shifting all the parts from top to down and left to right shown in **Figure 7**. A new storing concept is needed to be efficient. First, the carousels are layout into configuration known as a Pod, which consists of 2 carousels per store clerk as shown in **Figure 30**. Instead of the store clerk walking to the storage location, the storage location will automatically rotate to the clerk. The clerk worked on one carousel while the other one rotated to the next part to be pulled or put away. This concept was studied and documented in an academic journal to prove efficiency (Meller and Klote, 2004). The store clerk used barcode technology to make sure the correct products are pulled instead of reading the alpha numeric part number preventing transcription errors. With the new storing process the cycle time and part number error improve tremendously.

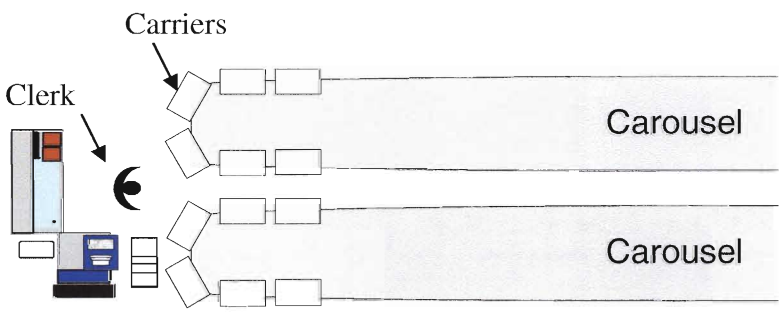


Figure 30.
A schematic of a Carousel POD.

First the clerk will take the products from RIT and place them on a tote type template shown in **Figure 31** with standard sizes derived from the random sampling study. The clerk will place the part on the template to determine the tote size that will be entering into the Warehouse Management System (WMS). Once the tote size is entered, the carousel will automatically rotate to the closest open location with the specified tote size. The clerk will then store the parts in the location and scan the location barcode with the part's barcode. The new put away process is shown on **Figure 32**.

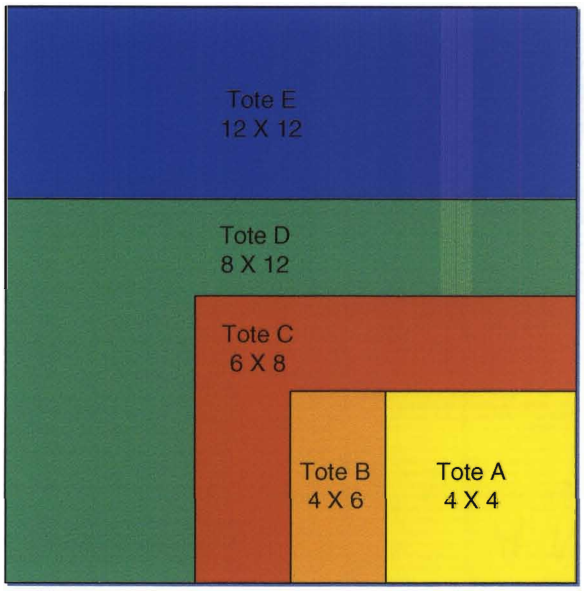


Figure 31.
An example of a standardize tote template place on the store clerk's workstation.

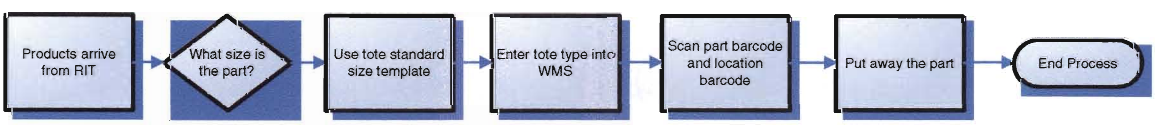


Figure 32.
A process flow of the new storage with carousel and partition.

Developing this new process dramatically improves the productivity of the warehouse. Total cycle time to retrieve a part and assemble into a kit has improved from 50 hrs to 0.25 hr. The total throughput for a product transacted more than quadrupled. Conducting the study and using the algorithm provided a systematic approach to reduce valuable real estate and eliminate redundant work. Most importantly, the customers are now receiving all required parts within a kit due to the new process, whereas; previously they were executing the work hoping the parts would come in time for the next assembly. This improves the overall productivity of the company. The final step in the algorithm is to execute the consolidation of warehouses once a practitioner completes the steps in the algorithm shown on **Figure 33**. The actual execution of consolidation is not within scope of this thesis and will not be discussed.

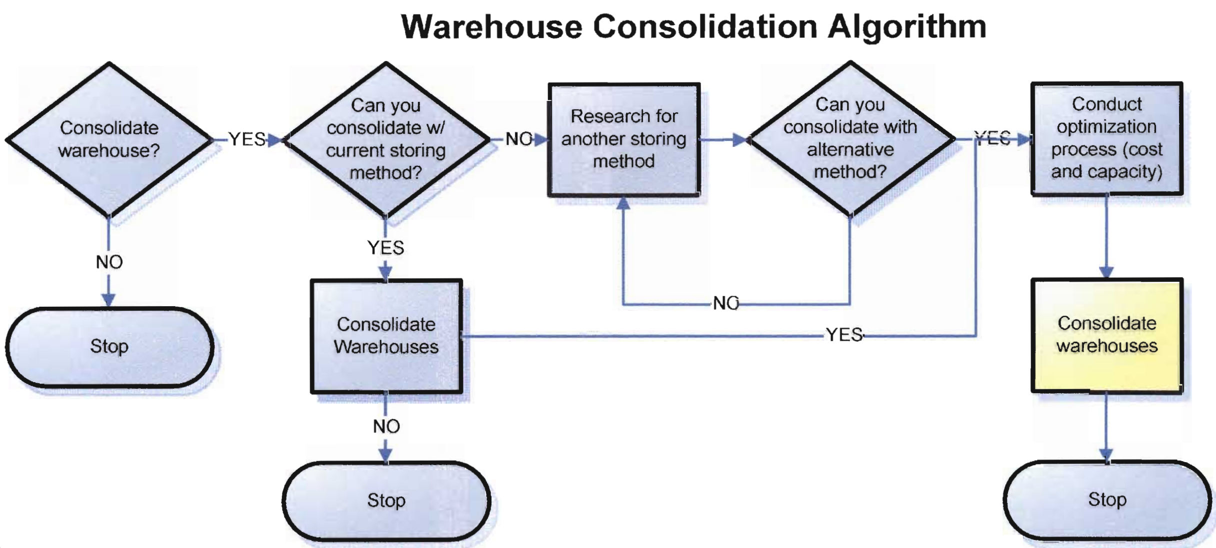


Figure 33.
The final step in the algorithm is to consolidate the warehouses.

CHAPTER 6

THE RESULTS

At the beginning of the thesis case study the objective was to consolidate all warehouses to a single location to reduce cost and improve efficiency. Originally, the data shows the current capacity is 2.40 unique part numbers for every square foot of available space. The warehouse now can hold 5.51 available locations for every square foot after the consolidation and the process are improved dramatically. This is more than twice the capacity that was consumed before the effort. Not only is the warehouse storing parts more efficiently as shown by the data from the WMS on **Figure 29**, the process has improved dramatically as well. One can see that the average parts pick and issue from the warehouse has improved dramatically since the consolidation with the new WMS in place. The company realized a savings of over $1.4 million in real estate and labor savings through this effort. Most importantly, the company can position itself for future growth while controlling cost.

	Dec 03	**Dec 05**	**Impact**
Parts per square foot	2.4	5.51	56.54% reduction
# of picks/ day	78 picks	335 picks	+4 X
Real estate savings (square footage)	43,501	22,750	20,751 extra square foot
Cycle time per kit	50 hr	.25 hr	99% reduction
Capacity consume	~ 80% observation	65% WMS data	23% capacity improvements
Savings impact: $1.4 M in real estate and labor savings $756 K in mitigated cost of incur capital (12 carousels)			

Figure 29.
A matrix of performance results from the algorithm.

CHAPTER 7

CONCLUSION

Real estate is at a premium and optimal usage of the available area is a competitive advantage to a company. Due to mergers and acquisitions a company can allocate and use real estate poorly. The purpose of this thesis was to examine traditional storage methods, identify opportunity areas and document the process to optimally use real estate in order to gain a competitive advantage. An algorithm is developed in this thesis utilizing several quantitative analyses to efficiently and optimally consolidate warehouses.

Raytheon Space and Airborne Systems division headquarter in El Segundo, CA was used as a test bed for the algorithm. The facilities to warehouse products are across the corridor due to recent mergers and acquisition and poor warehouse performance. The solution was to consolidate the warehouses in order to reduce real estate and redundant work cost. It also would provide better control of resources and service requests. The algorithm developed in the thesis consists of a series of quantitative analyses in order to optimize the execution of consolidation. The literature review does not provide any evidence of this type of algorithm for this application. Different concepts and research are put together to develop the algorithm.

The proposed algorithm consists of five steps asking distinct questions in order to move forward. The main questions from the algorithm are:

1. Do you want to consolidate?
2. Can you consolidate with the current storage method?
3. Can you consolidate with an alternative method?
4. Conduct an optimization process for cost and capacity.
5. Consolidate warehouses.

Within these questions are several quantitative analyses to determine the next step. The analyses consist of statistical inferences from basic arithmetic to linear programming. It will enable a practitioner to decide if one can consolidate. Consolidating warehouses take a lot of resources and investments. The proposed algorithm will help provide a detailed study for managers and leaders to make a sound decision.

The algorithm was tested and found extraordinary results. The algorithm provided the reduction of material handling costs and enabled denser storage of material. It also provided better throughput and visibility by identifying parts and their corresponding locations quickly, reducing search time. Consolidating warehouses enabled the company to utilize real estate more efficiently. The case study from Raytheon showed that the warehouse more than doubles its capacity while improving productivity. Most importantly, this positions the company for growth and provided a competitive advantage.

In conclusion, the algorithm was successfully implemented in a Fortune 500 company to demonstrate the analytical applications. The case study provided improving metrics which are a result of the detailed study from the algorithm. The proposed algorithm can be applied to any company where warehouse consolidation is needed and the parts are not on pallets. The storage optimization for bulk, environmental need, and sensitive handling parts are not within scope of this thesis. The focus of the thesis is about parts utilized in a horizontal carousel environment. By incorporating and combining different improvement and optimization techniques, a proposed algorithm is developed. The algorithm provides a study for decision makers to optimize capacity, cost, and process in order to consolidate warehouses.

CHAPTER 8

FUTURE RESEARCH

There are three keys area that need further research for the purpose of warehouse consolidation and optimization. The first is to develop an algorithm to consolidate warehouses that use bulk items on pallets, sensitive handling, and environment needed products. The second is to develop an efficient method to store products in a “library” shelf principle. The third is to develop a better method to quantify the efficient usage of storage in any given warehouse. These are areas that are not discussed in the thesis but should be considered for further research.

Future research can be conducted in developing an algorithm to consolidate warehouses with products that are bulk on pallets, sensitive handling, and environment needed products. The thesis focused on small electronic components that can be stored on shelves or carousels. The study took in account that bulk items and items that need to be stored in environmental control area would not be pursued. Several researches have shown bulk items can be optimized by efficient facility layouts using Linear Programming to prove the theory. Simulations are widely used to mimic the theorized layouts and the material handling flow to show improvements in throughput and reduction in traffic congestion. For the purpose of the thesis an algorithm to consolidate bulk and sensitive items are not analyzed. Better usage of bulk items can be a greater benefit because handling bulk items can be cumbersome and it takes up more space than other types of products. Consolidation of special handling and sensitive products can be a more difficult task because one has to devise a plan to ensure the safety of the products during transit. Also, it will need to require special handling equipment that may not be cost effective to relocate due to facility infrastructure. Further research is needed for these types of products.

During the development of the algorithm, the process to find another efficient storage method can cycle. However, if a storage method such as using partitions or carousels is not cost effective, one needs to find a better method to store products in a "library" shelving convention. The "library" shelving convention is used because it is the easiest way to store and locate a products alpha numeric. Through time this process can cause inefficiency due to new products and the travelling time to retrieve and store the products. A study is needed to understand if there is a better method to store products on shelves and retrieve the products quicker.

The third topic of future research can be in developing a mechanism to quantify the density in the warehouse using shelving mechanism. In the case study, the density in the warehouse is determined by two methods 1) determining the numbers of parts per square foot and 2) qualitative analysis of which shelves are open for storage. These two methods have flaws. The first method provides number of parts per square foot but does not tell the volume of space the products consume. The second method provides a good gauge of which shelves on a layout are consumed and which are free. However, this method does not allow accurate quantification of the available space. Determining the density of a warehouse can be tedious if one measures and analyzes each shelf. Therefore, more research is needed in this field to efficiently and accurately determine the density of a warehouse.

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APPENDIX

SCENARIO #1 (WITH STOCK AND ORDERS)

50-Carrier Carousel	
Total Carrier/Carousel	50
Carrier Height	97
Carrier Width	24.5
Carrier Depth	24
Shelf Height	4
Shelf Height w/Clearance	6.0625
Total Shelf/Carrier	16

Tote Type	A	B	C	D	E	F	G
Tote Size (W x D x H)	4 x 4 x 4	4 x 6 x 4	6 x 8 x 4	8 x 12 x 4	12 x 12 x 4	12 x 24 x 4	24 x 24 x 4
Count	214	264	136	204	146	105	18
Percent Mix of Totes	19.2%	23.7%	12.2%	18.3%	13.1%	9.4%	1.6%
Locations/Tote	6	4	3	2	2	1	1
Locations/Shelf	36	24	12	6	4	2	1
Locations/Carrier	110	91	23	17	8	3	0.26
Total Storage Locations/Carrier	252						
Locations/Carousel	5537	4554	1173	879	419	150	12
Total Storage Locations/Carousel	12724						

# of Carriers Needed:

**Total carrier storage locations needed	71,550
Total carrier storage locations available	252
Total carriers needed	**283.6**

# of Carousels Needed:

**Total horizontal carousel storage locations needed	71,550
Total horizontal carousel storage locations available	12,724
Total carousels needed	**5.6**

** Total of ICS (50,171) and ECS (12,898) inventory

40-Carrier Carousel	
Total Carrier/Carousel	40
Carrier Height	97
Carrier Width	24.5
Carrier Depth	24
Shelf Height	4
Shelf Height w/Clearance	6.0625
Total Shelf/Carrier	16

Tote Type	A	B	C	D	E	F	G
Tote Size (W x D x H)	4 x 4 x 4	4 x 6 x 4	6 x 8 x 4	8 x 12 x 4	12 x 12 x 4	12 x 24 x 4	24 x 24 x 4
Count	214	264	136	204	146	105	18
Percent Mix of Totes	19.2%	23.7%	12.2%	18.3%	13.1%	9.4%	1.6%
Locations/Tote	6	4	3	2	2	1	1
Locations/Shelf	36	24	12	6	4	2	1
Locations/Carrier	110	91	23	17	8	3	0.26
Total Storage Locations/Carrier	252						
Locations/Carousel	4429	3643	938	703	335	120	10
Total Storage Locations/Carousel	10178						

# of Carousels Needed:

**Total horizontal carousel storage locations needed	71,550
Total horizontal carousel storage locations available	10,178
Total carousels needed	**7.0**

	50-Carrier Carousel	40-Carrier Carousel
Total Carrier/Carousel	50	40
Carrier Height	97	97
Carrier Width	24.5	24.5
Carrier Depth	24	24
Shelf Height	4	4
Shelf Height w/Clearance	6.0625	6.0625
Total Shelf/Carrier	16	16

	Carriers Needed	Carousels Needed from calculations	Carousels Needed to procure
F Stores	74.9	1.5	2.0
J Stores	99.1	1.9	2.0
**Rest of Stores	283.6	5.6	6.0
Total	457.6	9.0	10.0
**All Production and Engineering products from ECS and ICS			

NOTE: Results calculated from using ICS Inventory data with stock on hand and orders already given

OPTIMAL CAROUSELS OPERATIONS RESEARCH PROBLEM

SCENARIO #1 (WITH ICS INV GROUP = 18,386)

Objective Function:

Minimize cost of purchasing carousels
Minimize Z = 42000x1 + 63000x2

Decision Variables:

Amount of 48 ft. & 60 ft. carousels
x1 = # of 48 ft. carousels
x2 = # of 60 ft. carousels

Input Data:

	Carousel 48 ft.	Carousel 60 ft.
Purchasing Cost	$42,000	$63,000
Total Carriers	40	50

Purchasing Plan:

	48 ft.	60 ft.	Carriers Obtained	Optimal Cost
Amount of carousels to purchase	1	5	290	$357,000

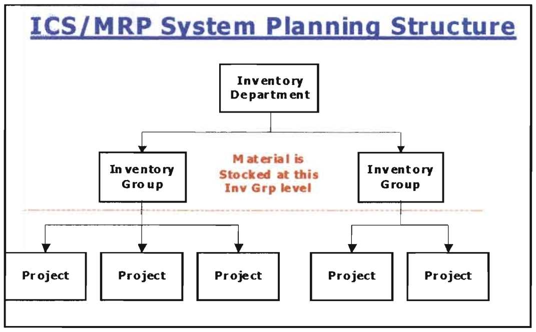
Target Cell
Cost = Z = 42000x1 + 63000x2

Constraints:

Carriers Needed	=	284
40x1 + 50x2	=	284
Carousels	=	6
x1 + x2	=	6
6	=	6
Maximum Spending	=	$363,000
42000x1 + 63000x2	?	$363,000

NOTE: With the purchasing plan of five 60-ft carousels and one 48-ft carousel, we will be able to meet our carriers constraint, while also gaining 6 additional carriers, and staying under budget (by $6,000).

ICS Storage requirements



ICS Data:		# of Part Numbers				
Inv Dept	Program Name	PRJ level	INV GRP level	INV GRP level with stock	INV GRP level with stock or orders	INV GRP level with stock or orders or MRP
62	Warehouse 1	25277	18655	13256	14678	18386
73	Warehouse 2	27661	15212	9434	9528	13213
74	Warehouse 3	9233	8266	5255	5374	7372
75	Warehouse 4	9549	7211	4872	4923	6389
TOTAL	**Total**	71,720	49,344	32,817	**34,503**	**45,360**

Horizontal Carousel storage locations (also called bin boxes or line items) required:

Unique Part Numbers (PN, Inv Dept, Inv Grp) with stock or orders	34,503	45,360
% that is bulk	3%	3%
Unique carousel Part Numbers	33468	43999
% or number that requires vertical carousel controlled storage (nitrogen, etc.)	20%	20%
Unique horizontal carousel Part Numbers	26774	35199
Growth factor (remember, this is hopefully offset by obsolescence)	20%	20%
Horizontal carousel Part Numbers with growth	32129	42239
Storage locations per Part Number (due to random stocking)	1.4	1.4
Horizontal carousel storage unique locations needed	44981	59135
Utilization factor (for efficient location of empty bin boxes when stocking)	90%	90%
Total horizontal carousel storage locations needed	**49,479**	**65,048**

ECS STORE SUMMARY

Excludes F, G, and S stores

For Records with Positive Stock Balances

Data as of February 26, 2004

STORE CODE	LINE ITEM COUNT	TOTAL STOCK VALUE	Lot	Clerks	Supervisors	Nitrogen Pur	Bulk
A	147					1	0
B	6,440					112	235
J	5,776					45	27
Total	12,363					158	262

Horizontal Carousel storage locations (also called bin boxes or line items) required:

Unique Part Numbers (PN, Inv Dept, Inv Grp) with stock or orders	12,363
Number of bulk line item	262
Unique carousel Part Numbers	12101
Number needed vertical carousel controlled storage (nitrogen, etc.)	158
Unique horizontal carousel Part Numbers	11943
Growth factor (remember, this is hopefully offset by obsolescence)	20%
Horizontal carousel Part Numbers with growth	14332
Storage locations per Part Number (due to random stocking)	1.4
Horizontal carousel storage locations needed	20064
Utilization factor (for efficient location of empty bin boxes when stocking)	90%
Total horizontal carousel storage locations needed	**22,071**

J STORES

J stores	line item	value	lot numbers	clerks	supervisor
Cabinets	13,415				
Bulk	3,446				
GN2	2226				

Horizontal Carousel storage locations (also called bin boxes or line items) required:

Unique Part Numbers (PN, Inv Dept, Inv Grp) with stock or orders	13,415
Number that is bulk	3446
Unique carousel Part Numbers	9969
Number that requires vertical carousel controlled storage (nitrogen, etc.)	2226
Unique horizontal carousel Part Numbers	7743
Growth factor (remember, this is hopefully offset by obsolescence)	20%
Horizontal carousel Part Numbers with growth	9292
Storage locations per Part Number (due to random stocking)	1.4
Horizontal carousel storage locations needed	13008
Utilization factor (for efficient location of empty bin boxes when stocking)	90%
Total horizontal carousel storage locations needed	**14,309**

F STORES

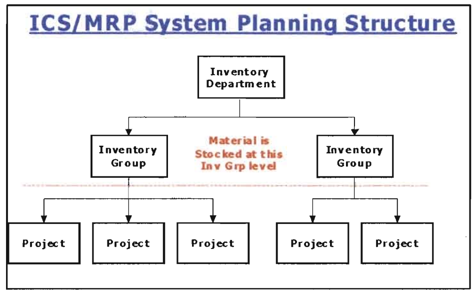
F stores	line item	value	lot numbers	clerks	supervisor
Cabinets	12,998				
Bulk	2,132				
GN2	1667				

Horizontal Carousel storage locations (also called bin boxes or line items) required:

Unique Part Numbers (PN, Inv Dept, Inv Grp) with stock or orders	12,998
% that is bulk	2132
Unique carousel Part Numbers	10866
Number that requires vertical carousel controlled storage (nitrogen, etc.)	1667
Unique horizontal carousel Part Numbers	9199
Growth factor (remember, this is hopefully offset by obsolescence)	20%
Horizontal carousel Part Numbers with growth	11039
Storage locations per Part Number (due to random stocking)	1.4
Horizontal carousel storage locations needed	15454
Utilization factor (for efficient location of empty bin boxes when stocking)	90%
Total horizontal carousel storage locations needed	**17,000**

ICS Storage requirements

Terminology
Carousel
Carrier
Shelf
Totes
Partition
Pods



ICS Data:		# of Part Numbers				
Inv Dept	Program Name	PRJ level	INV GRP level	INV GRP level with stock	INV GRP level with stock or orders	INV GRP level with stock or orders or MRP
85	R24 Centra	25277	18655	13256	14678	18386
88	ATFLIR	27661	15212	9434	9528	13213
98	EPPS	9233	8266	5255	5374	7372
99	R23 Fabs	9549	7211	4872	4923	6389
TOTAL		71,720	49,344	32,817	**34,503**	**45,360**

Horizontal Carousel storage locations (also called bin boxes or line items) required:	
Unique part numbers	34,503
Percentage that is bulk	3%
Unique carousel part numbers without bulk	33468
Percentage that requires special storage (environmental, sensitive, etc.)	20%
Unique carousel part numbers w/o bulk and environmental need	26774
Potential growth factor	20%
Horizontal carousel part numbers with growth	32129
Storage locations per part number through time factor	1.4
Horizontal carousel storage unique locations needed	44981
Utilization factor (for efficient location of empty bin boxes when stocking)	90%
Total horizontal carousel storage locations needed	49,479

Horizontal Carousel capacity information:

Average bin box configuration per carrier:

tote height:	2.75"	2.75"	2.75"	2.75"	5"	5"	5"	5"	**Total**
*tote width:	3.25"	6.5"	9.75"	13"	3.25"	6.5"	9.75"	13"	**per carrier**
# totes/carrier:	52	8	4	2	6	3	2	1	**78**

*Note - each shelf is 20" wide - therefore, as an example, 6 of the bin boxes that are 3.25" wide could fit on one shelf.

Horizontal Carousel storage locations available:

# Carriers	58	(based on Texas actuals)
Total horizontal carousel storage locations available	**4524**	(# totes/ carrier * # of carriers on a carousel)

# of carousels needed:

Total horizontal carousel storage locations needed	49,479
Total horizontal carousel storage locations available	4524
Total carousels needed	**11**

ECS STORE SUMMARY

Excludes F, G, and S stores

For Records with Positive Stock Balances

Data as of February 26, 2004

STORE CODE	LINE ITEM COUNT	TOTAL STOCK VALUE	Lot	Clerks	Supervisors	Nitrogen Pur	Bulk
A	147					1	0
B	6,440					112	235
J	5,776					45	27
Total	12,363					158	262

Horizontal Carousel storage locations (also called bin boxes or line items) required:

Unique Part Numbers (PN, Inv Dept, Inv Grp) with stock or orders	12,363
Number of bulk line item	262
Unique carousel Part Numbers	12101
% needed vertical carousel controlled storage (nitrogen, etc.)	158
Unique horizontal carousel Part Numbers	11943
Growth factor (remember, this is hopefully offset by obsolescence)	20%
Horizontal carousel Part Numbers with growth	14332
Storage locations per Part Number (due to random stocking)	1.4
Horizontal carousel storage locations needed	20064
Utilization factor (for efficient location of empty bin boxes when stocking)	90%
Total horizontal carousel storage locations needed	**22,071**

Horizontal Carousel capacity information:

Dimensions/specifications (based on McKinney carousels):

Total length	60 ft.
Total width	5 ft. 4 in.
Total height	8 ft. 8 in.
Total height (top of track)	9 ft. 8 in.
Total height (including motor, mechanical, etc.)	12 ft. 8 in.

Average bin box configuration per rack/carrier:

									Total per rack
bin box height:	2.75"	2.75"	2.75"	2.75"	5"	5"	5"	5"	
*bin box width:	3.25"	6.5"	9.75"	13"	3.25"	6.5"	9.75"	13"	
# bin boxes/carrier:	52	8	4	2	6	3	2	1	**78**

*Note - each shelf is 20" wide - therefore, as an example, 6 of the bin boxes that are 3.25" wide could fit on one shelf. Also, the widths of all bin boxes are multiples of 3.25", so one 6.5" wide bin box can be removed and replaced with two 3.25" wide bin boxes.

Horizontal Carousel storage locations available:

# Carriers	58	(based on McKinney actuals)
Shelves per carrier	19	(based on McKinney actuals)
Avg locations (bin boxes) per shelf	4.1	
Total bin boxes per carousel	4524	
# of divided compartments per bin box	1	
Total horizontal carousel storage locations available	**4524**	

# of carousels needed:

Total horizontal carousel storage locations needed	22,071
Total horizontal carousel storage locations available	4524
Total carousels needed	5

F stores	line item	value	lot numbers	clerks	supervisor
Cabinets	12,998	$10,779,497.00			
Bulk	950	$6,542,293.00			
GN2	133	$19,283.00			

Horizontal Carousel storage locations (also called bin boxes or line items) required:

Unique Part Numbers (PN, Inv Dept, Inv Grp) with stock or orders	12,998	
% that is bulk	2132	
Unique carousel Part Numbers	10866	
Number that requires vertical carousel controlled storage (nitrogen, etc.)	1667	need number
Unique horizontal carousel Part Numbers	9199	
Growth factor (remember, this is hopefully offset by obsolescence)	20%	
Horizontal carousel Part Numbers with growth	11039	
Storage locations per Part Number (due to random stocking)	1.4	
Horizontal carousel storage locations needed	15454	
Utilization factor (for efficient location of empty bin boxes when stocking)	90%	
Total horizontal carousel storage locations needed	**17,000**	

Horizontal Carousel capacity information:

Dimensions/specifications (based on McKinney carousels):

Total length	60 ft.
Total width	5 ft. 4 in.
Total height	8 ft. 8 in.
Total height (top of track)	9 ft. 8 in.
Total height (including motor, mechanical, etc.)	12 ft. 8 in.

Average bin box configuration per rack/carrier:

bin box height:	2.75"	2.75"	2.75"	2.75"	5"	5"	5"	5"	**Total**
*bin box width:	3.25"	6.5"	9.75"	13"	3.25"	6.5"	9.75"	13"	**per rack**
# bin boxes/carrier:	52	8	4	2	6	3	2	1	**78**

*Note - each shelf is 20" wide - therefore, as an example, 6 of the bin boxes that are 3.25" wide could fit on one shelf. Also, the widths of all bin boxes are multiples of 3.25", so one 6.5" wide bin box can be removed and replaced with two 3.25" wide bin boxes.

Horizontal Carousel storage locations available:

# Carriers	58	(based on McKinney actuals)
Shelves per carrier	19	(based on McKinney actuals)
Avg locations (bin boxes) per shelf	4.1	
Total bin boxes per carousel	4524	
# of divided compartments per bin box	1	
Total horizontal carousel storage locations available	**4524**	

# of carousels needed:

Total horizontal carousel storage locations needed	17,000
Total horizontal carousel storage locations available	4524
Total carousels needed	**4**

J stores	line item	value	lot numbers	clerks	supervisor
Cabinets	13,415	$2,551,378.00			
Bulk	1,641	$2,024,329.00			
GN2	29	$33,144.00			

Horizontal Carousel storage locations (also called bin boxes or line items) required:

Unique Part Numbers (PN, Inv Dept, Inv Grp) with stock or orders	13,415
% that is bulk	3446
Unique carousel Part Numbers	9969
Number that requires vertical carousel controlled storage (nitrogen, etc.)	2226
Unique horizontal carousel Part Numbers	7743
Growth factor (remember, this is hopefully offset by obsolescence)	20%
Horizontal carousel Part Numbers with growth	9292
Storage locations per Part Number (due to random stocking)	1.4
Horizontal carousel storage locations needed	13008
Utilization factor (for efficient location of empty bin boxes when stocking)	90%
Total horizontal carousel storage locations needed	**14,309**

Horizontal Carousel capacity information:
Dimensions/specifications (based on McKinney carousels):

Total length	60 ft.
Total width	5 ft. 4 in.
Total height	8 ft. 8 in.
Total height (top of track)	9 ft. 8 in.
Total height (including motor, mechanical, etc.)	12 ft. 8 in.

Average bin box configuration per rack/carrier:

bin box height:	2.75"	2.75"	2.75"	2.75"	5"	5"	5"	5"	**Total**
*bin box width:	3.25"	6.5"	9.75"	13"	3.25"	6.5"	9.75"	13"	**per rack**
# bin boxes/carrierl:	52	8	4	2	6	3	2	1	**78**

*Note - each shelf is 20" wide - therefore, as an example, 6 of the bin boxes that are 3.25" wide could fit on one shelf. Also, the widths of all bin boxes are multiples of 3.25", so one 6.5" wide bin box can be removed and replaced with two 3.25" wide bin boxes.

Horizontal Carousel storage locations available:

# Carriers	58	(based on McKinney actuals)
Shelves per carrier	19	(based on McKinney actuals)
Avg locations (bin boxes) per shelf	4.1	
Total bin boxes per carousel	4524	
# of divided compartments per bin box	1	
Total horizontal carousel storage locations available	**4524**	

# of carousels needed:

Total horizontal carousel storage locations needed	14,309
Total horizontal carousel storage locations available	4524
Total carousels needed	**4**

F Stores

Part Sizes	Percent	Cum %	Count
5.0 x 4.0 x 0.75 **to** 6.75 x 5.75 x 0.5	25.9	25.9	42
9.0 x 8.5 x 0.5 **to** 10.75 x 7.0 x 1.0	22.2	48.1	36
7.0 x 4.0 x 0.75 **to** 8.75 x 6.25 x 0.25	19.8	67.9	32
3.25 x 3.0 x 3.0 **to** 4.75 x 4.5 x 0.25	16	84	26
15.0 x 5.5 x 2.0 **to** 16.5 x 4.5 x 0.75	6.2	90.1	10
11.0 x 3.75 x 0.25 **to** 12.5 x 9.5 x 2.0	5.6	95.7	9
25.0 x 7.0 x 1.25 **to** 27.5 x 4.75 x 0.50		100	7
0.75 x 6.75 x 1.0 **to** 2.0 x 3.0 x 3.0	4.3		2
13.0 x 8.0 x 0.75 **to** 14.0 x 13.0 x 3.0			3
22.0 x 5.0 x 2.5 **to** 25.0 x 4.0 x 1.5			2

F Stores Sorted

Part Sizes	Percent	Cum %	Count
0.75 x 6.75 x 1.0 **to** 2.0 x 3.0 x 3.0	1.075		2
3.25 x 3.0 x 3.0 **to** 4.75 x 4.5 x 0.25	16	84	26
5.0 x 4.0 x 0.75 **to** 6.75 x 5.75 x 0.5	25.9	25.9	42
7.0 x 4.0 x 0.75 **to** 8.75 x 6.25 x 0.25	19.8	67.9	32
9.0 x 8.5 x 0.5 **to** 10.75 x 7.0 x 1.0	22.2	48.1	36
11.0 x 3.75 x 0.25 **to** 12.5 x 9.5 x 2.0	5.6	95.7	9
13.0 x 8.0 x 0.75 **to** 14.0 x 13.0 x 3.0	1.075		3
15.0 x 5.5 x 2.0 **to** 16.5 x 4.5 x 0.75	6.2	90.1	10
22.0 x 5.0 x 2.5 **to** 25.0 x 4.0 x 1.5	1.075		2
25.0 x 7.0 x 1.25 **to** 27.5 x 4.75 x 0.50	1.075	100	7

J Stores

Part Sizes	Percent	Cum %	Count
5.0 x 4.0 x 0.75 **to** 6.75 x 5.75 x 0.5	31.3	31.3	55
9.0 x 8.5 x 0.5 **to** 10.75 x 7.0 x 1.0	23.9	55.1	42
7.0 x 4.0 x 0.75 **to** 8.75 x 6.25 x 0.25	16.5	71.6	29
3.25 x 3.0 x 3.0 **to** 4.75 x 4.5 x 0.25	9.7	81.3	17
15.0 x 5.5 x 2.0 **to** 16.5 x 4.5 x 0.75	6.8	88.1	12
11.0 x 3.75 x 0.25 **to** 12.5 x 9.5 x 2.0	5.1	93.2	9
25.0 x 7.0 x 1.25 **to** 27.5 x 4.75 x 0.50	3.4	96.6	6
0.75 x 6.75 x 1.0 **to** 2.0 x 3.0 x 3.0	3.4	100	6

J Stores Sorted

Part Sizes	Percent	Cum %	Count
0.75 x 6.75 x 1.0 **to** 2.0 x 3.0 x 3.0	3.4	100	6
3.25 x 3.0 x 3.0 **to** 4.75 x 4.5 x 0.25	9.7	81.3	17
5.0 x 4.0 x 0.75 **to** 6.75 x 5.75 x 0.5	31.3	31.3	55
7.0 x 4.0 x 0.75 **to** 8.75 x 6.25 x 0.25	16.5	71.6	29
9.0 x 8.5 x 0.5 **to** 10.75 x 7.0 x 1.0	23.9	55.1	42
11.0 x 3.75 x 0.25 **to** 12.5 x 9.5 x 2.0	5.1	93.2	9
15.0 x 5.5 x 2.0 **to** 16.5 x 4.5 x 0.75	6.8	88.1	12
25.0 x 7.0 x 1.25 **to** 27.5 x 4.75 x 0.50	3.4	96.6	6

R24 Stores & ATFLIR combined

Part Sizes	Percent	Cum %	Count
11.0 x 6.25 x 0.25 **to** 12.75 x 10.75 x 0.5	25.5	25.5	78
9.0 x 4.0 x 0.75 **to** 10.75 x 10.75 x 1.5	23.5	49	72
7.0 x 4.0 x 1.5 **to** 8.75 x 8.0 x 0.5	18	67	55
13.0 x 4.5 x 2.25 **to** 14.75 x 10.75 x 0.5	12.4	79.4	38
5.0 x 3.5 x 0.25 **to** 6.88 x 5.63 x 0.13	5.9	85.3	18
15.0 x 10.5 x 2.5 **to** 16.0 x 8.5 x 0.5	3.6	88.9	11
3.5 x 2.63 x 2.0 **to** 4.75 x 4.75 x 2.13	3.6	92.5	11
25.0 x 7.0 x 1.25 **to** 27.5 x 4.75 x 0.5	2.6	95.1	8
17.0 x 11.5 x 1.25 **to** 18.5 x 15.25 x 2.5		100	15
19.0 x 16.0 x 0.5 **to** 20.0 x 16.0 x 5.0	4.9		
21.5 x 4.25 x 0.50 **to** 22.0 x 4.0 x 1.0			
23.0 x 9.0 x 3.5 **to** 24.5 x 4.5 x 0.25			

R24 Stores & ATFLIR Sorted

Part Sizes	Percent	Cum %	Count
3.5 x 2.63 x 2.0 **to** 4.75 x 4.75 x 2.13	3.6	92.5	11
5.0 x 3.5 x 0.25 **to** 6.88 x 5.63 x 0.13	5.9	85.3	18
7.0 x 4.0 x 1.5 **to** 8.75 x 8.0 x 0.5	18	67	55
9.0 x 4.0 x 0.75 **to** 10.75 x 10.75 x 1.5	23.5	49	72
11.0 x 6.25 x 0.25 **to** 12.75 x 10.75 x 0.5	25.5	25.5	78
13.0 x 4.5 x 2.25 **to** 14.75 x 10.75 x 0.5	12.4	79.4	38
15.0 x 10.5 x 2.5 **to** 16.0 x 8.5 x 0.5	3.6	88.9	11
17.0 x 11.5 x 1.25 **to** 18.5 x 15.25 x 2.5	1.225	100	15
19.0 x 16.0 x 0.5 **to** 20.0 x 16.0 x 5.0	1.225		
21.5 x 4.25 x 0.50 **to** 22.0 x 4.0 x 1.0	1.225		
23.0 x 9.0 x 3.5 **to** 24.5 x 4.5 x 0.25	1.225		
25.0 x 7.0 x 1.25 **to** 27.5 x 4.75 x 0.5	2.6	95.1	8

Average bin box configuration per rack/carrier:

Tote Type	A	B	C	D
bin box height:	4"	4"	4"	4"
bin box depth:	24"	24"	24"	24"
*bin box width:	4"	4"	4"	8"
# bin box sub slots	6	4	2	3
Total Cubic Inches	64	96	192	256
% Mix of Totes*	70%	10%	10%	10%

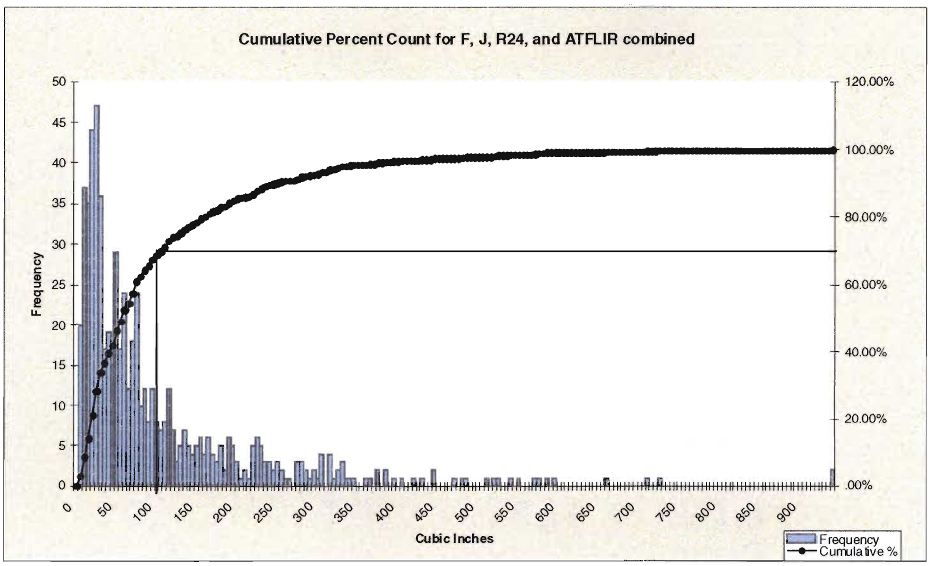
*Based on observations made in El Segundo by Abel Womack

Average bin box configuration per rack/carrier:

Tote Type	A	B	C	D	Extra
bin box height:	4"	4"	4"	4"	bin size greater
bin box depth:	24"	24"	24"	24"	than Tote Type D
*bin box width:	4"	4"	4"	8"	
# bin box sub slots	6	4	2	3	
Total Cubic Inches	64	96	192	256	
% Mix of Totes*	54.35%	13.51%	16.61%	6.21%	9.32%
% Mix of Totes**	2.80%	5.12%	1.71%	24.07%	66.30%

*Based on cubic in. of random sample of parts

**Based on actual dimensions of random sample of parts



RESULTS:

70% of the data	105 cubic inches or less
Population size	56,929
Sample size (@95% confidence)	644
Confidence Interval (+/-)	3.80%

ASSUMPTIONS:

* Results mentioned above are based on the combination of individual random sampling of each store

Length	Width	Depth	Cubic In.	Tote Size (based on dimensions)
5.50	4.00	0.07	1.54	B
0.50	8.00	0.50	2.00	C
5.00	4.00	0.13	2.50	B
4.75	4.25	0.13	2.62	D
4.75	4.75	0.13	2.93	D
3.5	3.5	0.25	3.06	A
3.5	3.5	0.25	3.06	A
5.50	4.75	0.13	3.27	D
3.75	3.5	0.25	3.28	A
4	3.5	0.25	3.50	A
4	3.5	0.25	3.50	A
4	3.5	0.25	3.50	A
6.50	4.75	0.13	3.86	D
6.00	5.00	0.13	3.90	D
4	4	0.25	4.00	A
4.75	3.5	0.25	4.16	B
4.75	3.5	0.25	4.16	B
6.00	5.75	0.13	4.31	D
5.00	3.50	0.25	4.38	B
6.88	5.63	0.13	4.83	D
0.75	6.75	1	5.06	C
6	3.5	0.25	5.25	B
4.75	4.5	0.25	5.34	D
4.75	4.5	0.25	5.34	D
4.75	4.5	0.25	5.34	D
4.75	4.5	0.25	5.34	D
4.75	4.5	0.25	5.34	D
4.75	4.5	0.25	5.34	D
4.75	4.5	0.25	5.34	D
7.50	5.75	0.13	5.39	D
4.75	4.75	0.25	5.64	D
4.75	4.75	0.25	5.64	D
5	4.75	0.25	5.94	D
6	4	0.25	6.00	B
6	4	0.25	6.00	B
6	4	0.25	6.00	B
6	4	0.25	6.00	B
6	4	0.25	6.00	B
6	4	0.25	6.00	B
3.5	3.5	0.5	6.13	A
9.00	5.75	0.13	6.73	Extra
6	0.75	1.5	6.75	B
5.75	4.75	0.25	6.83	D
8.50	3.25	0.25	6.91	C
5.75	5	0.25	7.19	D
6.5	4.5	0.25	7.31	D
4	3.75	0.5	7.50	A
4	3.75	0.5	7.50	A
6.5	4.75	0.25	7.72	D
7.00	4.50	0.25	7.88	D
5.75	5.5	0.25	7.91	D
6	5.5	0.25	8.25	D
5.5	3.25	0.5	8.94	C
6.75	5.5	0.25	9.28	D
5	3.75	0.5	9.38	B
6.5	6	0.25	9.75	D
6.5	6	0.25	9.75	D
4.75	4.25	0.50	10.09	D
4.5	4.5	0.5	10.13	D
4.5	4.5	0.5	10.13	D
11	3.75	0.25	10.31	C
6.75	6.25	0.25	10.55	D
10.00	8.50	0.13	10.63	Extra
4.75	4.50	0.50	10.69	D
4.75	4.5	0.5	10.69	D
8.5	5.25	0.25	11.16	**Extra (?)**
5.00	4.50	0.50	11.25	D
6	3.75	0.5	11.25	B
6	3.75	0.5	11.25	B
7	6.5	0.25	11.38	D
8.75	5.25	0.25	11.48	**Extra (?)**
8	5.75	0.25	11.50	D
4.75	3.25	0.75	11.58	B

Key
R24
F Stores
J Stores
ATFLIR

Tote Size	Frequency
A	18
B	33
C	11
D	155
Extra	427
	644

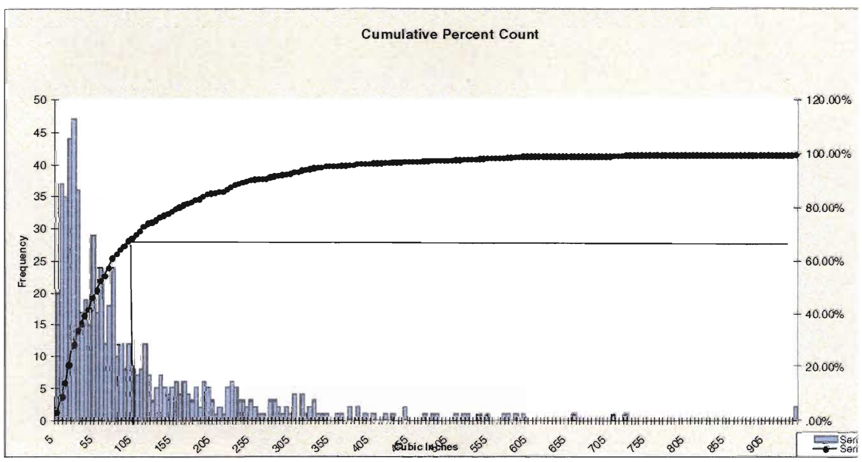
Cubic In.	Frequency	Cum	Cumulative %
0	0	0	.00%
5	20	20	3.11%
10	37	57	8.85%
15	35	92	14.29%
20	44	136	21.12%
25	47	183	28.42%
30	36	219	34.01%
35	17	236	36.65%
40	19	255	39.60%
45	15	270	41.93%
50	29	299	46.43%
55	17	316	49.07%
60	24	340	52.80%
65	12	352	54.66%
70	18	370	57.45%
75	24	394	61.18%
80	10	404	62.73%
85	12	416	64.60%
90	8	424	65.84%
95	12	436	67.70%
100	8	444	68.94%
105	**7**	451	**70.03%**
110	8	459	71.27%
115	12	471	73.14%
120	7	478	74.22%
125	3	481	74.69%
130	5	486	75.47%
135	7	493	76.55%
140	5	498	77.33%
145	4	502	77.95%
150	5	507	78.73%
155	6	513	79.66%
160	4	517	80.28%
165	6	523	81.21%
170	4	527	81.83%
175	3	530	82.30%
180	5	535	83.07%
185	2	537	83.39%
190	6	543	84.32%
195	5	548	85.09%
200	3	551	85.56%
205	1	552	85.71%
210	2	554	86.02%
215	1	555	86.18%
220	5	560	86.96%
225	6	566	87.89%
230	5	571	88.66%
235	3	574	89.13%
240	3	577	89.60%
245	2	579	89.91%
250	3	582	90.37%
255	2	584	90.68%
260	1	585	90.84%
265	1	586	90.99%
270	0	586	90.99%
275	3	589	91.46%
280	3	592	91.93%
285	2	594	92.24%
290	1	595	92.39%
295	2	597	92.70%
300	1	598	92.86%
305	4	602	93.48%
310	0	602	93.48%
315	4	606	94.10%
320	1	607	94.25%
325	2	609	94.57%
330	3	612	95.03%
335	1	613	95.19%
340	1	614	95.34%
345	1	615	95.50%
350	0	615	95.50%
355	0	615	95.50%
360	1	616	95.65%

with 4 in clearance

	Tote Size Name	A	B	C	D	E	F	G
	Tote size dimensions (L, W, H) inches	4 x 4 x 4	4 x 6 x 4	6 x 8 x 4	8 x 12 x 4	12 x 12 x 4	12 x 24 x 4	24 x 24 x 4
	Number of locations per shelf	36 loc	24 loc	12 loc	6 loc	4 loc	2 loc	1 loc
1113	Count of parts that fit in tote size	214	264	136	204	146	105	18
26	Percentage of parts that fit in tote size	19.2%	23.7%	12.2%	18.3%	13.1%	9.4%	1.6%
	Margin of error	+/- 2.4 %	+/- 2.6 %	+/- 2.0 %	+/- 2.3 %	+/- 2.0 %	+/- 1.7 %	+/- 0.76 %

Length	Width	Height
1.75	1	0.75
2.25	1.25	1.25
2.25	2	0.5
2.25	2	0.5
2.25	2	0.5
2.25	2	0.5
2.25	2	0.5
2.25	2	0.5
2.25	2	0.5
2.25	2	0.5
2.25	2	0.5
2.25	2	0.5
2.25	2	0.5
2.25	2	0.5
2.25	2	0.5
2.25	2.25	2.25
2.25	2.25	2.25
2.5	1.75	1
2.5	2.25	1.25
2.75	2.25	0.25

Bin	*Frequency*	*Cumulative %*
0	0	.00%
5	20	3.11%
10	37	8.85%
15	35	14.29%
20	44	21.12%
25	47	28.42%
30	36	34.01%
35	17	36.65%
40	19	39.60%
45	15	41.93%
50	29	46.43%
55	17	49.07%
60	24	52.80%
65	12	54.66%
70	18	57.45%
75	24	61.18%
80	10	62.73%
85	12	64.60%
90	8	65.84%
95	12	67.70%
100	8	68.94%
105	7	70.03%
110	8	71.27%
115	12	73.14%
120	7	74.22%
125	3	74.69%
130	5	75.47%
135	7	76.55%
140	5	77.33%
145	4	77.95%
150	5	78.73%
155	6	79.66%
160	4	80.28%
165	6	81.21%
170	4	81.83%
175	3	82.30%
180	5	83.07%
185	2	83.39%
190	6	84.32%
195	5	85.09%
200	3	85.56%
205	1	85.71%
210	2	86.02%
215	1	86.18%
220	5	86.96%
225	6	87.89%
230	5	88.66%
235	3	89.13%
240	3	89.60%
245	2	89.91%



	Percent Count of standardize partition with 4 inch clearance						
Partition Name	A	B	C	D	E	F	G
Tote Size (W x D x H)	4 x 24 x 4	4 x 24 x 4	6 x 24 x 4	8 x 24 x 4	12 x 24 x 4	12 x 24 x 4	24 x 24 x 4
Number of sublots per tote	6	4	3	2	2	1	1
Total locations per carousel	214	264	136	204	146	105	18
Percent Mix of Totes	19%	24%	12%	18%	13%	9%	2%

Cubing Optimization Report
Tuesday, December 05, 2006 06:51
Warehous ES01

Workcente	Activity Level	Locations In Use	Total Locations	% In Use		
CR03	H		6250			
CR03	L		4266			
CR03	M		2208			
CR04	H		6250			
CR04	L		4266			
CR04	M		2208			
CR05	H	4500	6250	72.00%	9219	
CR05	L	3444	4266	80.73%	12724	72.45%
CR05	M	1275	2208	57.74%		
CR06	H	5134	6250	82.14%	10552	82.93%
CR06	L	3856	4266	90.39%	12724	
CR06	M	1562	2208	70.74%		
CR07	H	4233	6250	67.73%	8529	67.03%
CR07	L	2785	4266	65.28%	12724	
CR07	M	1511	2208	68.43%		
CR08	H	3785	6250	60.56%	7738	60.81%
CR08	L	2755	4266	64.58%	12724	
CR08	M	1198	2208	54.26%		
CR09	H	4832	6250	77.31%	9895	77.77%
CR09	L	3596	4266	84.29%	12724	
CR09	M	1467	2208	66.44%		
CR10	H	5432	6250	86.91%	9835	77.29%
CR10	L	3294	4266	77.22%	12724	
CR10	M	1109	2208	50.23%		
		55768	76344		76344	73.05%
			12724			

SCENARIO #1 (WITH ICS INV GROUP = 35,500)

50-Carrier Carousel	
Total Carrier/Carousel	50
Carrier Height	97
Carrier Width	24.5
Carrier Depth	24
Tote Height	4
Shelf Height w/Clearance	6.0625 (actual is 5.51)
Total Shelf/Carrier	16

Tote Type	A	B	C	D	E	F	
Tote Size (W x D x H)	4 x 24 x 4	4 x 24 x 4	6 x 24 x 4	8 x 24 x 4	12 x 24 x 4	12 x 24 x 4	
Subslots	6	4	3	2	2	1	
Count	214	264	136	204	146	105	
Percent Mix of Totes	20.0%	24.7%	12.7%	19.1%	13.7%	9.8%	
Locations/Shelf	36	24	12	6	4	2	
Locations/Carrier	115	94	24	18	8	3	
Total Storage Locations/Carrier	262						
Locations/Carousel	5765	4741	1221	915	437	157	13236
Total Storage Locations/Carousel	13236						79416
# of Carriers	10.0	12.3	6.4	9.5	6.8	4.9	
# of Locations	5765.4	4741.6	1221.3	916.0	437.0	157.2	
# of Bins	961	1186	408	458	219	158	

# of Carriers Needed:

**Total carrier storage locations needed	94,269
Total carrier storage locations available	262
Total carriers needed	**359.8**

# of Carousels Needed:

**Total horizontal carousel storage locations needed	94,269
Total horizontal carousel storage locations available	13,236
Total carousels needed	**7.1**

** Total of ICS (70,540) and ECS (23,729) inventory

NOTE: Data is based on 96% of parts. The 4%, which yields 2,020 parts, will need to be located elsewhere.