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A METHODOLOGY TO EVALUATE OBSOLETE INVENTORY IN HEALTH CARE

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By

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Adviser: Erick C. Jones

Many organizations are currently facing inventory management problems such as distributing inventory on-time and maintain the correct inventory levels to satisfy the customer or end users. Organizations understand the need for maintaining the accurate inventory levels but sometimes fall short leading a wide performance gap in maintaining inventory accurately. The inventory inaccuracy can consume much of the investment on purchasing inventory and many times leads to excessive inventory. The research objective of thesis is to provide a decision making criteria to the management for closing or maintaining the warehouse based on basic purchasing and holding cost information. The specific objectives provide information regarding the impact of inventory carrying cost, obsolete inventory, inventory turns. The methodology section explains about the carrying cost ratio that would help inventory managers to adopt best practices to avoid obsolete inventory and also reduce excessive inventory levels. The research model was helpful in providing a decision making criteria based on the performance metric developed. This research model and performance metric had been validated by analysis of warehouse data and results indicated a shift from two-echelon inventory supply chain to a one-echelon or Just In Time (JIT) based inventory supply chain. The recommendations from the case study were used by a health care organization to reorganize the supply chain resulting in the reduction of excessive inventory.

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Chapter 1.0 Introduction

The supply chain costs of any organization contribute the major part of the investments. The investments in supply chain must be monitored continuously and some improvement decisions to optimize the supply chain can yield positive strategic results. Savings from the implementations of these strategic decisions can be utilized in the overall improvement of the organization. The focus of this research problem is continuous improvement recommendations for managing inventory costs in health care facility. These improvements can be achieved by a decision tool developed from this research. The supply chain includes warehouses and storerooms, purchasing and distribution practices, and end customer defined as personnel who order supplies from the warehouses.

The scope of the research is to lead the overall continuous improvement efforts in the supply chain which includes analysis of current processes, problem quantification, and documentation of relevant best practices (including typical supply chain facility types and amount inventory held).

From the literature review of an article by DeScioli (2001), the supply chain must enable this strategy by:

- Ensuring product availability,
- Minimizing storage space,
- Reducing material handling time and costs for all medical staff (nurses, pharmacists, physicians), and
- Minimizing non-liquid assets (inventory) and maximize the value added tasks.

The improvement criteria based on research objectives are:

- Utilizing ABC inventory analysis to categorize important inventory for setting inventory policy,
- Utilizing available data metrics will be created in order to measure scope of inventory costs to the warehouse,
- Comparison of relevant metrics will evaluated for ease of use to show "hard evidence" of problems and
- Utilizing optimization techniques and current supply chain costs most cost efficient types of warehouses for the organization will be derived.

The major anticipated benefits of this research are:

- Reduction of supply chain logistics cost of distribution of products ,
- Improvement in inventory control,
- Improvement in warehousing functions such as
    - Reduced travel time,
    - Improved inventory accuracy and fill rate, and
    - Improvement in the management of item cube utilization, and
- Identification of relevant systems needed to support better inventory visibility at the warehouse.

Effective use of resources does not always correlate to reduction of resources that are currently available. In many organizations, some of the services deploy more resources than they intend to use or deploy lesser resources than the required service levels and thus creating an imbalance in the overall services. The decision to develop a plan for the effective usage of resources must be developed strategically by top level management with the inputs from middle and lower level management. The theory or principles of resource management or material management have integrated into supply chain management or sometimes also referred to as logistics management.

Creating an effective supply chain with respect to the strategy and the nature of any organization is the primary area of improvement and often considered as quick hits for improvement.

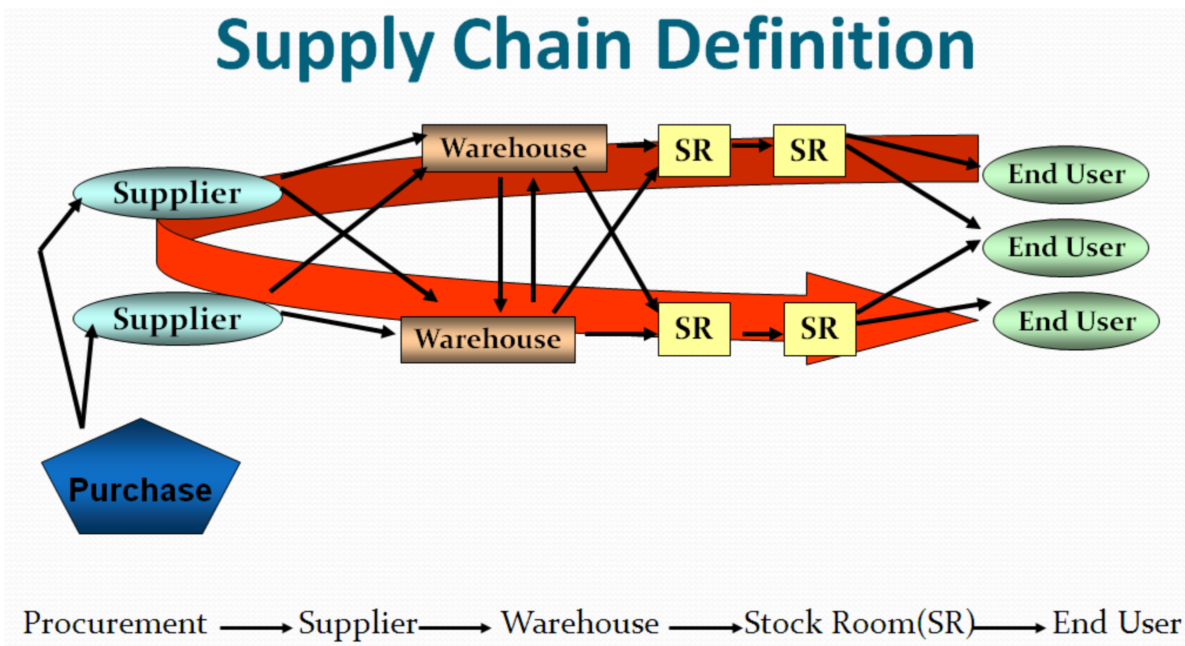

Figure 1.1: Supply Chain in an Organization

The design of supply chains is very complex and must satisfy many federal and institutional regulations. The supply chain products in an organization consist of high cost and low cost items that may be perishable and at times non perishable and products that are consumed at varying demand rates. The demand for products depends on various customer requests. In addition, there are highly critical and non critical items. Supply chains have to be constructed such that they can handle products with all combinations of highly critical, low volume, high cost, and perishable goods. An organization's size, geographic location, diversification, and various specializations all affect the nature of its service level, and, hence, the requirements of its supply chain. Likewise, each department/division within an organization is unique. The variety of products and demand of those products, for example in a health care facility, demand varies greatly from an emergency room to a cardiac laboratory to a primary clinic.

Therefore, the optimal supply chain in one area of a particular hospital may not be the necessarily the best solution for other area in that hospital or in any other hospital. Nor should the supply chain policy for a particular product within an area be identical to that of other products in the same area. For that reason, this study focuses on developing a supply chain decision criterion within a health care organization that can improve the standard operation procedures (SOP's). That is, the supply chain developed for a particular product should reflect the nature of that product; for example different products may require different quantity levels on hand. The research proposes that a health care organization should develop its supply chain for a specific warehouse based on the demand level and perishability, variability, physical size, criticality and product's unit cost. Thus, a health care organization requires a dynamic supply chain policy in order to achieve it mission and goals of service to patients without incurring prohibitive costs.

The continuous improvement process is initiated by understanding the process and the product flow from the distributors (or manufacturer's) shipping dock to the points of care, but does not address the supply chain design elements at the distributor or manufacturer. Improvement of supply chain indicates an improvement in the inventory levels. Inventory level is an indicator of investments of an organization and holding inventory consumes space, requires resources to maintain and protect them from damages. In this process of holding inventory, some of the product inventory may become obsolete and useless. From the discussion above it can be noted that inventory is the crucial component of health care organization and it must be handled carefully. The detailed supply chain for a hospital and healthcare organization can be seen in the Figure 1.2 below.

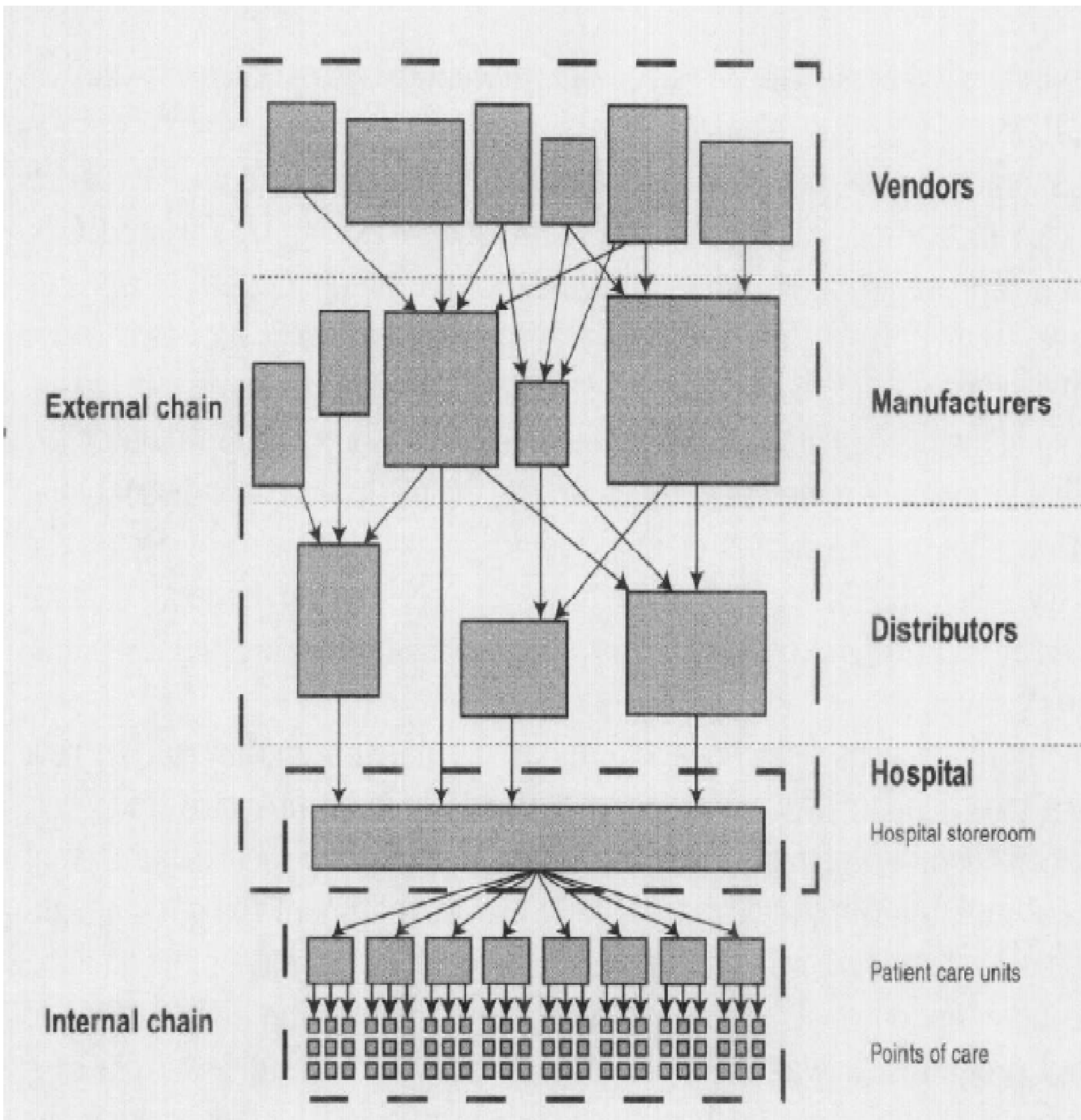

Figure 1.2: Hospital Supply Chain. (Rivard Royer et al, 2002)

Chapter 2.0 Background

The theory of supply chain and inventory control can be dated back to early 19th century. Inventory theory has been studied by many researchers and they have developed a logical and theoretical methodology to understand the importance of inventory and how important was it to have accurate information of inventory on hand and not to have any inventory on hand (also called as Just In Time methodology). The process of determining the safety stock and having sufficient inventory on hand has been termed as "economic order quantity" (EOQ). EOQ was first derived by F. W. Harris. The EOQ concept has been at the core of inventory theory, and has been widely used. Apart from evolution of EOQ, the level of quantity in invenory for sudden change in product demand is known as the buffer stocks.

Classical buffer-stock principles date back to 1934 when R. H. Wilson advanced the reorder-point concept, in which he suggested the reorder-point concept must be used in combination with the Harris EOQ formula. Wilson presented the ideal ordering point for each stocked item as "the least number of units on the shelves, when a restocking order is started, which will prevent the item from running out of stock more often than is desirable for efficient operation." That least number of units includes enough stock to cover the usual lead time, plus a safety or buffer stock for uncertainty. In a study done by Nicole DeHoratius (2004) to understand the inventory inaccuracy, the results indicated that nearly 370,000 inventory records from 37 stores of one retailer 65% of the records were found to be inaccurate. That is, the recorded inventory level of an item fails to match the quantity found in the store. The Figure 2.1 shown below explains an example of supply chain model with suppliers, distributors, manufacturers, wholesalers, retailers/customers. The next section presents a detailed background review of the concept of Economic Order Quantity (EOQ).

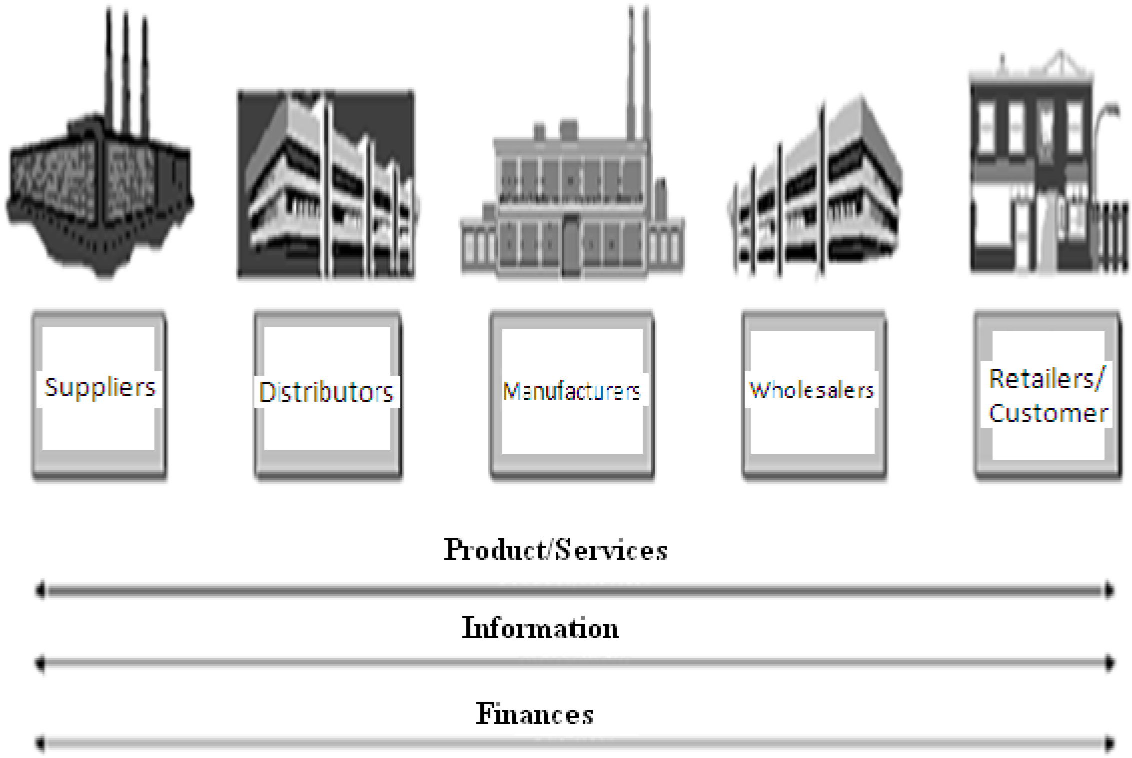

Figure 2.1: The Layout of Supply Chain

2.1 Economic Order Quantity (EOQ) Models

EOQ is essentially an accounting formula that determines the point at which the combination of order costs and inventory carrying costs are the least. The result is the most cost effective quantity of products to order. In purchasing this is known as the order quantity, in manufacturing it is known as the production lot size. In an article by Rogers and Tsubakitani (1991), the focus was on finding the optimal par levels for the lower echelons to minimize penalty costs subjected to the maximum inventory investment across all lower echelons being constrained by a budgeted value. The article provides a methodology that can determine the optimal par levels by a critical ratio (for the newsboy model) adjusted by the Lagrange multiplier related to the budget constraint. Sinha and Matta (1991) analyzed a multi-product system where they focused on minimizing holding costs at both echelon levels plus penalty costs at the lower echelon level. Their results indicate that par levels at the lower echelon level is determined by the critical ratio while the par level for the upper echelon is determined by a search of the holding cost function at that level. Detailed explanation about two echelon and one echelon supply chain model has been provided in the later part of this chapter.

Schonberger (1982) illustrates the tradeoffs associated with decreasing the setup cost in the classical EOQ model. One of the objectives of this paper is to establish a framework for studying those tradeoffs. A research survey conducted by J. E. Holsenback in 2007 demonstrates the necessity of accurately measuring and monitoring inventory holding costs (IHC). The study further demonstrates that knowledge of the underlying statistical pattern of supply and demand variations can significantly improve forecasting and impact the appropriate the levels of safety stock inventory in a variety of industries. IHC assumes that it is linearly proportional to the amount of inventory held, when the rate itself very well may decay (or increase) with increasing quantities. In fact, IHC may change from one accounting period to the next. Failure to accurately determine IHC and use this cost to make decisions fails to recognize that inventory can represent one-third to one-half of a company's assets.

A company with a 36% IHC will pay for the inventory twice in slightly more than two years: once to purchase it, and a second time to carry it for about 25 months. Hence, it seems problematic that nearly one half of companies do not use IHC to make their inventory management decisions. The IHC affects profitability, and may affect a company's business plan in terms of make-buy, or make-to-order/make-to-stock, as well as other top-level decisions (IOMA, Dec. 2002). While EOQ may not apply to every inventory situation, most organizations will find it beneficial in at least some aspect of their operation. Anytime you have repetitive purchasing or planning of an item, EOQ should be considered. Obvious applications for EOQ are purchase-to-stock distributors and make-to-stock manufacturers, however, make-to-order manufacturers should also consider EOQ when they have multiple orders or release dates for the same items and when planning components and sub-assemblies.

$$EOQ = \frac{\sqrt{2 * \text{Annual usage in units} * \text{order cost}}}{\sqrt{\text{Annual}}\ \text{carrying cost}}$$

The inputs for calculating EOQ are annual usage, ordering costs, carrying costs and miscellaneous costs. The values for order cost and carrying cost should be evaluated at least once per year taking into account any changes in interest rates, storage costs, and operational costs. A related calculation is the total annual cost calculation.

Ordering costs are the sum of the fixed costs that are incurred each time an item is ordered. These costs are not associated with the quantity ordered but primarily with physical activities required to process the order.

In research thesis by DeScioli (2001), the main objective of the research was to develop an inventory policy to optimize the total material management costs associated with inventory carrying costs, ordering costs, and stock out costs. For any given product, the total cost, TC, can be expressed by the formula listed below

$$TC = (I_{avg} * C_c) + (A * N_O) + (CS_O * NS_O)$$

I_{avg} is the average inventory, Cc is the carrying cost, A is ordering cost, N_O is the number of orders, CS_O is the stock out cost, and NS_O is the number of stock outs. The research by DeScioli compares four supply chain policies and investigates the efficiency of each of the four supply chains based on carrying cost, total inventory cost, ordering cost, shortage costs.

2.1.1 Carrying Cost

The Figure 2.2 shows the breakdown of different cost into categories that would be classified under carrying costs. Carrying cost sometimes is also referred as holding cost. It is the cost associated by having inventory on hand and primarily comprises of the factors that are associated with the dollars invested for having sufficient inventory on hand and storing inventory safely in the warehouses.

EOQ calculations and optimizations have been explained by Piasecki (2001 as, if the cost does not change based upon the quantity of inventory on hand it should not be included in carrying cost. In the EOQ formula, carrying cost is represented as the annual cost per average on hand inventory unit. Major costs of high inventory include increased rent expense and handling costs, greater product damage, more frequent product obsolescence, and longer delay in noticing quality errors. For most products, the annual carrying cost of inventory is an astounding 20 percent to 40 percent of the materials cost. Many businesses underestimate the carrying cost of inventory. They calculate carrying cost based on the borrowing cost of money alone. Other factors can outweigh this cost. Below are the primary components of carrying cost explained in detail.

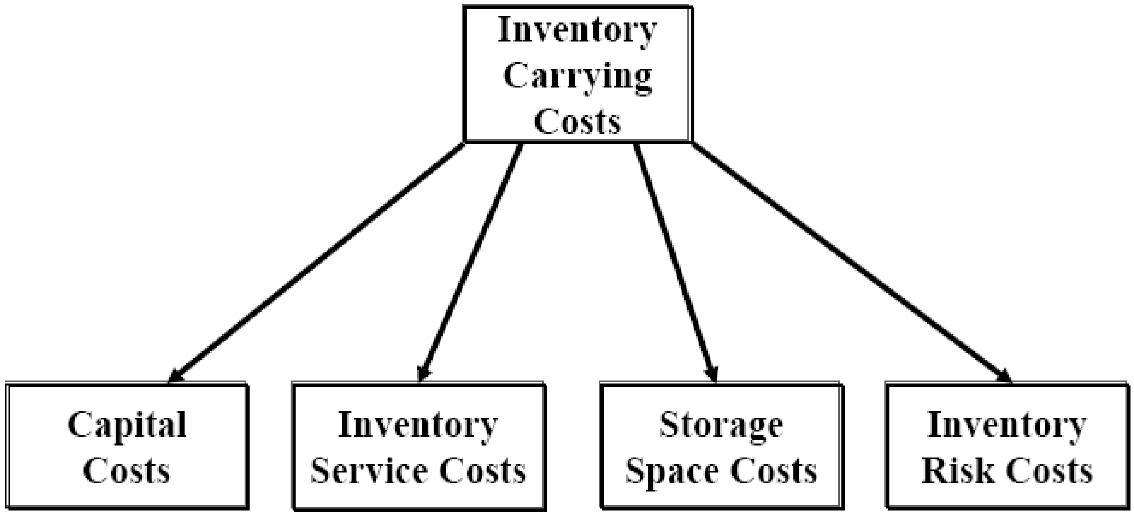

Figure 2.2: Inventory Cost Breakdown (REM Associates)

2.1.1.1 Capital Costs

If you had to borrow money to pay for your inventory, the interest rate would be part of the carrying cost. If you did not borrow on the inventory, but have loans on other capital items, you can use the interest rate on those loans since a reduction in inventory would free up money that could be used to pay these loans. If by some miracle you are debt free you would need to determine how much you could make if the money was invested.

2.1.1.2 Insurance

Since insurance costs are directly related to the total value of the inventory, these costs would also be included in carrying cost.

2.1.1.3 Taxes

If you are required to pay any taxes on the value of your inventory they should also be included in carrying cost.

2.1.1.4 Storage Costs

Errors in calculating storage costs are common in EOQ implementations. Generally companies consider all costs associated with the warehouse and divide it by the average inventory to determine a storage cost percentage for the EOQ calculations. This tends to include costs that are not directly affected by the inventory levels and does not compensate for storage characteristics. Carrying costs for the purpose of the EOQ calculation should only include costs that are variable based upon inventory levels.

Apart from the above explained costs, supply chain and warehouses incur additional costs such as fleet control, security, depreciation, utilities and other costs

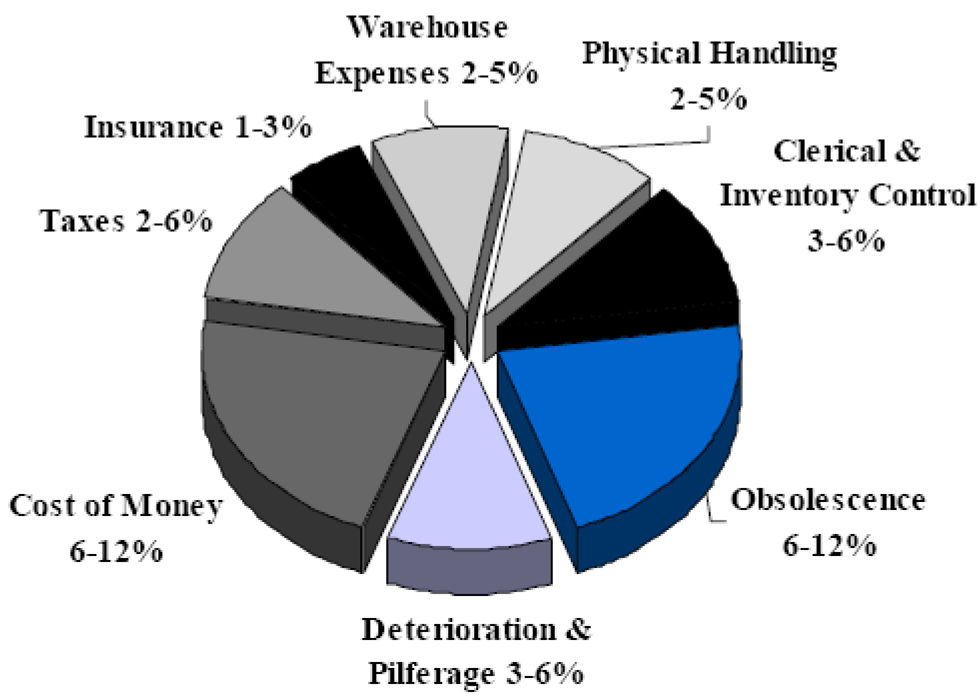

Figure 2.3: Average Percentage of Inventory Carrying Cost Breakdown (Helen, 1995)

2.1.2 Safety Stock

The amount of safety stock inventory (SSI) that a firm invests out of the total inventory costs is a measure of the relative uncertainty of the product demand, component supply, or both. Where demand and supply are maintained constant (such as in JIT systems), SSI can be minimized. Most manufacturing firms exhibit variable demand and fairly determinable supply. Agricultural and fishing type firms, on the other hand exhibit fairly predictable demand of products.

Safety stocks of these different industry types have manifested themselves with the items on the shelf, silos of grain, fish farms, and frozen foods. Supply and demand can be described by statistical distributions such as Normal, Chi-square, and Poisson. Therefore, in order to quantify the safety stock of a product, which is a function of the distribution of its supply and demand, it is necessary to understand the statistical nature of both supply and demand separately, since they may exhibit different behaviors. The Table 2.1 as shown below explains the statistical nature of demand and lead time of various inventory models.

Table 2.1: Different Inventory Models and Safety Stock Formulations
(Talluri & Gardner 2004)

		Lead Time		
		Constant	**Variable**	Key
Demand	Constant	I No Safety Stock	II $R_L=RL$ $\sigma_L=\sqrt{R_2 s^2_L}$ $SS=F^{-1}_s(CSL)\ \sigma_L$	R= Average Demand per period L= Average Lead-Time for Replenishment SS= Safety Stock σ_L = Standard Deviation of demand per period
	Variable	III $R_L=RL$ $\sigma_L=\sqrt{\sigma^2_R L}$ $SS=F^{-1}_s(CSL)\ \sigma_L$	IV $R_L=RL$ $\sigma_L=\sqrt{(\sigma^2_R L+R^2 S^2_L)}$ $SS=F^{-1}_s(CSL)\ \sigma_L$	S_L=Standard Deviation for lead time F^{-1}_s =Inverse Normal CSL=Cycle Service Level R_L=Reorder Point

"Even though the effect of the IHC upon the EOQ is smoothed by taking its square root, nothing smoothes out its impact when it is drastically underestimated and applied to an unnecessary excess of inventory". It is evident from the studies presented that IHC should be painstakingly measured, and routinely monitored for accuracy, especially in an economy that shows as many macroeconomic swings as have been exhibited in recent years. Safety in SSI means knowing the up-to-date variability of supply and demand, as these are the key components to formulating SSI. Since not all demand and supply distributions are alike, knowing the underlying statistical pattern of these variations have been shown to significantly improve forecasting and the levels of inventory in every kind of industry. Armed with these lessons of analysis, inventory managers should demonstrate more expertise in defining actual values for these quantities, and less reliance upon age-old, arbitrary estimates" (J. E. Holsenback et.al, 2007).

In a research thesis by DeScioli (2001), calculations have been demonstrated on how to calculate the safety stock based on the service level in the mission statement of the organizations. The cost of a stock out is implied by the targeted service level and required safety stock to achieve such a service level such that:

$$SS*Cc = NS_O*CS_O$$

Where SS is safety stock, Cc is carry cost, NS_O is number of stock outs and CS_O is cost of a stock out.

From this research by Descioli (2001), the cost of a stock out was estimated using the actual current practice in the organization. Assuming a target of 99% service level (which is the current level obtained by organization) a stock out has an implied cost of $77.75. This analysis assumed the majority of inventory with no demand was slow moving inventory, and hence, used $3.6 million as the average inventory rather than the $1.9 million that was actually included in the generated demand model.

2.1.3 Obsolete and Excessive Inventory

Obsolete inventory has become a prominent phenomenon in most of the organizations. Many organizations are striving to avoid obsolete inventory and are also trying to avoid excessive inventory. There have been many articles in the literature that identify the best practices to control obsolete and excessive inventory.

The items when become obsolete are unusable and it does not yield any value to the services and in turn they consume valuable storage space in the warehouses, added are the taxes. These excessive costs may yield to increase in the overall facility costs. The organizations must implement steps and methods that can help inventory managers identify the excessive inventory and make use of the excessive inventory before it turns out to be obsolete. There have been many research articles that help in designing steps to avoid obsolete inventory. Having excessive inventory can be attributed as the primary causes of obsolete inventory. A literature review on inventory control and reduction of inventory shows that it is common to all the organizations that excess inventory translates to more dollars spent. Tony Wild (2002) suggests "more inventory means worse delivery time".

Mark Williams, in his article about ways to reduce inventory, shows that carrying costs account to 20-36% of the annual inventory costs (2009). In this article Williams, formulates 10 keys ways of inventory reduction. Reducing obsolete inventory, implementing ABC inventory management strategies, reducing lead times are the main areas that have been briefly discussed in this research article. A significant amount of investment can be saved when organizations have no obsolete and excessive inventory. Any decrease in these numbers can reduce the operational costs and most importantly taxes paid due to inventory stored in the warehouse will also decrease. Gary Gossard has statistics on percentage reduction in inventory when certain ways to reduce operating inventories are adopted (2003). According to Gossard, conducting reviews reduced the inventories by 65%. The use of the ABC approach to reduce the inventory will, most likely, save money invested to buy 37% of the total inventory. Lawrence Nicholson (2004) explains a case study and has a detailed literature review of inventory management in health care industry and pharmaceutical industry.

A detailed explanation and analysis of ABC analysis has been explained in a case study done at a hospital by Larry (1983). The case study was done to implement a computerized ABC /EOQ inventory system. The primary objective were:

- To design an inventory system that would can consider the operational cost as an integral part of ordering process.
- To develop management indices of inventory performance and develop a decision factors for interpreting the indices.
- To create a purchasing strategy to comply with the ABC/EOQ model.

The results of implementing the inventory system based on ABC analysis were found to increase the turnovers, decrease in inventory stock outs, reduction in inventory on hand. This article provides an ABC analysis. The details have been explained in the Table 2.2. ABC analysis categorizes the inventory into three categories. It is based on Pareto 80/20 rule i.e. 10-15% of the items consume 70-80% of the investment denoted as “A” items and 65-70 % of the item consume 20 -25% of the investment. These are categorized as “B” items. The remaining 10-15% items consume 10 - 20% are denoted as “C” items.

Table 2.2: An Example of ABC Analysis

Category	% of items	% of inventory investment	monthly purchases ($)
A	10--15	70-80	100
B	20-25	15-20	25-100
C	60-70	10--15	25

An EOQ simulation scenario explained in Larry (1983) lists the decision rules for inventory management. The Table 2.3 below has been explained in Larry (1983).

Table 2.3: Decision Rules for Evaluation of Inventory Simulation Model

Incident	Decision Rule
Stock outs	More than two stock out episodes in one month require an increase in order point require an increase in order point
Overstocks	Two consecutive months of overstocks requires a reduction in the order point and interpretation of applicability of the EOQ model to the A item
Price increases	All price increases are assessed for alternate source of supply, bid authorization through prime vendor, quantity purchase instead of EOQ purchase
Returned for credit	More than one episode monthly suggests reassessment of EOQ model item or change in physician mix in the institution

Major costs of high inventory include increased rent expense and handling costs, greater product damage, more frequent product obsolescence, and longer delay in noticing quality errors. For most products, the annual carrying cost of inventory is an astounding 20 percent to 40 percent of the materials cost.

2.2 Best Practices of Reducing Inventory

Reducing lead times, reducing obsolete inventory, using ABC analysis, increasing the inventory turn ratios can help the organizations in effective inventory management and thus saving investment in maintaining inventory. The Table 2.4 below shows the percentage reduction in inventory with the implementation of each of these methodologies.

Consider the detailed aspects of reducing inventory and also reducing inventory costs. From the Table 2.4 listed below, the top seven methods of reducing excessive inventory can be incorporated in one comprehensive inventory management technique. The Inventory Quality Ratio (IQR) is a simple, straightforward way of measuring inventory performance, managing inventory dollars and identifying inventory reduction opportunities. The IQR logic was developed collectively by the materials managers of 35 companies. It was used by them to reduce inventories a total of $500 million (25% average reduction) while improving on-time deliveries. It has since been used by planners and buyers in manufacturing and distribution companies worldwide to reduce inventories 20% to 40% (Gossard, 2003).

Table 2.4: Top Ten Inventory Reduction Practices (Gossard, 2003)

Top ten inventory reduction practices	Percentage reduction
Conduct periodic reviews	65%
Analyze usage and lead times	50%
Reduce safety stocks	42%
Use ABC approach (80/20 rule)	37%
Improve cycle counting	37%
Shift ownership to suppliers	34%
Re-determine order quantities	31%
Improve forecast of A and B items	23%
Give schedules to suppliers	22%
Implement new inventory software	21%

The IQR logic first divides inventory into three groups: items with future requirements, items with no future requirements but with recent past usage, and items with neither. The items in these groups are then stratified into typical ABC-type classifications based on their future dollar requirements, their past dollar usage, or their current dollar balances, respectively. A target inventory level expressed in days' supply is set for each item based on its classification. The balance on hand of each item is compared to the target, and the dollars of each item are categorized as either Active (A1 and A2), Excess (E1, E2), Slow Moving or Obsolete (SM1, SM2). These are called the inventory quality categories. The Inventory Quality Ratio is the ratio of the active inventory dollars to total inventory dollars. In a theoretically perfect situation (i.e., with no excess, slow moving or obsolete inventories) the IQR would be 100%.

The IQR incorporates the best practices of periodic reviews and ABC analysis with forward-looking days' supply and user-defined parameters. It provides inventory managers with a dynamic methodology to review and reassess lead times, safety stocks, order quantities and replenishment cycles on a weekly or monthly basis. The IQR also enhances existing MRP systems by adding a dollar focus to prioritize current reduction opportunities.

$$Inventory\ Quality\ Ratio\ (IQR)$$

$$= (Active\ Inventory\ Dollars)/(Total\ Inventory\ Dollars$$

$$\text{IQR} = \frac{A1 + A2}{A1 + A2 + E1 + E2 + E3 + SM1 + SM2}$$

2.2.1 Eliminating Obsolete Inventory

Many business owners have difficulty throwing away products they paid good money for. But holding on to obsolete products just burns up even more investments. Eliminating obsolete stock promptly, and use the cash and space you save for something more profitable.

Literature review on how to eliminate obsolete stock were, creating a “red tag” program to identify old inventory has been widely cited in the literature. Tag old inventory with large red stickers. Note on the sticker the date tagged, person doing the tagging and a review date. Move these products into a quarantined area of your warehouse. If the warehouses have not used the products by the review date, cut the losses and liquidate the merchandise. Red tagging of obsolete items is something that originated with Japanese automakers. Examples such as Toyota's Red Tag sales events are common. These companies are just moving out old stock to make room for newer, more profitable inventories. Many companies empower employees to red tag items themselves. Red tagging works for anything in your warehouse, not just consumable inventories. Gather a small group of employees and do a one-hour red tag "blitz" in an area. Items that appear as though they don't belong in the work area are placed in a pile. This might include items such as jigs and fixtures, tools or personal belongings. Next, items in the pile are offered back to the employees in an auction-style format. Unclaimed items are tagged and moved to the red tag quarantine area and then discarded if not claimed by the review date.

The Table 2.5 below shows the various industrial metrics followed in order to attain improvement. The Table 2.5 indicates the customer perspective and organization for each metric and also shows the measurement criteria.

Table 2.5: Industrial Bench Marking Metrics (Raghuram)

INVENTORY METRICS	CUSTOMER PERSPECTIVE	FORECAST ACCURACY
Turnover Inventory Turns	In-Stock Percent at Point of Sale	Sales Forecast Accuracy Track actual sales vs. forecasted sales variances
		Forecasting Utilization of Inventory Assets The higher the inventory turns, the better the firm uses its inventory assets.
Inventory Levels Dollars and/or units at various points in supply chain	Purchase Order Fill Rate Percent Percent Shipped on time Percent Delivered on time	Order Forecast Accuracy
Order Quantity Order processing/ Setup cost, Inventory carrying cost, Back order Cost, Excess and Obsolete stock cost	Reliability Stock out percentages, delays, loss and paperwork involved.	Order Forecast Accuracy
Critical Inventory Average Inventory, EOQ	Stock out percentage, Percentage of orders fulfilled	Maintaining proper Inventory levels
		Determining method for reordering inventory
Space Utilization & Layout % space utilized (cum.)		Forecasting Storage Space and Lead Times involved
Stock to Sales Ratios Weeks/days of supply	Lost Sales Analysis Evaluate actual/potential lost sales due to lack of inventory	Track actual order qty. vs. forecasted order qty. variances at critical times that could influence production Includes non-compliant orders with frequency and volume as two options
Industry ratio Comparison with others	Part Count Accuracy Percentage Quality-Percentage Defects	Percent Variability in Lead Time
	Price of Non-Conformance	
Engineering changes per Month	Communication Effectiveness Measure collaborative cycle time/issue resolution time	Customer Satisfaction

2.3 Supply Chain Models

The layout of the supply chain as in Figure 1.1 and Figure 2.1 shows the flow of the products moving from suppliers to manufacturers, distributors, retailers, and finally to the customer. The initial starting point of any supply chain would be the need of a product i.e. the demand of the product and ending point of the supply chain would be the delivery of the product to the customer. The different stages of supply chain the product is handle are called echelons. The Figure 2.4 as shown below is the layout of the two echelon supply chain.

The effectiveness of the supply chain depends on the level uncertainty of the product availability. Lesser the uncertainty the more efficient is the supply chain. The level of uncertainty in the supply chain has been widely discussed, in terms of resolving the problem of supply chain in the community of lean construction (Howell and Ballard 1995). Comparing them with manufacturing scope, the researchers have endeavored to develop supply chain ideas over a more dynamic construction environment (Tommelein 1999; Mecca 2000). We would limit our discussion to two echelon and one echelon supply chain models only. The complexity increases as the number of echelons in the supply chain increases.

2.3.1 Two Echelon Model

The discussion in Caglar's (2003) model about optimizing two-echelon inventory models has been cited by many research articles. Caglar developed a model to minimize the system-wide inventory holding costs while meeting a service constraint at each of the field depots. The service constraint considered was based on the average response time. It was defined as the average time it takes a customer to receive a spare part after a failure is reported. The model was been verified by using several cases referred to in his original article. A two-echelon multi-consumable goods inventory system consisting of a central distribution center and multiple customers that require service is investigated. The system is illustrated in Figure 2.4.

Each secondary warehouse acts as a smaller warehouse. These secondary warehouses in turn supplies to many customers and maintain a stock level S_{iM} for each item. So each secondary warehouse consists of a set *i* of *n* items that are used with a mean rate λ. When an item is used by a customer the customer replenishes itself by taking item i from the secondary warehouse *M* and supply stock if the item is in stock. If the item is not in stock the item is back ordered and the customer has to wait for the item to become available at the secondary warehouse.

There has been some related research to understand the characteristics of multi-echelon inventory model and the dynamics of a two echelon supply chain in particular. The conclusion from these studies state that over 65% of most companies do not compute inventory carrying costs, they calculate carrying cost based rough estimates. Leading researchers and logistics experts place the cost of carrying inventory between 18% per year and 75% of total supply chain costs per year depending on the type of products and business. The standard "rule of thumb" for inventory carrying cost is 25% of total inventory value on hand. The cost of capital is the leading factor in determining the percentage of carrying cost.

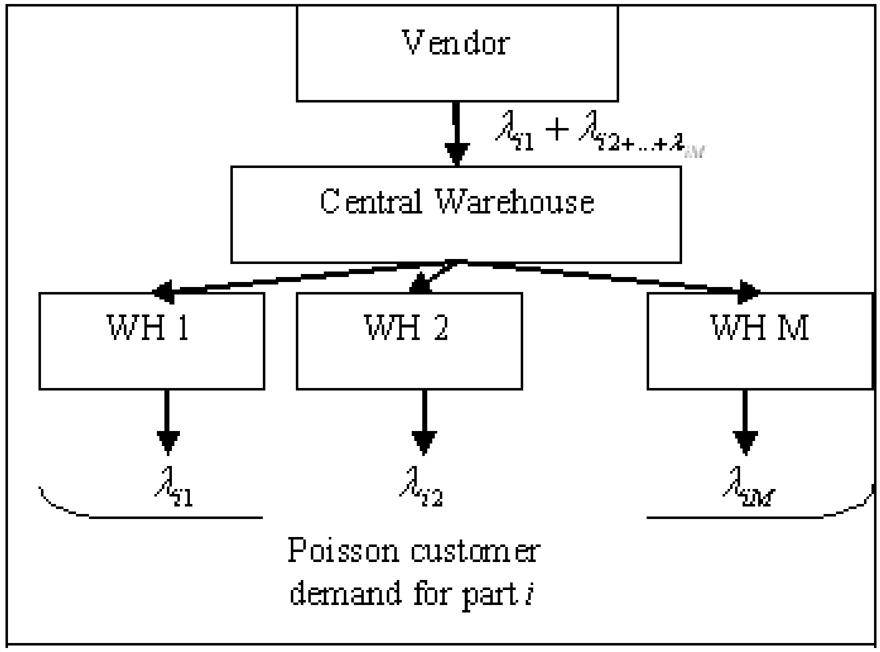

Figure 2.4: Two Echelon Supply Inventory Model

If all supply and demand variability for a particular product were known, then the holding cost for inventory could be minized. An important technique to reduce inventory costs is to reduce supply variability by including suppliers in demand planning activities. This leads to improved lead times, and can result in up to 25% reduction in inventory carrying costs (Holsenback et.al, 2007).

The objective of our research was to make a decision of supply chain type based on basic purchasing and holding cost information, while maintaining an average response time that will not negatively impact the customers. This may include the elimination of the primary warehouse.

Caglar (2003) optimization equation for minimizing total inventory costs subject to a time constraint, which also sets the percent availability for items available to a customer could was used to determine proper stocking levels at each of secondary and primary warehouse. Caglar (2003) response time equation was used to quantify expected response time.

Minimize

$$\sum_{i \in I} h_i \bar{I}_i (S_{i0}) + \sum_{i \in I} \sum_{i \in I} h_i \bar{I}_i (S_{ij,} S_{i0,})$$

$$W_j \le \tau_j, \qquad (j \in J),$$

when,

$$0 \le S_{ij} \le \hat{S}_{ij}, \quad S_{ij} \text{ integer} \qquad (i \in I; j \in J),$$

$$0 \le S_{i0} \le \hat{S}i0, \ S_{i0} \text{ integer} \qquad (i \in I),$$

τ_j = customer expectation for maximum expected response time and W_j is calculated using Caglar's (2003) response time equation and Little's Law from Caglar (2003).

According to Little's law in queuing theory of stochastic processes, $L = \lambda W$, where L is the mean number in the system and W_j is the mean response time in the context of this paper. However, even though this model is very good at optimizing a two echelon supply chain, it requires a large amount of data and assumptions. The was developed in Caglar (2003) in a way that it would provide an approximate distribution for inventory on-hand and also provide information on backorders at each depot for a two-echelon system .

2.3.2 The One-Echelon model

The one-echelon model is a one warehouse model with JIT system. The JIT requires better planning of demand from customers and additional procurement cost per unit is higher due to high variation in demand. There are many cases where the elimination or significant downsizing of a warehouse can save money without sacrificing service to the customer. The layout of one echelon supply is shown below in the Figure 2.5.

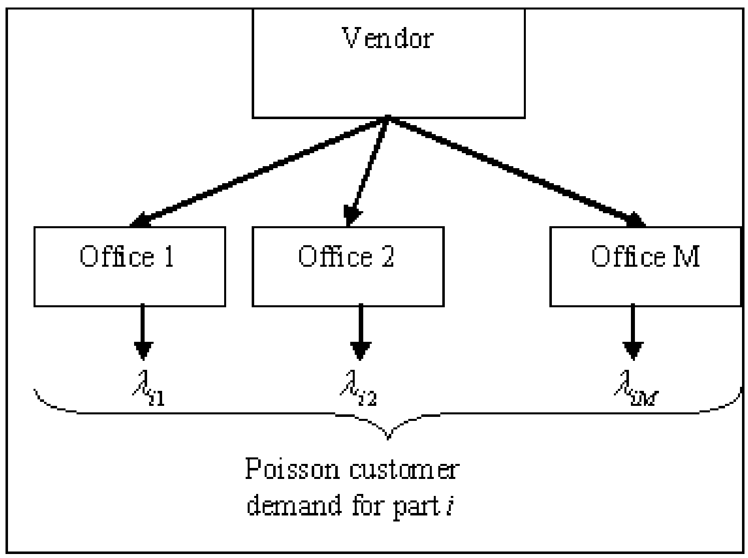

Figure 2.5: One Echelon Supply Chain Model

JIT is a concept widely used by many Japanese manufacturers and is now becoming popular in the western world. The theory of JIT is suppliers deliver items when the item is needed. If implemented properly, this lowers inventory levels for the customer and drives down the cost of maintaining inventories but may sometimes increase the procurement costs.

To compare the total cost of a one-echelon JIT system to all other system, the same service level W_j was used. Also, the system turns into a one-echelon inventory problem. This simplified the model, as there were fewer levels for the system to queue from.

The JIT system in this model works by items ordered going directly from the vendor to the secondary warehouse, where a smaller stock level is used versus the primary warehouse. One-echelon systems do not have an intermediary warehouse between the vendors and the secondary warehouse. This system is shown in Figure 2.

Costs associated with the JIT system contained all of the fixed costs of the system as well as additional costs of requiring more service from vendors. In some instances, per unit price of a product can remain constant by ordering large quantity orders or several small quantity orders. However shipping rates for the several smaller orders may increase. Due to this, it may be important to select vendors that are close to the secondary warehouses.

Once again, in many situations the data needed to optimize may not be available in the time frame. This is where carrying cost ratio can provide a decision to move to a two-echelon model.

Chapter 3.0 Research Objective

3.1 Research Question

From the literature review rationale, there has been limited research on how to measure the efficiency of warehouses. The previous research describes optimizing the warehouse and supply chain operations based on complex equation and hard to collect data. There has been lack of measurement criteria or metric that can identify the reasons for warehouse to perform below average. The objective of this research is to provide a useful decision support tool that allows management to make more effective decisions about inventory policy.

The proposed research model seeks to provide decision criteria for the organizations whether to continue the operations of the warehouse or to close the warehouse based on the calculations based on easy to collect data related to facility costs, procurement costs and distribution costs.

The carrying cost ratio model was used to compare the total cost of the purchasing inventory from retail operators to the amount of money spent on receiving, stocking and delivering it to a warehouse. The objective of this research is to provide a methodology for reducing cost incurred over the supply chain process from the time an inventory item is loaded on a truck from the original vendor to the time the individual secondary warehouse sells/makes use of the item for their business. The merits of understanding these incurred costs include

- An understanding of the cost of items,

- Knowledge of the cost the operation would be required to overcome these costs, and
- Guidelines for what actions an operation can take to decrease the cost/dollar spent ratio.

The current research objective of this model seeks to evaluate the two echelon supply chain models, calculate the carrying cost of inventory, develop a carrying cost ratio for the evaluation of all the secondary warehouses. The ratio would identify warehouses that have more facility costs than inventory. Calculate the inventory turns/year to identify the warehouses that have excessive inventory and store obsolete inventory.

This research has been designed to study the following hypothesis. The proposed hypothesis of this research is:

- Hypothesis: We hypothesize that the metric and the methodology that is based upon inventory control theory can be used in a consistent manner to effectively manage inventory.

3.2 Specific Objectives

The specific objectives of this research was to analyze the present supply chain, develop an effective supply chain to reduce the overall costs associated with storing the product in the warehouse to the point of time product was actually delivered to the end user/point of care.

In order to meet our research objective, the model has to satisfy three specific objectives:

- Specific Objective #1: Demonstrate how the suggested metric compares to other commonly used inventory control metrics
- Specific Objective #2: Develop an "easy to use" inventory control methodology
- Specific Objective #3: demonstrate a methodology for applying the metric for management

3.3 Intellectual Merit

The intellectual merit in meeting the specific objectives are:

- A tested inventory control metric that extends theoretical inventory control methods
- An introduction of a methodology that provides a useful approach for practitioners
- Comparison of the usage of this metric and method against previous theoretical inventory control models

Chapter 4.0 Research Methodology

4.1 Notations

The research methodology describes our approach on evaluating the aforementioned inventory supply chain models. The decision criterion is based upon total cost of the purchasing, storing, and delivering items to the customer. The model can determine which system has a better chance of success based upon the weighting of the inventory holding costs. The next sections describe a comparison of two-echelon, one-echelon and the proposed carrying cost ratio.

We used the assumptions listed below:

- The consumable goods network consists of the primary warehouse, secondary warehouses, and the customers.
- The shipment time between the warehouse and the secondary warehouse j is stochastic with mean T_j.
- The travel time from a secondary to a customer is negligible, as they are in the same building.
- In the JIT analysis, ordering costs will be included in the negotiated JIT contract.
- The secondary warehouses will review base stock policy based on an ABC analysis with the base stock level for item i at secondary warehouse j set at S_{ij}, which cannot exceed a limit $\hat{S}_{ij}$ specified by management.
- Every item is crucial for the customers to function properly. In example, dentists cannot serve clients without toothpaste.
- When a part is ordered from a secondary and it is available at the primary, a vehicle is sent immediately and the response time for that action is zero.

- We assume Kj, the number of customers served by the secondary warehouse j, is large and we model the demand rate for item I at secondary j as a Poisson arrival process with rate $\lambda_{ij} = K_j l_i$. However this assumption is typically violated whenever an order is made by the customer, it is common in the literature (Graves, 1985) when dealing with machine failure rates).
- Lateral shipments between secondary warehouses are not allowed.

The notations used in research are listed in Table 4.1 for all of the illustrated models.

Table 4.1: Notation of Terminology

Notation	Description
A_w	Annual fixed cost of warehouse operation;
C_I	Total cost of holding inventory;
C_{Lj}	Labor cost at warehouse *j*:
C_V	Cost of vehicles and maintenance at office *j*;
C_{Uj}	Cost of utilities at office *j*:
C_W	Lease price or depreciation and cost of capitol of warehouse;
C_{Mj}	Annual property maintenance for warehouse *j*;
$J = \{1, 2,\ldots,M\}$	Set of offices;
K_j	Customer at office *j*;
l_i	Demand rate of item *i*;
L_{JITij}	JIT lead time for an expedited order of item *i* at office *j*;
$\lambda_{ij} = K_j l_i$	Demand rate for item *i* at office *j*;
θ_c	Organizations cost of capital;
θ_{Oij}	Obsolescence rate for item *i* at office *j*;
θ_S	Shrinkage rate based on total inventory in system;
P_{Wi}	Purchase price using warehouse system of item *i*;
P_{JITi}	Negotiated JIT purchase price for item *i*;
S_{ij}	Base stock level for item *i* at office *j*;
SS_{ij}	Safety stock of item *i* at office *j*;
V_{Wj}	Value of warehouse *j*;
W_{ij}	Waiting time for a customer ordering item *i* from office *j*;
W_j	Waiting time for a customer ordering from office *j*;

4.2 Two-Echelon Model

In 2003, Caglar, Li, and Simchi-Levi presented a two-echelon supply chain model that we consider very useful in making cost-effective decisions about warehouse inventory levels. We utilize this model to demonstrate the current two-echelon supply chain in practice by the city department. First, we will consider a two-echelon multi-consumable goods inventory system consisting of a central distribution center and multiple customers that require service as illustrated in Figure 2.4.

Each service center office acts as a smaller warehouse. This is because they each supply many customers and maintain a stock level S_{CM} for each item. Therefore, each office consists of a set I of *n* items that are used at a mean rate. When an item is used by a customer, the customer replenishes itself by taking item *i* from office M's. If the item is not in stock, the item is back ordered and the customer has to wait for the item to become available at the office. The decision criteria of supply chain based on basic purchasing and holding cost information, while maintaining an average response time that will not negatively affect the customers. This may include the elimination of the central warehouse.

Using the notation in Table 4.1, a model of the cost of operating a warehouse and implementing a JIT system was derived. This information can then be used to determine if the organization benefits from operating the warehouse. There are many operating costs associated with warehouse management. These operating costs include fixed costs such as racking, utilities, labor, vehicle fleet maintenance, property maintenance, property depreciation, and a lease or any other tied up capital. The costs included can be variable and fixed and it depends on the organization. Let *Aw* be all periodic fixed costs that the savings of purchasing in large quantities have to justify in order to minimize the total cost of the operation. For this model, we will use annual costs.

$$A_w = \sum_{j \in J} C_{Wj} + C_{Uj} + C_{Lj} + C_{Vj} + C_{Mj} + \theta_c * V_{Wj} \tag{4.1}$$

These fixed costs in addition to item-associated costs make up the total cost of having a warehouse in operation. Many of these costs are hidden and are frequently overlooked when procurement managers decide the level of quantities to purchase. Shrinkage in the form of lost items, stolen items, or damaged items, obsolescence, and the cost of capitol on the inventory is typically among these hidden costs. These costs can be modeled as a percentage of the total inventory on hand.

4.3 One-Echelon model

The second model used for reference is the common one-echelon JIT system. JIT requires better planning of demand from customers and can sometimes make management feel uneasy about the extra procurement cost of items on a per unit basis.

But there are many cases where the elimination or significant downsizing of a warehouse operation can save money without sacrificing service to the customer. In the JIT system depicted in this model, ordered items go directly from the vendor to the office, where a smaller stock level is used versus the warehouse. One-echelon systems will differ in that there is no intermediary between the vendors and the offices (Cagler et al. 2003; Lee 2003; Wang, Cohen, and Zheng 2000). This system is shown based on a simplification of Cagler et al.'s model in Figure 2.5

The JIT contracts that will need to be made with the vendors is established based upon demand rate λ_{ij}. We determine the expected time of backorders of item i in office j by the following:

$$W_{ij} = E\left[L\left(S_{ij}\right)\right] = \sum_{j\in J}\sum_{i\in I}\left(L_{JITij} * \left(1 - \sum_{i=0}^{SS_{ij}}\left(\frac{\lambda_{ij} L_{JITij}}{n!}\right)^{n} \exp\left(\lambda_{ij} L_{JITij}\right)\right)\right), \tag{4.2}$$

In this case, items are delivered to the offices at the same rate the items are being used. The symbol t_{ij} represents time between deliveries for item i at office j. Therefore, by substitution, $\lambda_{ij}t_{ij}$ is also the order quantity.

$$S_{ij} = \lambda_{ij} t_{ij} + SS_{ij} \tag{4.3}$$

Keeping the expected wait time for the customer for each system the same will allow for a comparison of costs without changing the response time to the customer. Costs associated with the JIT system contain all of the fixed costs of the system as well as any additional costs of requiring more service from vendors. In some instances, the unit price can remain constant by ordering a couple of large quantity orders or several small quantity orders. However, shipping rates for the smaller orders may increase. Due to this, it may be important to select vendors that are near to the offices. After factoring in a possible increase in purchase and shipping prices, we suggest that the total cost for the JIT system will be as follows:

$$C_{JIT} = \sum_{i\in I}\sum_{j\in J} P_{JITi}\lambda_{ij} + C_I \tag{4.4}$$

when,

$$C_I = \sum_{i\in I}\sum_{j\in J}\left(I_{ij} * \left(\theta_C + \theta_{\mathrm{S}} + \theta_{Oij}\right)\right) \tag{4.5}$$

Once again, in many situations the data needed to use this optimization may not be available in the time allotted to the project. This is where our simplified carrying cost ratio model simplifies the decision to move to a two-echelon system.

4.4 Model Description of Carrying Cost Ratio

The proposed carrying cost ratio model focuses on comparing the two systems and selecting the best choice of operational model. As long as the total cost for purchasing, storing, and delivering items to the customer can be derived, we can determine which system is a better economic choice with our decision model. The ratio compares the total cost of the purchased inventory to the amount of money spent holding and delivering it to the offices. This cost ratio has been developed to evaluate and analyze supply chain costs for operations relying on inventory delivery from a supplier. The purpose is to provide a methodology for determining cost incurred over the supply chain process from the time an inventory item is loaded on a truck from the original vendor to the time an operation buys or requisitions the item for use in their business. The merits of understanding these incurred costs include

- An understanding of the cost of each item,
- Knowledge of the cost the operation would be required to overcome, and
- Guidelines for which actions an operation can take to decrease the cost/dollar spent ratio.

The carrying cost model takes into account the importance the inventory turns ratio and also the carrying cost ratio. In most of the models only take inventory turns as a decision tools. We hypothesize that the cost of inventory plus the fixed costs comprises the total cost of the warehouse operation, given by the equation below. The research methodology is to determine whether cost of inventory plus the fixed costs make up the total cost of the warehouse operation.

$$TotalWarehouseCost = A_w + C_I \tag{4.6}$$

We suggest that after identifying the stock levels using the aforementioned formulas or current accounting information, the next step would be to use our ratio to determine which system is better for the operation. We present the ratio as a calculation that can be used in operations. The ratio of the total cost of maintaining the inventory divided by the total inventory purchase price.

After identifying the stock levels using the above mentioned formulas or current accounting information, the next step was to develop a ratio to determine which system is better for the operation. This model developed in this research is used as a metric in analyzing and comparing the one-echelon and two-echelon inventory models. The metric μ_w used in the decision making is a ratio of the total cost of maintaining the inventory and the total inventory purchase price.

$$\mu_W = \frac{A_W + C_I}{\sum_{i \in I} C_{Wi}} \tag{4.7}$$

when: all costs are annual and $\sum_{i \in I} C_{Wi}$ = total dollars purchased.

The decision needed to adopt for the supply chain based on a scale is shown in Table 4.2. The range of ratio between 0.1-0.2 has been regarded as the best possible supply chain to reduce the overall costs. The range between 0.2-0.4 has been considered as the acceptable to accommodate the additional costs that are the result of the improving the supply chain and to accommodate any changes in the supply changes based on procurement. The range of ratio above 0.4 need improvement and must be reduced in order to reduce the overall costs.

Table 4.2: Decision Tool for Operating Warehouses

Ratio	Range	Decision
μ_W	0.1-0.2	Best possible supply chain
μ_W	0.2-0.4	Adopt this solution for reduced supply chain costs
μ_W	0.4-0.6	Needs minor improvements
μ_W	0.6-0.9	Needs rapid improvements
μ_W	>1	Change the components of supply chain

The above relationship provides a baseline for the financial efficiency of the operation. This unit less number is a ratio of total dollars spent maintaining inventory to the total purchase price of all the items in the inventory. Industrial practices include the additional costs due to Just In Time contracts that are in the range of 15-25% increase. Thus if an organization's carrying cost ratio is above this target, Just In Time one-echelon options needs to be considered such as buying directly from the retailer.

4.4.1 Impact of Holding Cost

A research survey conducted by J. E. Holsenback in 2007 demonstrated the necessity of accurately measuring and monitoring inventory holding cost. The study further demonstrated that knowledge of the underlying statistical pattern of supply and demand variations can significantly improve forecasting and impact the appropriate the levels of safety stock inventory in a variety of industries.

> "Inventory holding cost/carrying cost assumes that it is linearly proportional to the amount of inventory held, when the rate itself very well may decay (or increase) with increasing quantities. In fact, holding cost may change from one accounting period to the next. Failure to accurately determine the holding cost and use this cost to make decisions fails to recognize that inventory can represent one-third to one-half of a company's assets. For instance with a company with a 36% holding cost will pay for the inventory twice in slightly more than two years: once to purchase it, and a second time to carry it for about 25 months. So, it seems problematic that nearly one half of companies do not use holding cost to make their inventory management decisions. This holding affects profitability, and may affect a company's business plan in terms of make-buy, or make-to-order/make-to-stock, as well as other top-level decisions" (IOMA, Dec. 2002).

Table 4.3 shows a widely cited breakdown of holding costs associated with warehousing merchandise (Johnson, 1999). So if the ratio is above this baseline for any particular contribution, focus can be turned to that area. In the event that the storage facilities is above the baseline, lowering facilities cost by elimination of facilities in conjunction with a JIT system is recommended.

Table 4.3: General Handling Cost (REM Associates)

Cost Source	% of Purchase Price
Insurance	0.25%
Storage Facilities	0.25%
Taxes	0.50%
Transportation	0.50%
Handling	2.50%
Depreciation	5.00%
Interest	6.00%
Obsolescence	10.00%
Total	25.00%

The equation in the calculation of carrying cost ratio defines the total cost determined over the course of the supply chain. It combines the cost of delivering an item with the cost incurred during the process of holding that item in inventory. This equation is the ratio of warehouse cost per item to purchase price per item. This effectively demonstrates the ratio of money a supplier spends storing and shipping an item to the actual monetary investment put in to each inventory item, represented by the ratio $(C_{System})/ C_P$. This ratio, when combined with holding cost, can be extremely effective in determining the efficiency of a supply chain as well as providing an indicator of the inventory turn rate for the entire system. For this project, our primary focus was the eventual calculation of this ratio. In this case study we shall consider five secondary warehouses for our analysis.

4.4.2 Impact of Inventory Turns

Inventory turns have a significant impact on the warehouse operations. The turns assist the inventory manager to identify the items that are fast moving and needs continuous monitoring. The inventory turnover ratio measures the efficiency of the business in managing and selling its inventory. This ratio gauges the liquidity of the firm's inventory.

The proposed model doesn't directly depend on the inventory turns but the variables involved in the calculation of inventory turns directly relate to the proposed model to reduce obsolete inventory. The expression below explains the calculation of inventory turns ratio

$$\text{Inventory turnover rate} = \frac{\text{Cost of Goods Sold from}}{\text{Average Inventory}} \tag{4.8}$$

Generally, a high inventory ratio means that the company is efficiently managing and selling its inventory. The faster the inventory sells the fewer funds the company has tied up. Companies have to be careful if they have a high inventory turnover as they are subject to stock-outs.

If a company has a low inventory turnover ratio, then there is a risk they are holding obsolete inventory which is difficult to sell. This may erode a company's profit. However, the company may be holding a lot of inventory for legitimate reasons. They may be preparing for a holiday season in the case of the retail industry or preparing for a strike, among other reasons.

From the description above about inventory turn ratio, the effectiveness of the proposed model would depend on the inventory turns of the warehouses. The calculation related to inventory turns has been explained in results section.

4.4.3 Impact of Obsolete Inventory

Obsolete inventory as explained in the earlier section can be due to the inventory that has low turnover ratio. The proposed model has been developed to reduce obsolete inventory and increase the inventory turnover ratio.

The literature review section earlier has explained in detail about the ways to reduce the obsolete inventory. From the ABC analysis, the items that are labeled as C items or otherwise called slow moving items. These slow moving items can impact the holding cost and these items have significant impact on the proposed model. In the denominator of carrying cost expression as shown earlier, the average inventory increases as the obsolete inventory increases and thus the inventory turns reduces. In the calculation of the carrying cost ratio, the total dollars purchased keeps increasing as the warehouses procures products that have low turnover ratios.

Chapter 5.0 Case Study

5.1 Case Study: Description

A large city health and human services (C0XHHS) department in United States had a trend of increasing operational costs and decrease in overall performance of the warehouses was observed. The city managed primary warehouses and these primary warehouses distributed supplies throughout the city at different points of care. These points of care act as secondary warehouse. Preliminary analysis of the warehouses indicated that warehouses procured higher levels of products than required.

CoXHHS followed a two-echelon supply chain inventory model. Detailed explanation about the two-echelon supply chain inventory model is included in the literature review section. A sample schematic of a two echelon model has been in the Figure 1.3 showing a two-echelon supply chain inventory model below would be similar to the one that was in practice for the healthcare organizations.

The performance metric for warehouses was the decrease in percentage of obsolete inventory. Best industry practice is to have excessive inventory in the range of 3% to 6% of total inventory. Secondary performance metric used in this research was supply chain inventory turns. Best industry practice was to have inventory turns above 1.2. The warehouse has been experiencing stock outs of supplies and thus resulting in unhappy customers.

The expected results from this research were that the introduction of new supply chain model would reduce holding/storing excessive inventory products and also reduce obsolete inventory. These organizations had central warehouses that would deliver the requested products to the warehouse in the organization.

Thus the need to improve the operational supply chain and aims to reduce the obsolete inventory and help organizations in generating revenues by reducing obsolete inventory and avoiding expired supplies to be distributed to the points of care. The health department had a two echelon supply chain. Figure 1.3 shows the schematic layout of the two echelon supply chain model.

The research methodology was used in the analysis of the warehouse and inventory management systems of “City of X” health and human services (CoXHHS) department that had its own distribution network to service five secondary warehouses. An analysis was then done to determine inefficiencies in the supply chain (slow inventory turn items) and the information was then used to perform a cash flow analysis for which actions would be useful in reducing cost/dollar purchased. The methodology can be very beneficial in determining which actions yielded the most positive results in reducing costs and/or increasing net profits for an organization.

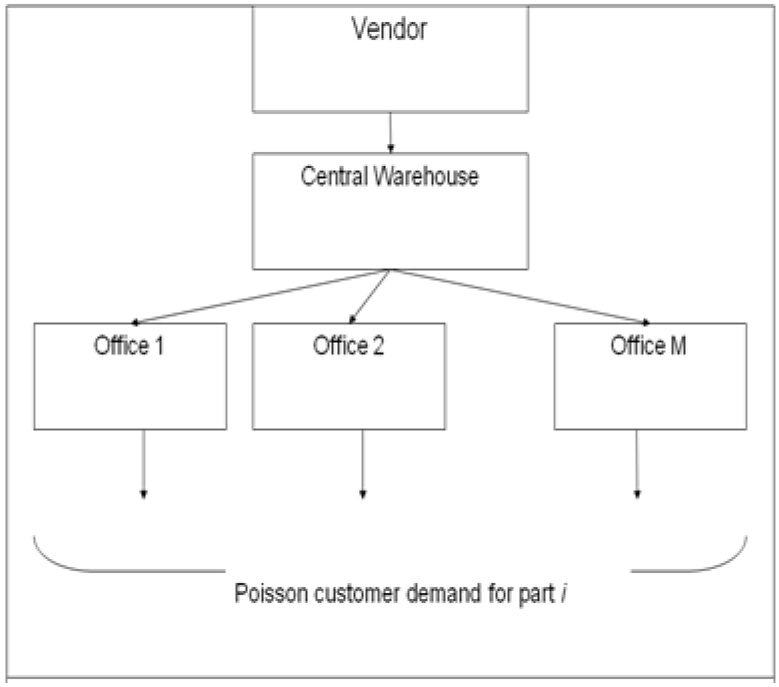

Figure 5.1: Two Echelon Supply Chain Model

5.2 Data Collection

The notations used below follow the same definitions described in the Table 4.1. From the annual reports, the organization had an inventory value of $500,000

Data relating to supply chain costs was gathered from the annual reports and the subsections of supply chain costs as explained was collected. Holding costs would be calculated by the addition of cost of allocating space for storage and cost of procurement of products (C_P).

Space cost (C_s) would include costs related to utilities, labor (picking, packing, and shipping). The expressions for calculating holding costs are shown below.

$$\text{Holding costs} = C_s + C_p$$

$$\text{Space cost} = Cs$$

Procurement costs (C_P) would include cost of items, inbound trucking delivery to warehouse, opportunity cost of tied up money. Customer Service or delivery Costs (C_d) would include fleet maintenance costs, cost of delivery (such as cost per mile for pick-up or use of courier services such as UPS).

5.3 Facilities Costs

The facility cost calculation involved compiling the total facilities cost for each of the warehouses involved in the operation's supply chain. The data about individual facility costs is included in Table 5.1.

Additionally, CoXHHS was leasing the WH 2, at a cost of $78,000 a year. This cost of lease was incremental price and lead to a possibility of elimination of the warehouse, since all the other warehouse facilities were owned by the city. Factors such as extra lease cost would be a crucial in decisions yielding from the model.

Table 5.1: Facility Costs for Secondary Warehouses

WH j	Labor Cost	Utilities & Supplies	Lease Cost	Facility Total Cost
WH 1	123,000	356,000	0	480,000
WH 2	30,000	50,000	78,000	158,000
WH 3	26,000	74,000	0	100,000
WH 4	26,000	62,000	0	89,000
WH 5	12,000	28,000	0	40,000
Total	217,000	570,000	78,000	867,000

5.4 Purchasing Costs

Schnetzler, Sennheiser, and Schonsleben (2007) note that in trying to achieve lower inventories and shorter lead times, operational costs are affected. With facilities costs in Table 5.2 and individual warehouse turn rates shown in Table 4.3; it was possible to proceed to a more in depth analysis of the data. A first step was to calculate an average turn rate for each facility in the CoXHHS supply chain. The desired result is that each facility would have at least a turn rate of 1.0, indicating that the inventory in each warehouse was overturned once a year. The results are summarized in Table 5.2.

Table 5.2: Inventory Turns Ratio for Secondary Warehouses

Warehouse #	Turns / Year	Total. Receipts
WH 1	0.36	$48,065.62
WH 2	2.18	$501,062.43
WH 3	0.07	$34,541.00
WH 4	0.49	$531,931.75
WH 5	0.15	$25,475.21
Total Purchases		$1,141,076.01

Table 5.2 shows that the only facility which demonstrated a desired average turn rate was warehouse 2. The other buildings, especially the warehouse 3, featured extremely low turn rates. The most likely cause of low inventory turns ratio was the high inventory costs in the form of obsolete or excess inventory stored in the facility, to explain in detail the warehouse had inventory supplies stored for longer periods of time. The longer the time supplies were stored in the primary warehouse the more expensive it gets to hold the inventory in the form of handling storage spaces, security and other costs explained the earlier sections. The Figure 5.2 below shows the investments in dollars that was received by warehouse 2 for period of one year. The graph shows that the warehouse

2 had good history of inventory receipts and inventory issues. Hence the warehouse 2 had the highest inventory turn ratio. Similarly, the warehouse 4 was among the warehouse that had significantly lower inventory turnover ratios. The Figure 5.3 indicates that the warehouse 1 had almost same distribution history as that of warehouse 2, but it had high ending balances of inventory resulting in high holding costs for storing excess inventory. The remaining distribution of warehouses has been included in Appendix (a).

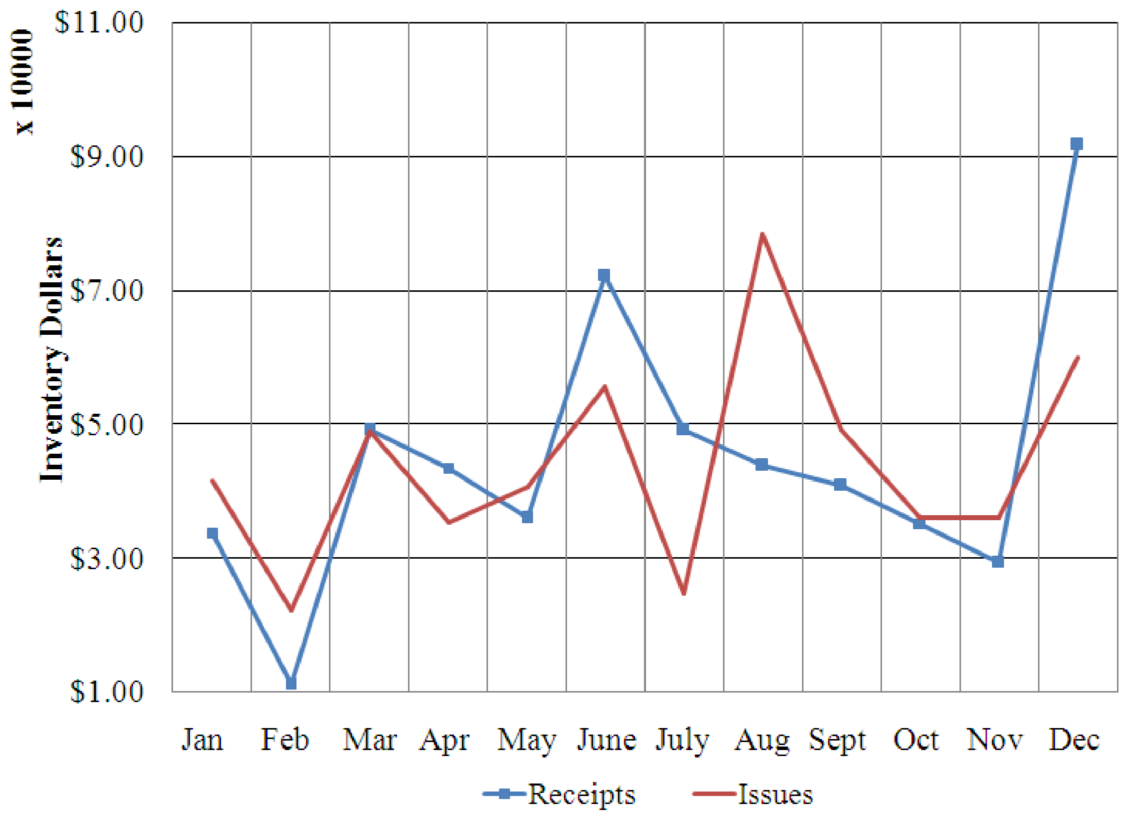

Figure 5.2: Distribution of Warehouse 2

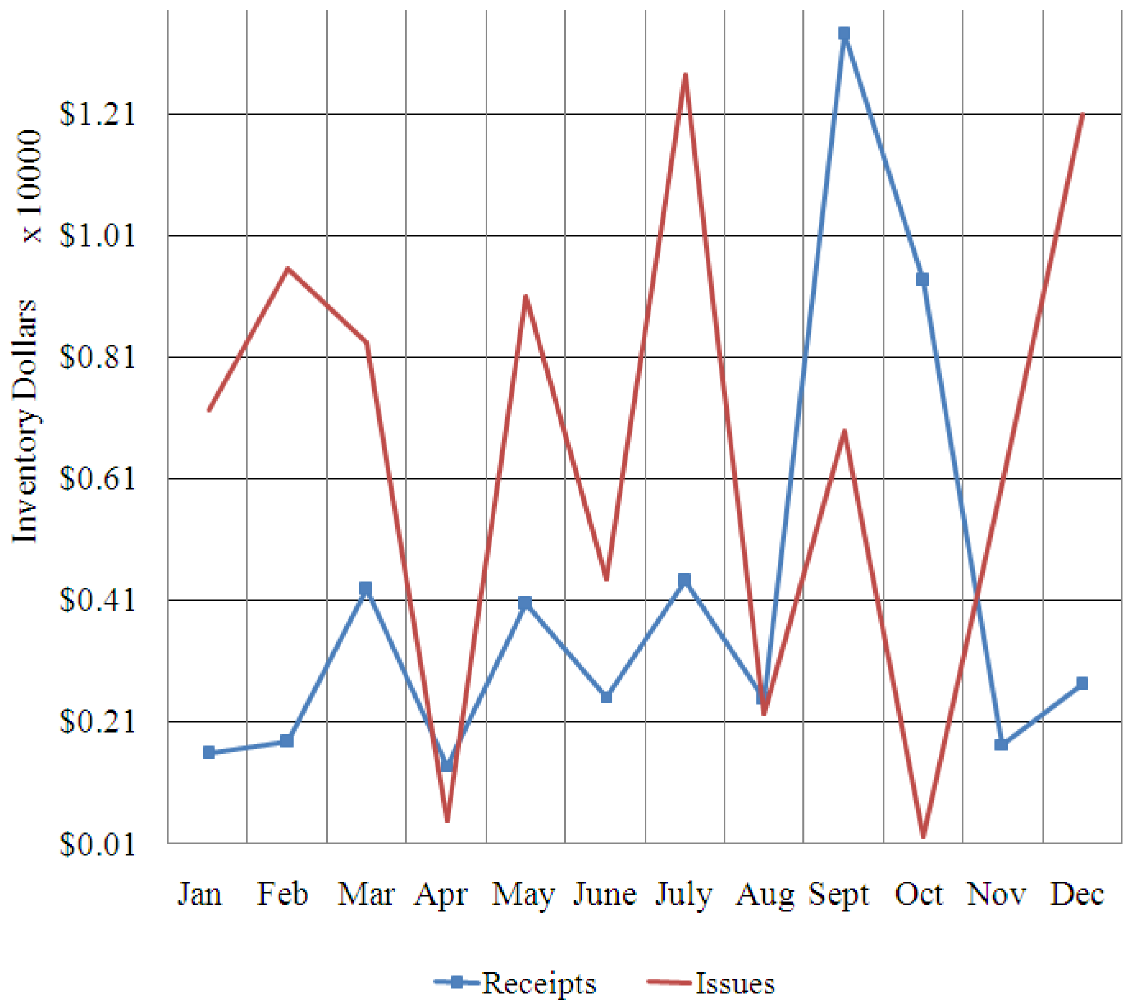

Figure 5.3: Distribution of Warehouse 1

The low receipts for the WH 5 shows that they were not ordering any items, a fact which is consistent with its role as an intermediary building in the supply chain. Thus their low turn rate is acceptable given the building's role. However, the facilities each sent out a large number of orders but experienced an unacceptably low turn rate.

5.5 The Carrying Cost Ratio

The total cost incurred per item was calculated for the entire CoXHHS supply chain and compared to the total purchase cost; resulting in the warehouse cost per dollar spent on holding the inventory in the warehouse. This calculated value was also exceptionally high; netting an average of \$0.95 per dollar purchased being spent to store and transporting each inventory item. Lowering this ratio could be accomplished through a variety of methods including consolidating inventory, increasing efficiency by standardizing procedures and optimizing storage use, and most importantly through elimination of obsolete inventory items from each facility. Table 5.3 shows the calculations for the CoXHHS carrying cost ratio. The shrinkage was included by the organization and no specific information was available on this. Fleet costs are the transportation. We assume that shrinkage and fleet costs are same for all the warehouses in this study.

Table 5.3: Carrying Cost Ratio of COXHHS

Costs	**Facilities**	**Shrinkage**	**Fleet**	**Sum**
Annual	867,000	127,000	87,000	1,081,000
Purchases	\$1,141,076			\$1,141,076
			$\mu=$	0.95

5.6 Inventory Turn Analysis

Secondary research metric was the average supply chain inventory turns. The objective was increase the average inventory turns from the present 0.775 per year to a 2.0 per year. The range of present inventory turns was as high as 2.18 and as low as 0.07. Best industrial practices are usually in the range of 1.2 to 2.4.

The ratio showed that the facilities cost of the system was well above 25% of the total purchase price. So in order to eliminate facilities and implement JIT inventory turns data was needed. Inventory turns are defined as the average number of items kept in stock divided by the annual usage of the item.

$$T = \frac{S_{ij} + S_{i0}}{\lambda_{ij}}$$

From the above expression, Table 5.4 shows the sample calculations for calculating the inventory turns for warehouse 2. The calculation of inventory turns for all the warehouses has been included in Appendix (b).

Table 5.4: Calculation of Inventory Turns for Warehouse 2

Month	Receipts	Issues	Ending Balance	Inventory Turns Projected Rate
Jan	$33,743.97	$41,396.82	$241,814.45	2.05
Feb	$10,996.46	$22,098.34	$214,561.54	1.24
Mar	$49,052.13	$48,812.51	$207,328.94	2.83
Apr	$43,417.58	$35,162.41	$220,699.94	1.91
May	$35,934.11	$40,559.21	$256,198.47	1.9
June	$72,153.98	$55,617.79	$256,099.58	2.61
July	$49,097.26	$24,727.25	$301,216.67	0.99
Aug	$43,699.36	$78,316.46	$230,303.09	4.08
Sept	$40,814.80	$48,988.60	$243,880.23	2.41
Oct	$35,104.14	$35,950.06	$239,340.29	1.8
Nov	$29,170.13	$35,932.18	$226,527.14	1.9
Dec	$91,622.48	$60,019.94	$260,678.96	2.76

Table 5.5: Average Inventory Turns for Warehouse 2

Total Receipts	Total Issues	Avg. Ending Balance	Inventory Turn Rate	Total Adjustments
$501,062.43	**$527,581.55**	**$241,554.11**	**2.18**	**$11,351.78**

The ABC analysis compares all the items ordered and prioritizes them according to use. Results of an ABC analysis are indicated in Table 5.6 for the primary warehouse of CoXHHS. Category "D" items were extremely slow moving items and it was observed that none of the "D" items had at least one issue in the past one year. The high percentage of "D" category items accounted for the entire obsolete inventory in the primary warehouse.

Table 5.6: ABC Analysis of Primary Warehouse

Category	# of items	% of items
A	104	3.5%
B	150	5.0%
C	476	15.9%
D	2263	75.6%
Total	2992	100.0%

ABC analysis classifies all the supplies by the percent of total dollars invested in purchasing the supplies. ABC analysis of secondary warehouse 2 as shown in Table 5.7 shows that, 80% of all the investment in inventory accounts to 8% of the supplies (referred to items in A category) and 15% of the investment accounts to 10% of the supplies (referred to items in B category) and 5% of the investment inventory accounts to 82% of the supplies (referred to items in C category). ABC analysis of warehouse 2, with results is indicated below in Table 5.7. ABC analysis of other warehouses has been included in the appendix.

Table 5.7: ABC Analysis of Secondary Warehouse 2

Category	# of items	% of items	Inventory value	% of Inventory value
A	36	8%	367035.6	80%
B	49	10%	68698.59	15%
C	384	82%	24859.63	5%
Total	469	100%	460593.82	100%

Order policy for each type of movers are set by movement category. Items that are deemed as "A" movers were placed on continual review for reordering. "B" movers have a review quarterly. "C" movers can be reviewed annually.

5.7 The Decision

After determining that the current carrying cost ratio for the CoXHHS was above the expected 15-25% procurement cost increase, a decision was made to switch from a two-echelon system to a one-echelon system. The switch had Earnings Before Interest and Taxes (EBIT) of $250,000 with a payback period of just over one year. Ordering policies were simplified and managed by each secondary warehouse, eliminating the need for a centralized logistics system. The carrying cost ratio was reduced from 0.95 to 0.39. From the series of iterations as shown in Table 5.8 and referring back to Table 4.2 for decision criterion, consolidating Wh1 and Wh3 would reduce the overall supply chain costs. Though the Wh5 also had low inventory turn ratio, the carrying cost model considers the impact of inventory turnover ratio and carrying cost ratio. So, the ratio is

0.39 when Wh1 and Wh3 are consolidated with other warehouses. Ordering policies were simplified and managed by each secondary and thus eliminating the primary warehouse. Most of the savings were due to lowering the total volume of the obsolete inventory in the supply chain. The reduction in obsolete inventory produced a 75% percent reduction in racking requirements.

Table 5.8: Carrying Cost Ratio Iterations for Decision

Iteration	**Carrying Cost Ratio**	**Decision Criterion**
1	0.51	When Wh1 is consolidated with other warehouses
2	1.38	When Wh2 is consolidated with other warehouses
3	1.63	When Wh3 is consolidated with other warehouses
4	1.56	When Wh4 is consolidated with other warehouses
5	0.89	When Wh5 is consolidated with other warehouses
6	0.60	When Wh1 and Wh2 are consolidated with other warehouses
7	0.39	When Wh1 and Wh3 are consolidated with other warehouses
8	0.76	When Wh1 and Wh4 are consolidated with other warehouses
9	0.45	When Wh1 and Wh5 are consolidated with other warehouses
10	1.22	When Wh3 and Wh2 are consolidated with other warehouses
11	6.92	When Wh4 and Wh2 are consolidated with other warehouses
12	1.30	When Wh5 and Wh2 are consolidated with other warehouses
13	1.40	When Wh3 and Wh4 are consolidated with other warehouses
14	0.79	When Wh3 and Wh5 are consolidated with other warehouses
15	1.48	When Wh4 and Wh5 are consolidated with other warehouses

The carrying cost ratio criterion of decision helps mangers to make strategic and tactical decisions so that the decision can reduce the overall costs of the supply chain. The organization has consolidated Wh1 and Wh3 with other warehouses. From the Table 5.8, no other iteration had carrying cost ratio in the acceptable range.

Chapter 6.0 Conclusion

Many organizations operate warehouses in order to reduce costs. Oftentimes in governmental operations, if not carefully managed these warehouse operations become bloated with inventory that is no longer needed or is needed at a much lower demand. Unless managers periodically analyze the contents of their warehouses, the carrying cost of all items purchased can outweigh savings from procurement when purchasing in bulk.

Decrease in carrying cost ratio demonstrates consolidating commodities into fewer facilities will lower costs. Allow cost justification, and priority quantification on which facilities should be eliminated and in what order. Secondary metric/goal to increase supply chain inventory turns has been achieved with the increase in inventory turns to 1.2 after the implementation of recommendations from this research.

In today's fast-paced business world, the time to evaluate business operations is not available, and quick decisions need to be made. This carrying cost ratio, based on easily found data, shows when a warehouse's operations are inefficient and not cost-effective. This model speeds up the process and thereby speeds change and cost savings in a company.

Our results from the analysis of the model include the evaluation of warehouses using carrying costs ratio, identification of obsolete inventory in warehouses resulting in low inventory turns ratio. Current research model describes decision criteria for the inventory managers in terms of stocking importance of high moving items and slow moving items. The future benefits for the current organization include a reduce building and facility costs, decrease in annual operating budgets, reduce warehouse operational cost, improve labor productivity, improve warehouse space utilization, establish performance measures,.

6.1 Limitations

However there are some limitations to this model. One limitation would be very large systems where JIT contracts would be too complicated. Organizations with a large service range such as a regional or larger retailer may not benefit from this ratio as is. But, for a smaller company or a city, this model can be very effective at recognizing overcapacity or inefficiencies in a supply chain. Operational considerations such as budget and lease were not considered. The data was collected from accounting records and hence any errors in the accounting can change the outcome of this case study.

6.2 Contribution to Body of Knowledge

The model developed in this research would provide researchers and practitioners a model to calculate the efficiency of warehouse in terms of reducing inventory and avoiding obsolete inventory. The research model develops a carrying ratio that can be calculated easily from easy to find data. This model can help managers estimate how inefficient warehousing can become if inventory is not periodically checked for obsolescence. The decision tool from this research can be used at tactical and for making strategic decision. A model to calculate the efficiency of warehouses in terms of reducing inventory and avoiding obsolete inventory the model can help managers estimate how inefficient warehousing can become if inventory is not periodically checked for obsolescence and this research develops a carrying cost ratio.

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Chapter 8.0

8.1 Appendix (a)

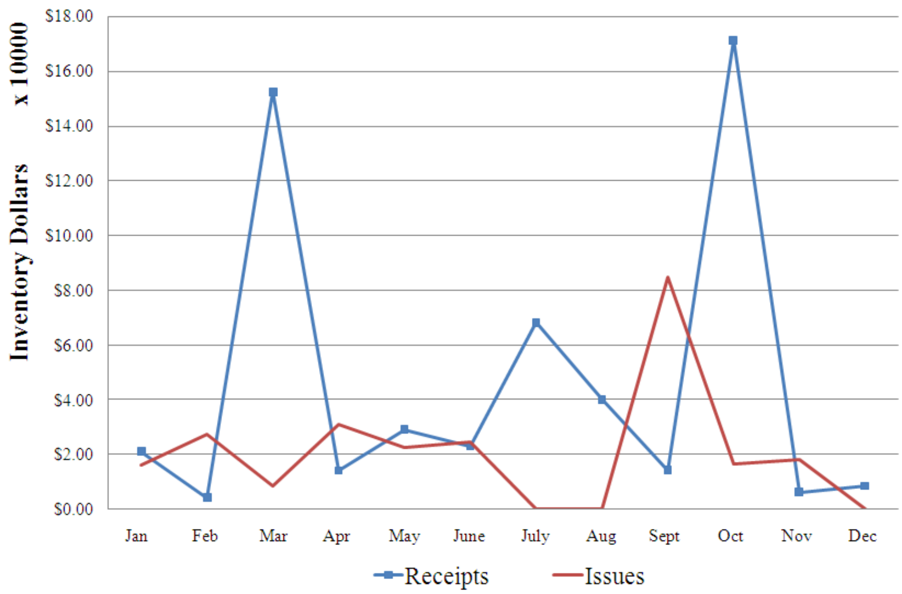

Figure 8.1: Distribution of Warehouse 4

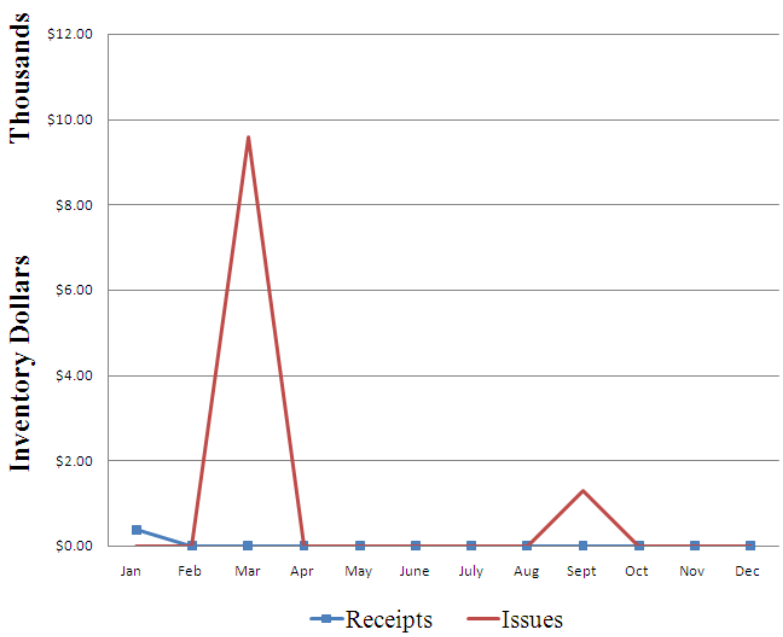

Figure 8.2: Distribution of Warehouse 3

8.2 Appendix (b)

Table 8.1: Calculation of Inventory Turns for Warehouse 1

Month	Receipts	Issues	Ending Balance	Inventory Turns Projected Rate
Jan	$1,568.36	$7,236.51	$202,869.62	0.43
Feb	1,761.13	9,551.05	195,812.47	0.59
Mar	4,287.56	8,331.95	202,217.92	0.49
Apr	1,376.41	481.05	203,421.35	0.03
May	4,036.50	9,081.41	204,298.67	0.53
June	2,511.46	4,442.58	200,335.48	0.27
July	4,409.40	12,733.49	201,053.26	0.76
Aug	2,475.40	2,232.99	191,966.22	0.14
Sept	13,410.46	6,882.61	255,630.13	0.32
Oct	9,355.39	207.81	264,354.49	0.01
Nov	1,725.00	6,002.56	265,309.89	0.27
Dec	2,716.90	12,102.76	256,821.40	0.57

Table 8.2: Average Inventory Turns for Warehouse 1

Total Receipts	Total Issues	Avg. Ending Balance	Inventory Turn Rate
$48,065.62	**$79,286.77**	**$220,340.91**	**0.36**

Table 8.3: Calculations for Inventory Turns for Warehouse 3

Month	Receipts	Issues	Ending Balance	Inventory Turns Projected Rate
Jan	$380.50	$0.00	$176,160.86	0.00
Feb	0.00	0.00	176,160.86	0.00
Mar	0.00	9,574.71	166,586.12	0.69
Apr	0.00	0.00	166,586.12	0.00
May	0.00	0.00	166,586.12	0.00
June	0.00	0.00	166,586.12	0.00
July	0.00	0.00	166,586.12	0.00
Aug	0.00	0.00	166,586.12	0.00
Sept	0.00	1,285.27	165,300.85	0.09
Oct	0.00	0.00	165,300.85	0.00
Nov	0.00	0.00	135,890.72	0.00
Dec	0.00	0.00	135,890.72	0.00

Table 8.4: Average Inventory Turns for Warehouse 3

Total Receipts	Total Issues	Avg. Ending Balance	Inventory Turn Rate
$0.00	**$10,859.99**	**$162,851.80**	**0.07**

Table 8.5: Calculation of Inventory Turns for Warehouse 4

Month	Receipts	Issues	Ending Balance	Inventory Turns Projected Rate
Jan	$21,064.40	$16,068.08	$551,494.86	0.35
Feb	4,285.37	27,255.85	528,864.35	0.62
Mar	152,430.30	8,551.39	477,191.54	0.22
Apr	14,224.90	30,906.12	480,220.13	0.77
May	29,101.65	22,447.35	485,137.98	0.56
June	23,086.43	24,459.24	444,811.66	0.66
July	68,153.57	0.00	505,870.59	0.00
Aug	40,169.52	0.00	558,767.55	0.00
Sept	14,358.71	84,839.63	455,376.68	2.24
Oct	171,228.53	16,379.99	548,123.65	0.36
Nov	6,281.58	18,284.57	508,378.06	0.43
Dec	8,611.20	0.00	516,703.66	0.00

Table 8.6: Average Inventory Turns for Warehouse 4

Total Receipts	Total Issues	Avg. Ending Balance	Inventory Turn Rate
$531,931.75	**$249,192.21**	**$505,078.39**	**0.49**