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Evaluating Obselete Inventory Policies in a Hospital's Supply Chain

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EVALUATING OBSOLETE INVENTORY POLICIES

IN A HOSPITAL'S SUPPLY CHAIN

By

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Numerous organizations are currently facing inventory management problems including distributing inventory on time and maintaining the appropriate inventory level to satisfy the end user. Organizations understand the importance of inventory accuracy as any error will increase the purchasing and holding costs affecting investment decisions. Lack of information about effective measures that will allow management to make important business decisions motivated this research to identify a decision criterion for warehouse management. A feasible solution of calculating the carrying cost ratio from purchasing and holding cost is the main objective of this thesis. The carrying cost ratio will allow managers to make critical decisions on supply-chain management. Similar to the carrying cost ration, this thesis also provides a methodology for warehouse management using inventory turns that can be used to identify obsolete inventory. Friedman's Rank test was performed to validate the decision using primary turns for the dataset obtained from a local hospital. Recommendations have been made to the hospital to facilitate their supply chain that will result in the reduction of excessive inventory. A reduced carrying cost ratio demonstrates consolidating commodities into fewer facilities. The future benefits for the current organization include a reduce building and facility costs, decrease in annual operating budgets, reduction in warehouse operational cost, improvement in labor productivity, warehouse space utilization, and establish

performance measures. In conclusion, findings from this research will allow organization to move towards the one-echelon model known as Just-In-Time (JIT) system.

To My Grandfather,

Donald "Buddy" Cavitt (In Memoriam)

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Finally I close with this **"I would never have amounted to anything were it not for adversity. I was forced to come up the hard way" (J.C. Penney)**.

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Chapter 1

Introduction

The supply chain can consist of many different entities. These entities consist of organizations, people, technology, activities, information and resources that may be involved in the movement of a product from the initial supplier to the end user. The nodes of the supply chain in which materials travel are as follows: supplier, internal supply chain which consist of purchasing, production, and distribution ending with the end user which is the customer. Figure 1.1 below describes the flow of the components of the supply chain.

This thesis focuses on continuous improvement recommendations for managing inventory costs in a health care facility. It is envisioned that a decision tool developed from this research can achieve these improvements. Different components within the supply chain were evaluated including warehouses, storerooms, purchasing and distribution practices, and end customer. Each component was critical for overall success of the supply chain. The scope of the thesis was to focus on overall continuous improvement efforts in the organizations supply chain.

Improvements of the supply chain consisted of evaluation of current processes, problem quantification, and documentation of relevant best practices within the supply chain (including supply chain facility types and amount inventory held). The improvement criterion in this thesis is based upon the development of a decision tool that allows managers to make better decisions with limited data.

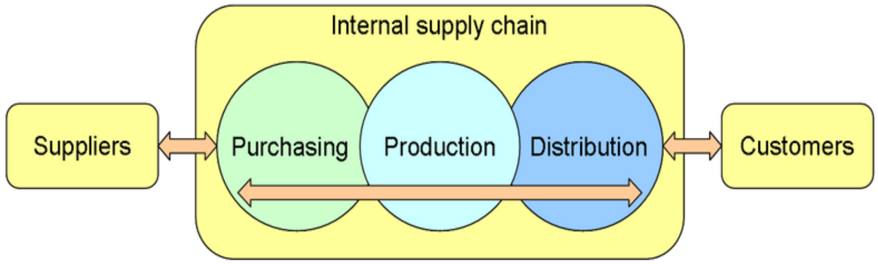

Figure 1.1 An illustration of supply chain

1.1 Thesis Outline

The rest of this thesis is divided in five chapters. Chapter 2 discusses the Economic Order Quantity (EOQ) model and background of the inventory carrying cost. Each primary and secondary component of the inventory carrying cost is discussed. Chapter 3 discusses the research objective. This Chapter describes the research questions, specific objectives, and the intellectual merit of the proposed research. Chapter 4 details the research methodology including notations, significance of the two and one echelon models and the development of a carrying cost ratio that has the potential to be very beneficial to organizations managing inventory. Chapter 4 considers factors that may influence the carrying cost ratio. Those factors include but are not limited to: holding cost, inventory turns and obsolete inventory. Chapter 5 describe the case study in which the research methodology is implemented and analyzed. Chapter 5 describes the data collection procedure, facility cost, purchasing cost, and the carrying cost ratio. The carrying cost ratio is the proposed inventory parameter that helps management with measuring inventory levels. Potential cost reduction strategies such as closing a warehouse and saving the organization thousands of dollars can be identified by use of the carrying cost ratio. After the ratio is discussed the inventory turns will be discussed, followed by Friedman's Rank test and decision. Finally, the conclusions discuss the research limitations and the potential contribution to the body of knowledge.

Chapter 2

Background

The theory of supply chain and inventory control dates back to early 19^{th} century. Many researchers have studied inventory theory and have developed a logical and theoretical methodology to understand the importance of inventory. It was also important 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 was related to determining how much to order known as the "Economic Order Quantity" (EOQ). A great industrial pioneer F. W. Harris first derived this model. The EOQ model is widely utilized in inventory theory. In addition to the EOQ model and its concept, the level of inventory on-hand to act as a buffer against sudden increase in product demand is classified as 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 utilized in combination with the 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 conducted by Nicole DeHoratius (2004) to understand inventory inaccuracy, results indicated that nearly 370,000 inventory records from 37 stores were 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 a different 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).

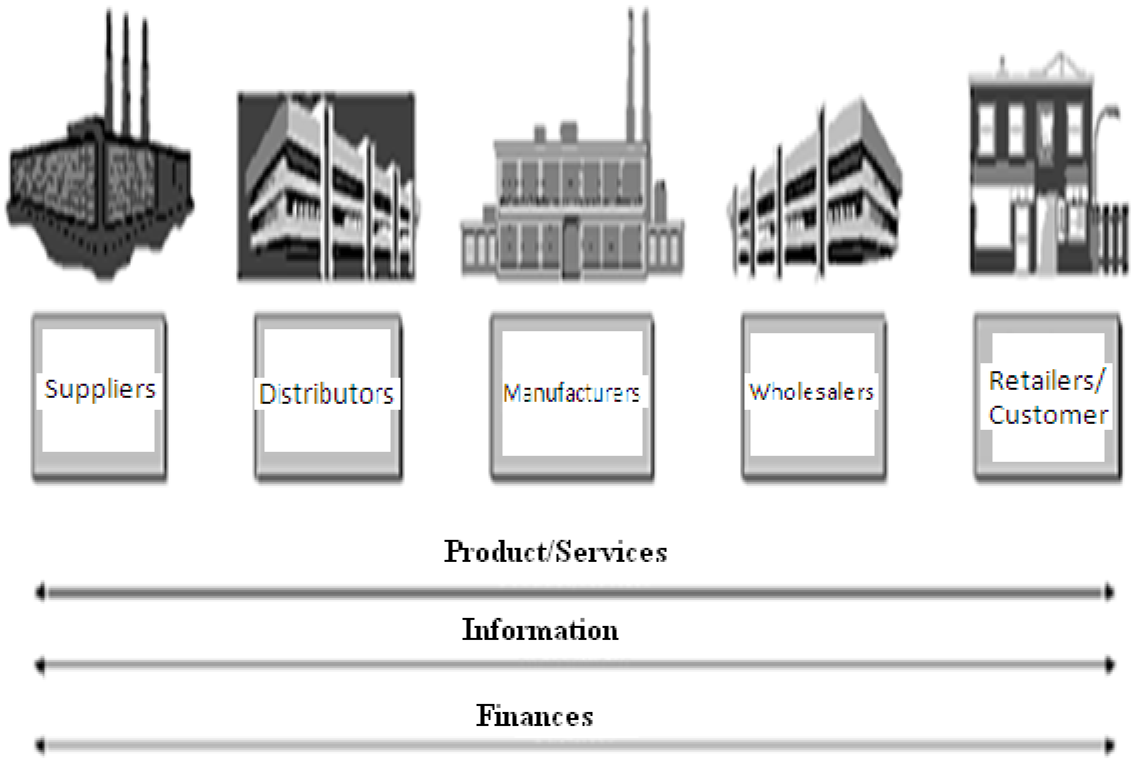

Figure 2.1 Layout of Supply Chain

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 holding costs are minimized. The result is the most cost effective quantity of products to order. In purchasing, this is recognized as the order quantity, in manufacturing it is known as production lot size. In an article by Rogers and Tsubakitani (1991), focus was set on locating 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 focus on minimizing holding costs at both echelon levels plus penalty costs at the lower echelon level was desired. Results indicated that par levels at the lower echelon level where determined by the critical ratio while the par level for the upper echelon was determined by a search of the holding cost function at that respected level. Detailed explanation about two echelon and one echelon supply chain model has been provided in the later part of this chapter.

Schonberger (1982) illustrated the tradeoffs associated with decreasing the setup cost in the classical EOQ model. This is a key study that contributes key points to this study. A research survey conducted by J. E. Holsenback in 2007 demonstrated the necessity of accurately measuring and monitoring inventory-holding costs (IHC). The study also further demonstrates that knowledge of the underlying statistical pattern of supply and demand variations can significantly improve forecasting and influence the appropriate 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 its impacts on decision making, fails to recognize that inventory can represents one-third to one-half of a organizations overall assets.

Literature suggests that an organization with an IHC of 35% to 36% pay for the inventory twice in slightly more than two-year period: once for purchasing the inventory and a second time for carrying the inventory 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). Even though EOQ may not apply to every inventory situation, most organizations find it beneficial in at least some one aspect of their operation. Anytime an organization has continuous purchasing or planning of an item, the EOQ model should be under consideration. Standard 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. Equation for the EOQ model and its components are provided below.

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

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 cost.

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 a research thesis by DeScioli (2001), the 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, total cost, TC, can be expressed by the formula listed below

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

Where 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 compared four supply chain policies and investigated the efficiency of each of the four supply chains based on carrying cost, total inventory cost, ordering cost, shortage costs.

2.2 Inventory Carrying Cost

The Figure 2.2 shows the breakdown of different cost that contributes to inventory carrying cost. The term carrying cost is interchangeable with the term holding cost. Inventory Carrying Cost (I_{cc}) has four primary components that contributes to this cost. Of the four primary components there are several secondary components described later in the chapter. The four components that make up Inventory Carrying Cost are Capital Cost, Inventory Service Cost, Storage Space Cost, and Inventory Risk Cost. Inventory Carrying Cost is cost associated with 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.

Piasecki (2001) has explained EOQ calculations and its optimizations. Piasecki stated that, if cost does not change based upon the quantity of inventory on hand then it should not be included in the Inventory Carrying Cost. In the Economic Order Quantity (EOQ) formula, carrying cost is represented as the annual cost of inventory on hand per unit. Major cost increases in inventory carrying cost include an increase in the major components respective subcomponents. These costs include an increase in capital cost, inventory service cost, storage space cost and inventory risk cost. For most inventory on hand within the organization, the annual carrying cost is between 20 to 40 percent of the estimated materials cost. Many organizations do not accurately estimate carrying cost of inventory. Organizations simply estimate carrying cost simply on borrowing money alone. There are many factors such as capital, inventory service, storage space, and inventory risk cost that has the ability to outweigh inventory carrying cost. Below are the primary components and secondary components of carrying cost in detail.

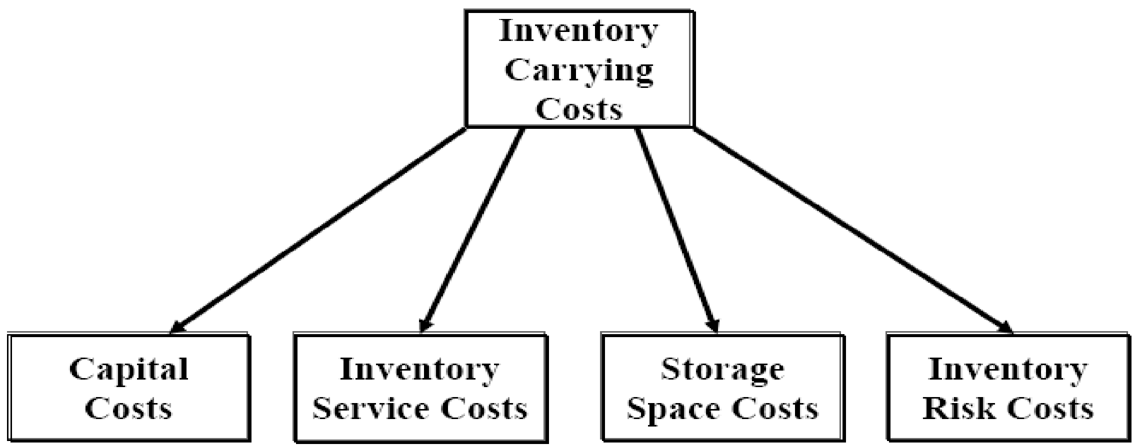

Figure 2.2 Inventory Cost Breakdown

2.2.1 Capital Costs

Capital cost is the first primary component of Inventory Service Cost. This cost is defined as cost an organizations fund from an investor perspective including both debt and equity. Organizations are able to simply calculate debt cost given that it is the cost composed of interest. Simply an organization borrows funds to purchase inventory, the interest rate would be part of the carrying cost.

2.2.2 Inventory Service Cost

Inventory service cost is the second primary component of Inventory Service Cost. This cost is defined as the cost to manage inventory. Inventory service cost is focused on many components. The perspective of inventory service cost focus upon replenishment lead times, asset management, future inventory price forecasting, and inventory valuation. Successful analyzing these components organizations are able to calculate the service cost of their inventory on hand.

2.2.3 Storage Space Cost

Storage Space cost is the third primary component of Inventory Service Cost. This is the cost to store inventory within an organization. Storing inventory consist of four different criteria's. First criteria consist of space to store the inventory including heat or air conditioning, rent and maintenance issues. The second criterion is the money tied up in inventory that the organization may have on hand at the time. The third criterion is the cost of insurance tied to the inventory as well as any property taxes. The last criterion that contributes to the overall cost of Storage Space Cost is cost of deterioration of the items hand. Deterioration tends to occur when the inventory has been on hand over long durations of time also known as obsolescence of inventory. The cost to store or carry inventory is stated on an annual basis, such as $3/per unit or 15% of the items cost (Harold Averkamp 2008).

2.2.4 Inventory Risk Cost

Inventory Risk cost is the final primary component of Inventory of Inventory Service Cost. This cost is also known as inventory liability or risk management cost. Inventory risk cost has four secondary components that contribute to the overall cost of inventory. Details of the subcomponents are provided in detail later in the chapter.

2.3. Inventory Investment Cost

Inventory Investment cost is the first and only secondary component of capital cost. An organization focuses on this cost when trying to develop sales for their organization. Each month it is typical that an organization forecasts actual sales and expenses. In a situation where sales are lower than normal, management usually take the necessary action to ensure that the company bottom-line remains profitable. In addition, inventory investments consist of different tools that management utilize to determine the cost of their invested inventory. A good management tool that can be utilized is budgets, but unfortunately, a few organizations disregard this tool, which has the ability to project their largest asset.

It is critical to the success of organizations inventory management system, and business in general, to develop a budget to determine the value of stocked inventory maintained in each warehouse. This budget is referred to as the "target inventory investment" (Schreibfeder 1997).

Organizations utilize the following ratio to calculate their targeted inventory investment.

$$\text{Target Inventory Investment} = \frac{\text{Projected Annual Cost of Goods Sold from Stock Sales}}{\text{Target Inventory Turnover}}$$

where, Projected Annual Cost of Goods Sold from Stock Sales is the realistic projection of what the organization sales from the warehouse stock will be (at cost) during the next 12 month period (Schreibfeder 1997).

In addition, the Target Inventory Turnover is the organization’s Projected Annual Sales divided by their Target Inventory Investment. Table 1.1 below demonstrates sample calculation. These calculations can be compared to Jon Schreibfeder (1997) Effective Inventory Management Target Inventory Investment calculations.

Table 1 Sample Calculation of Target Inventory Turnover

Projected Annual Sales (Cost)	Targeted Inventory Turns	Target Inventory Investment
$10,000.00	2.857	$3,500.00
$10,000.00	4	$2,500.00
10,000.00	2.5	$4,000.00
10,000.00	2.0	5,000.00

Based from Effective Inventory Management, Inc. Schreibfeder, Jon 1997

2.4. Insurance Cost

Insurance cost is the first secondary component of Inventory Service Cost. Insurance cost accounts for one to three percent of the overall carrying cost (REM Associates 2010). Since insurance costs and the total value of inventory are related, organizations often assume that insurance costs are included in the carrying cost.

2.4.1 Physical Handling Cost

Physical Handling cost is the second secondary component of Inventory Service Cost. This cost accounts for two to five percent of the overall carrying cost. Physical Handling cost is the cost associated with the movement of finish goods from the end of production operation to the end user.

2.4.3 Taxes Cost

Taxes Cost is the final secondary component of Inventory Service Cost. This cost accounts for two to six percent of the overall carrying cost. Taxes cost is the cost associated with the inventory calculated into the overall carrying cost on product and facility.

2.5. Obsolescence Cost

Obsolescence cost is the first secondary component of Inventory Risk Cost. This cost accounts for six to twelve percent of stock material that is purchased but not sold, used to provide a service, or is part of an assembly or finished good. This includes material that is lost, stolen, broken, scrap, or becomes obsolete in the warehouse (Schreibfeder 1997).

2.5.1 Damage Cost

Damage cost is the second secondary component of Inventory Risk Cost. This is the cost due to damaged inventory within an organization. This cost varies and organizations tend to have higher damage cost when there is more inventory on hand.

2.5.3 Shrinkage Cost

Shrinkage cost is the third secondary component of Inventory Risk Cost. This cost is identical to obsolescence cost.

2.5.4 Relocation Cost

Relocation Cost is the final secondary component of Inventory Risk Cost. The movement of inventory from one location to another is what companies classify as relocation cost. Relocating inventory can be by air or land. This cost is similar to Physical Handling Cost. Figures 1 through 5 below provide an overview of the primary and secondary components of Inventory Carrying Cost.

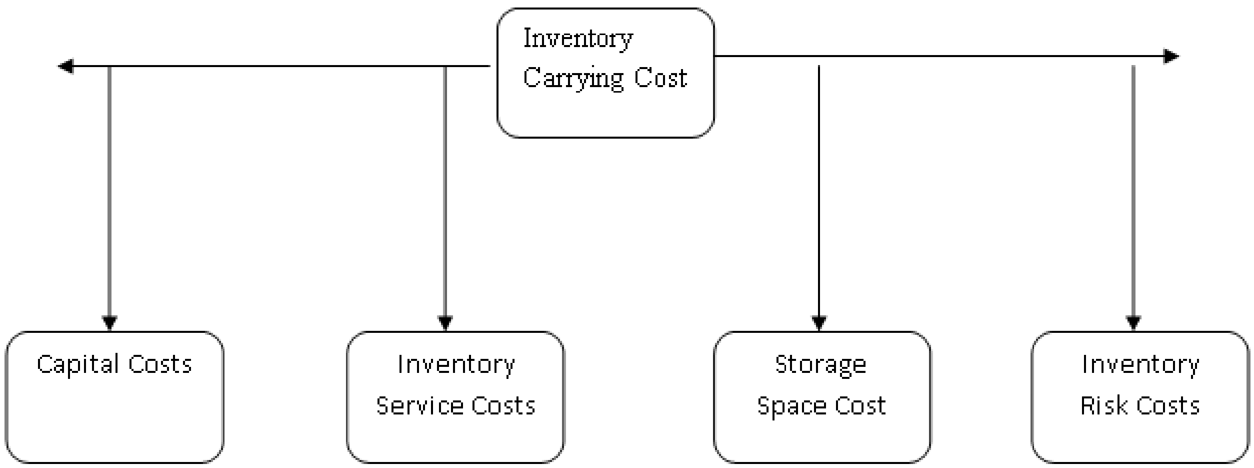

Figure2.3 Inventory Carrying Cost Components

The flow diagram above describes four components that contribute to Inventory Carrying Cost (I_{CC}). Of the four components stated above, there are subcomponents that contribute to the main components that are in direct correlation to the overall affect of the Inventory Carrying Cost as stated above. For example, if the Inventory Carrying Cost increased by 10 percent then the Capital Cost is subject to change as well. On the other-hand if Inventory Investment, the only subcomponent of capital cost increased by 5 percent then there is no affect on capital, which does not affect the Inventory Carrying Cost.

Diagram of the four major components; capital cost, inventory service cost, storage space cost, and inventory risk cost are displayed below with respective subcomponents.

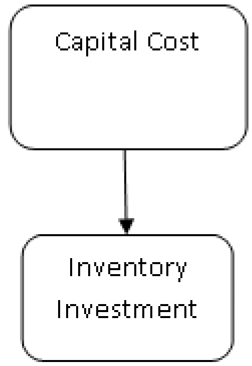

Figure 2.4 Capital Cost Includes Inventory Management

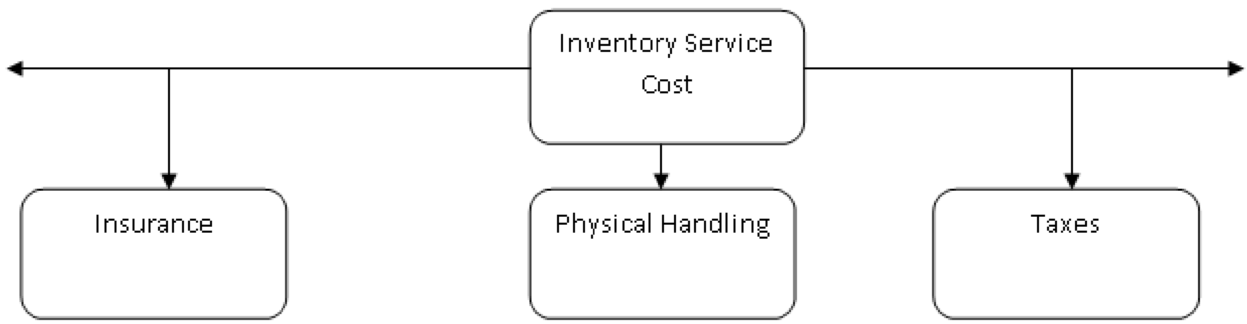

Figure 2.5 Inventory Service Cost - Insurance, Physical Handling and Taxes

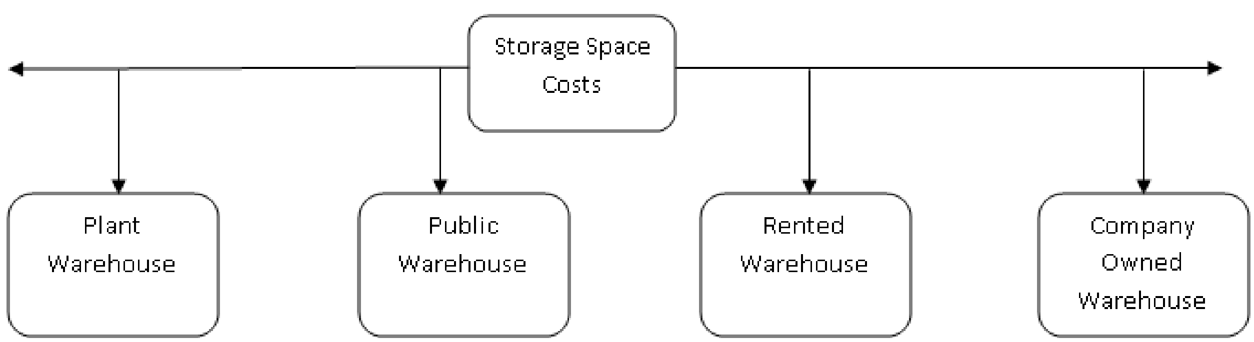

Figure 2.6 Storage Space Cost - Plant, Public, Rented, and Company Owned Warehouse

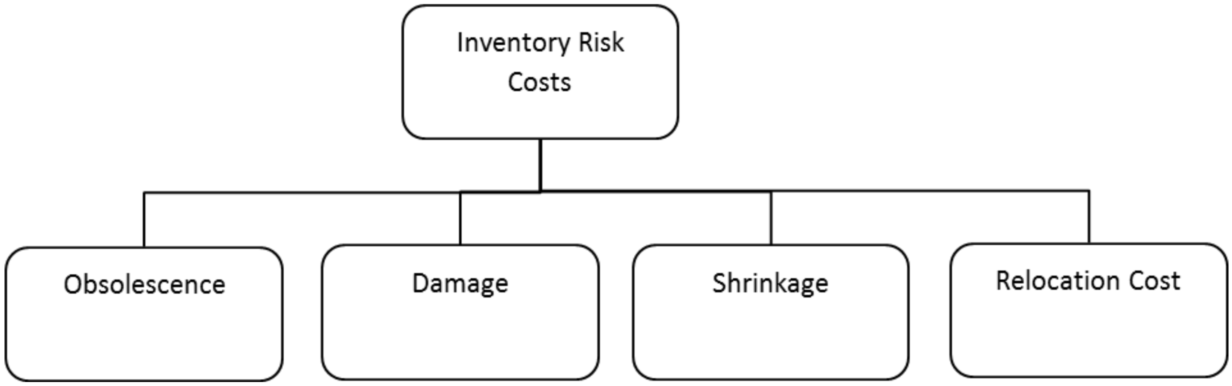

Figure 2.7 Inventory Risk Cost - Obsolescence, Damage, Shrinkage and Relocation Cost

2.6 Best Practice of Reducing Inventory

Reducing lead times, obsolete inventory, and improving the inventory turn ratio support organizations in effective inventory management and thus saving investment in maintaining inventory. Table 2 below illustrates the top ten inventory reduction practices and their estimated percentage. If an organization implemented these tools in managing their inventory, they would see an improvement in reduced inventory.

Table 2 Top Ten Inventory Reduction Practices

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%

2.6.1 Eliminating Obsolete Inventory

Many organizations fail at throwing away inventory that they have paid for. In return, holding on to this inventory makes it obsolete, which burns up other inventory investments that the organization may have. Eliminating obsolete inventory promptly, organizations are able to utilize the money and allocated space for more profitable situations. Companies have turned to a program to identify obsolete inventory known as "Red Tag" event. This is done by placing a red sticker with the following information; individual conducting the inspection, date tagged, and the review date. Once properly labeled the inventory is moved to quarantined area of the organizations warehouse. If the inventory is not used by the review date, the inventory is liquidated.   This program was originated by Japan's automakers.

Example of a Red Tag event in effect is when a car dealership is advertising car deals at the end of the year. They are simply trying to eliminate obsolete inventory to make room for more profitable inventory.

2.7 Supply Chain Models

The layout of the supply chain as in Figure 1.1 and Figure 2.1 illustrate the flow of the products moving from suppliers to manufacturers, distributors, retailers, and finally to the end-user. 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 stage of supply chain in which the product travels is called echelons. Figure 2.8 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. If uncertainty is minimized the supply chain is more effective. The level of uncertainty in the supply chain has been widely discussed in terms of searching for a solution to 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). As the number of echelons increase in the supply chain, analyzing becomes more complicated. The scope of this thesis was limited to the two echelons and one echelon supply chain model.

2.7.1 Two Echelon Model

Many research articles have cited the discussion in Caglar's (2003) model about optimizing two-echelon inventory models. Caglar developed a two-echelon 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 average response time. Caglar defined the service constraint as the time it takes a customer to receive a spare part after a failure is reported. 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 2.7.

Each secondary warehouse acts as a smaller warehouse. These secondary warehouses supply to many customers and maintain a stock level S_{iM} for each item. In addition, each secondary warehouse consists of a set *i* of *n* items that are used with a mean rate λ. When a given customer uses an item, the customer replenishes itself by taking item supply stock and I from the secondary warehouse M if the item is available. If the item is unavailable at the time, the item is ordered and the customer has to wait for the item to become available at the secondary warehouse.

There has been related research to understand the characteristics of multi-echelon inventory model and the dynamics of a two-echelon supply chain in particular. Zhang 2007 utilizes an example of the two-echelon model, where the researcher analyzed reducing the inventory level of raw material, work in process and finished items, which is the focus of the supply chain (Zhang 2007). In the article Zhang proposed a integrated vendor managed inventory (VMI) model for a single vendor and multiple buyers and the processes for raw material ending with the delivery of finished items to multiple buyers. Zhang concluded in his article by presenting a solution procedure of the optimal investment amount and replenishment decision for all buyers and a proposed vendor. Figure 2.8 below illustrates the two-echelon supply model.

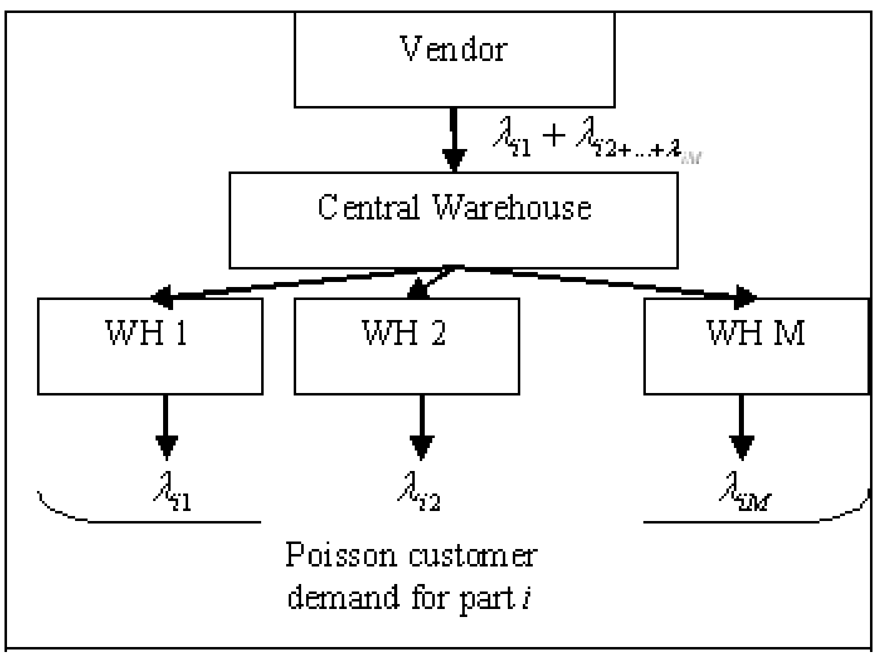

Figure2.8 Two Echelon Supply Inventory Model

If all supply and demand variability for a particular product are known, then the holding cost for inventory can be reduced. 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 goal 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 did not negatively influence the customers. This included eliminating the primary warehouse if necessary.

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 was utilized to determine proper stocking levels at each of secondary and primary warehouse. Caglar (2003) response time equation was also 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 equation 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. This model is very useful in optimizing the two-echelon model but requires a large amount of data and many assumptions. Caglar (2003) utilized the model in a way that would provide an approximate distribution for inventory on-hand and provide information on backorders at each depot for the two-echelon system.

2.7.2 One Echelon Model

The one-echelon model is a one-warehouse model with a JIT system. JIT is an inventory strategy that organizations utilize to improve their Return On Investment (ROI) by simply reducing inventory and carrying cost. The JIT production method is part of the Toyota Production System pioneered by Japans automakers. To meet JIT objectives, the process relies on signals known as Kanban signals. These signals are classified as the different points in the process, which informs production when to make the next part. If the JIT system is implemented strategically, organizations can improve their overall efficiency, ROI, and quality. The layout of the one-echelon model is provided below in Figure 2.9.

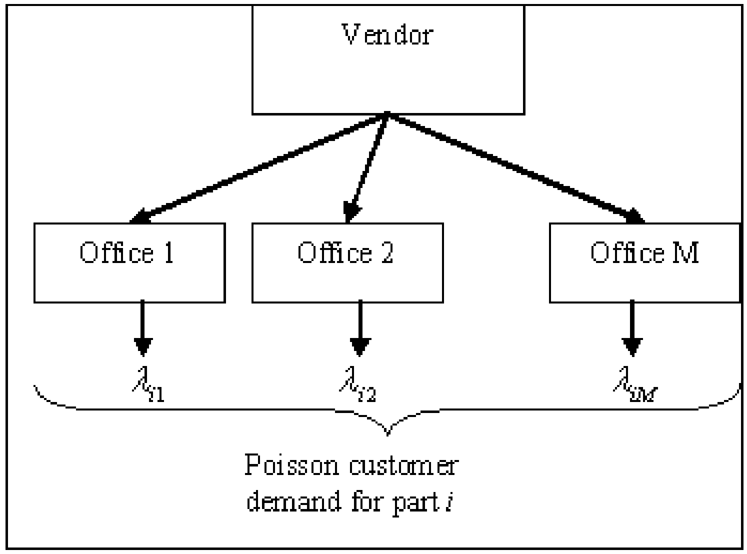

Figure 2.9 One Echelon Supply Inventory Model

To compare the total cost of a one-echelon JIT system to all other system, the same service level W_j was utilized. In addition, the system turns into a one-echelon inventory problem. This simplified the model, as the levels from which the system queued from reduced.

The JIT system in this model works simply by items that are ordered goes directly from the vendor to the secondary warehouse, where a smaller stock level is utilized 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 2.8.

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 may remain constant by ordering small or large orders. In addition, shipping rates for several small orders at a time may exponential increase. In such situation, suggestion is to select a vendor in close proximity to the secondary warehouse.

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

Chapter 3. Research Objectives

3.1 Research Question

Literature illustrates limited research to measure the performance of warehouses. In Chapter 2, explanation of optimizing warehouses and supply chain operations were based on complex equations and hard to collect data. In addition, the availability of an accurate measurement criterion or metric that has the ability to identify key factors that were correlated with the poor performance of an organizations warehouse were limited as well. The overall objective is to provide a useful decision support tool that gives management the ability to make effective decisions pertaining to their inventory.

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

3.2 Specific Objectives

The specific objective is to describe a carrying cost ratio and its components. The model supports three specific objectives but focus was geared toward Specific Objective #2.

- Specific Objective #1: Demonstrate how the suggested metric compare to other metrics.
- Specific Objective #2: Development of carrying cost ratio.
- Specific Objective #3: Demonstrate methodology for applying metric

It was hypothesized that the carrying cost ratio determines which warehouse was more profitable to close. Our null hypothesis was that the carrying cost ratio determined the warehouse to shut down which resulted in the largest overall profit or the largest overall cost reduction.

3.3 Intellectual Merit

The intellectual merit in meeting the specific objectives are as stated:

- A tested inventory control metric that extends theoretical inventory control methods,
- Introduction of a methodology that provides a useful perspective approach for managers, and
- Comparison of the usage of this metric and method against previous theoretical inventory control models

Chapter 4

Research Methodology

4.1 Notations

The research methodology approach was to describe how to evaluate the supply chain model. The decision criterion was based upon total cost due to labor and facility cost. The model describes which system had a better chance to succeed based upon the weighting of the inventory holding costs. Sections 4.2 and 4.3 describe a comparison of two-echelon, one-echelon and the proposed carrying cost ratio.

The following assumptions were made.

- The consumable goods network consisted of the primary warehouse, secondary warehouses, and the customers.
- The shipment time between the warehouse and the secondary warehouse j was a stochastic process with a mean T_j.
- The travel time between secondary warehouse and customer was negligible, because they were in the same location.
- In the JIT analysis, ordering costs was included in the negotiated JIT contract.
- Every item was crucial for the customers to function properly. For example, physicians cannot execute surgery procedure without proper equipment.
- When an order was placed from a secondary warehouse and it is available at the primary, a vehicle was sent and the response time for that action was zero.
- We assumed Kj, the number of customers served by the secondary warehouse j, was large and we modeled the demand rate for item, I, at secondary warehouse, 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).

Table 3 Notations

Notation	**Description**
A_w	Annual fixed cost of warehouse operation;
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*;
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*;

Notations	**Description**

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*;
S_{CM}	Stock level for each warehouse
V_{Wj}	Value of warehouse *j*;
W_{ij}	Waiting time for a customer ordering item *i* from office *j*;

4.2 Two Echelon Model

In 2003, Caglar, Li, and Simchi-Levi presented a two-echelon supply chain model that was used in making cost-effective decisions about warehouse inventory levels. Caglar model in 2003 illustrated an inventory problem faced by a manufacture that developed electronic parts at different location. In Caglar’s paper, the problem was modeled utilizing a mutli-echelon model. We utilize Caglar’s model to demonstrate the current two-echelon supply chain of this research. First, we considered a two-echelon multi-consumable goods inventory system consisting of a central distribution center and multiple customers that required service as illustrated in Chapter 2 Figure 2.7.

Each service center in this two-echelon model acted as a smaller warehouse because the service rate was customers that are receiving supplies. In addition, the level of stock for each warehouse was maintained at a level of S_{CM} for each item. Therefore, each office consisted of a set, I, of *n* items that was utilized at a mean rate. When an item was used by a customer, it replenished itself by taking item, *i*, from office M's.

If an item was not available at the time, an order was placed and the customer had to wait until the item arrived at the office. The decision criteria of the supply chain was based on basic purchasing and holding cost information while maintaining an average response time that would not negatively impact the customer. In case that the customer was negatively impacted elimination of the central warehouse was suggested.

Utilizing notations in Table 3 above, a model to determine operating a warehouse and implementing a JIT system was derived. From this model it can be determined if the organization benefits from operating the warehouse. The warehouse management processes consist of various operating cost. These operating costs include fixed costs such as labor cost and supplies cost. The cost included can be either variable or fixed cost and solely 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 utilized the annual costs. Notations to the components that contribute to annual cost are listed above in Table 4.1 as mentioned.

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

Equation 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 was the common one-echelon JIT system. JIT requires better planning of demand from customers and can sometimes make management feel uncomfortable about the extra procurement cost of items on a per unit basis.

However, 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 illustrated in this model, items ordered go directly from the vendor to the office, where a smaller stock level was utilized versus the warehouse. The one-echelon system differs due to the fact that there was no intermediary between vendor and the offices (Cagler et al. 2003; Lee 2003; Wang, Cohen, and Zheng 2000). This system was shown based on a simplification of Cagler et al.'s model in Figure 2.5

The JIT concept emphasis that contracts are made with the vendors and established based upon demand rate λ_{ij}. The following expected times of backorders of item *i* in office j are found by the following equation:

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

Equation (4.2)

In this case, items were delivered to the offices at the same rate they were being utilized. The symbol t_{ij} represents time between deliveries for item *i* at office *j*. Therefore, by substitution, $\lambda_{ij}t_{ij}$ is also consider the order quantity formulation which is shown below.

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

Equation (4.3)

Keeping the expected wait time for the customer for each system the same allowed for a comparison of costs without changing the response time to the customer. Costs associated with the JIT system contained all of the fixed costs of the system as well as any additional costs of requiring 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 would be important to select vendors that were in proximity of the offices. After factoring in a possible increase in purchase and shipping prices, we suggest that the total cost for the JIT system will was as follows:

$$C_{JIT} = \sum_{i \in I} \sum_{j \in J} P_{JITi} \lambda_{ij} + C_I \quad \text{Equation (4.4)}$$

when,

$$C_I = \sum_{i \in I} \sum_{j \in J} \left(I_{ij} * \left(\theta_C + \theta_S + \theta_{Oij} \right) \right) \quad \text{Equation (4.5)}$$

Once again, in many situations the data needed to use this optimization may not be available in the timeframe of the project. When cost data was not readily available, 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 operational model. This was possible as long as the total cost for purchasing, storing, and delivering items to the customer can be determined. The validity of the carrying cost ratio was evaluated utilizing a sample data set consisting of supplies cost from seven warehouses. The data set was collected from a local healthcare organization as part of a Six Sigma project to improve inventory management. The collection of the data was over a one-year period and was analyzed using a non-parametric statistical test. The Friedman rank test is emphasized in Chapter 5.

The purpose of the carrying cost ratio model was to determine a cost developed over the supply chain process from the time inventory was processed for shipment until it reaches its point of interest. The merits of understanding these incurred costs include

- An understanding of the cost of each item,
- Operational cost that would have to be overcome and
- Procedure for which actions an operation can take to decrease the cost/dollar spent ratio.

The carrying cost model takes uses the carrying cost ratio. We hypothesize that the cost of inventory and fixed costs accounts for majority of the total cost of the warehouse operation, stated by equation 4.6 below.

$$TotalWarehouseCost = A_w + C_I \qquad \text{Equation (4.6)}$$

After identifying the stock levels or current accounting information, the next step was to implement the carrying cost ratio to determine which system was better for the procedures. The ratio of the total cost of maintaining the inventory divided by the total inventory purchase price was the ratio carrying cost ratio.

After identifying stock levels using the above-mentioned formulas or current accounting information, the next step was to implement a ratio to determine which warehouse was better for operation. This model created was utilized as a metric in analyzing and comparing the one-echelon and two-echelon inventory models in this research. The metric, $\mu_{w,}$ implemented in the decision-making is the ratio of the total cost of maintaining the inventory and the total inventory purchase price.

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

Equation (4.7)

where: all costs were annual and $\sum_{i \in I} C_{Wi}$ = total purchased in dollars

The decision for the supply chain was based on the scale shown in Table 4. The range of the ratio between 0.1-0.2 has been estimated as the best possible supply chain to reduce the overall costs. The range between 0.2-0.4 has been considered the acceptable range to accommodate the additional costs that result in the improvement of the supply chain and the accommodation in any changes of the supply changes based on procurement. The range of ratio above 0.4 suggests a need in improvement to reduce overall costs.

Table 4 Decision Tool for “Carrying Cost Ratio” (CCR) 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

Source: Dr. Erick C. Jones and Tim Farnham “Obsolete Inventory Reduction with Modified Carrying Cost Ratio”(2006)

The above relationship provides a standard for performance of the warehouse operations. The ratio consists of total dollars spent maintaining inventory to the total purchase price of all the items in the inventory. Practice included the additional costs due to Just in Time contracts in the range of 15-25% increase. If an organization's carrying cost ratio was above this proposed target, the Just in Time (JIT) option was considered which was buying directly from the retailer.

Chapter 5

Case Study

5.1 Case Study: Description

A medium sized hospital in the Unites States had a trend of increasing operational costs and decrease in overall performance of the warehouses. The hospital operated from one primary warehouse and seven secondary warehouses. When a particular device was needed, inventory was sent from the primary warehouse and distributed at different points of care. The different points of care acted as the secondary warehouses. Analysis of the primary and secondary warehouse indicated that inventory was procured at higher levels than needed.

The hospital followed a two-echelon supply chain inventory model. Detailed explanation of the two-echelon inventory model was provided in Chapter 2. A sample schematic of the two-echelon model is provided below in Figure 2.9. The model shown below of the two echelons below was to the one in practice by healthcare organizations.

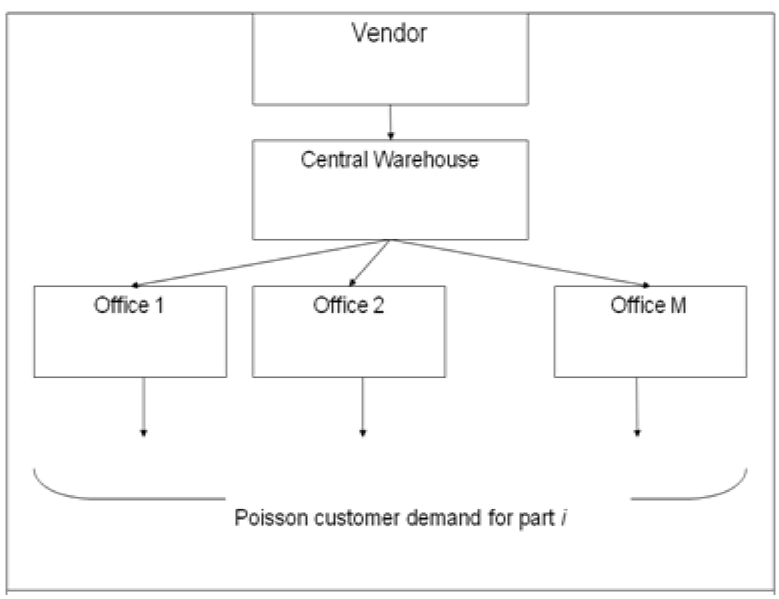

Figure 2.9 Hospital Two Echelon Supply Chain Model

5.2 Data Collection

The performance metric for the warehouses was the decrease in percentage of obsolete inventory. Best industry practices suggest having excessive inventory in the range of 3% to 6% of total inventory is acceptable (Gary 2003). The expected result from this research was the introduction of a new supply chain model that would reduce holding/storing excessive inventory products and reduce obsolete inventory.

The research methodology was utilized in the analysis of the warehouse and inventory management systems of “City of Y” hospital that operated from its own distribution network to service seven secondary warehouses. An analysis was then conducted to determine if there were any constraints in the supply chain. This information was determined from the results of the Freidman’s Rank test provided below. It is envisioned that the methodology can be very beneficial for management to determine which action yields positive results in reducing costs and/or increasing net profits for an organization. From the annual reports, the organization had an inventory value of $169,894.00.

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

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

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

Space cost = Cs

Procurement costs (C_P) include cost of that item, inbound trucking delivery to warehouse, and opportunity cost of tied up funds. Delivery costs (C_d) include fleet maintenance costs and cost of delivery (such as cost per mile for pick-up or use of courier services such as UPS).

5.3 Facilities Cost

The facility cost calculation involved compiling the total facilities cost for each of the warehouse involved in the operations supply chain. This data is provided in Table 5 below.

Table 5 Secondary Warehouses from April 2009 - April 2010

Warehouse	Labor Cost	Utilities & Supplies Cost	Facility Cost
Warehouse 1	$11,932.00	$3,762.00	$48,000.00
Warehouse 2	$11,932.00	$13,153.00	$15,800.00
Warehouse 3	$11,932.00	$26,614.00	$10,000.00
Warehouse 4	$11,932.00	$48,58.00	$8,900.00
Warehouse 5	$11,932.00	$42,661.00	$4,000.00
Warehouse 6	$11,932.00	$36,324.00	$34,900.00
Warehouse 7	$11,932.00	$42,523.00	$26,100.00
Total Cost	**$83,524.00**	**$169,894.00**	**$147,700.00**

5.4 Labor Cost

Labor cost from this project is assumed a total of $83,524.00 for the seven warehouses combined. The total labor cost was divided by the total number of warehouses bringing the total to $11,932.00 for labor cost/ per warehouse.

5.5 Utilities and Supplies

Utilities and Supplies cost per warehouse were determined by summing the total number of utilities and supply cost per month for each warehouse. Table 6 and 7 below provides a detailed explanation for utilities and supplies cost for each month over a one-year period starting in April 2009 until April 2010.

Table 6 Utilities and Supply Cost for Secondary Warehouse for April 2009-Octocber 2009

Secondary Warehouses	Apr. 09	May 09	June 09	July 09	Aug.09	Sep.09	Oct. 09
Warehouse 1	$494.00	$162.00	$289.00	$62.00	$165.00	$400.00	$156.00
Warehouse 2	$265.00	$361.00	$603.00	$603.00	$2,230.00	$1,446.00	$2,233.00
Warehouse 3	$2,992.00	$3,077.00	$2,659.00	$1,043.00	$2,611.00	$2,818.00	$1,506.00
Warehouse 4	$620.00	$710.00	$209.00	$721.00	$722.00	$516.00	$39.00
Warehouse 5	$4,847.00	$5,418.00	$4025.00	$5,597.00	$4,529.00	$4,097.00	$0.00
Warehouse 6	$3,112.00	$2,869.00	$2,902.00	$1,585.00	$4,824.00	$3,675.00	$1,428.00
Warehouse 7	$4,839.00	$4,862.00	$3,946.00	$1,288.00	$2,694.00	$4,350.00	$4,025.00

Table 7 Utilities and Supply Cost for Secondary Warehouse for November 2009-April 2010

Secondary Warehouses	Nov. 09	Dec. 09	Jan.10	Feb.10	Mar. 10	Apr. 09-Mar10
Warehouse 1	$366.00	$182.00	$362.00	$525.00	$601.00	$3,762.00
Warehouse 2	$664.00	$777.00	$1,093.00	$707.00	$2,171.00	$13,153.00
Warehouse 3	$2,635.00	$1,971.00	$1,758.00	$2,356.00	$1,187.00	$26,614.00
Warehouse 4	$88.00	$390.00	$24.00	$525.00	$293.00	$4,858.00
Warehouse 5	$3,685.00	$4,251.00	$2,198.00	$728.00	$3,285.00	$42,661.00
Warehouse 6	$2,494.00	$4,199.00	$3,811.00	$2,123.00	$3,251.00	$36,324.00
Warehouse 7	$3,784.00	$3,879.00	$2,242.00	$2,597.00	$4,081.00	$42,523.00
Average	**$1,959.00**	**$2,235.00**	**$1,641.00**	**$1,366.00**	**$2,115.00**	**$24,271.00**
Total	**$13,716.00**	**$15,648.00**	**$11,488.00**	**$9,561.00**	**$14,806.00**	**$169,894.00**

5.6 Purchasing Cost

Purchasing cost refers to cost that an organization acquires from goods or services, to accomplish the goals set forward for their organization. Purchasing cost has a standard that organizations try to follow but the cost still has the ability to vary from organization to organization. The total purchasing cost for the organization analyzed in this study was $169,894.00 as indicated in Table 7 above.

5.7 Carrying cost ratio

Total cost was calculated for the hospitals supply chain. Once the total price was calculated, comparison of the total price and purchasing cost was conducted. The calculated carrying cost ratio was 0.87. This value was on the high end, which suggests that there is a need for a major improvement within the supply chain. It was recommended to implement a method to reduce the ratio. Consolidating inventory was the method addressed to lower this ratio. Consolidating inventory from the bottleneck warehouses had the ability of improving the performance within the organizations supply chain. Consolidating the inventory also has the ability to reduce any obsolete inventory within supply chain as well. Emphasis will be focused on this decision in Section 5.8 of the thesis. Table 8 below displays the carrying cost ratio for the hospital. Given the constraints of the data, shrinkage and fleet cost were not available and assumed to negligible.

Table 8 Carrying Cost Ratio for hospital

Costs	**Facilities**	**Shrinkage**	**Fleet**	**Sum**
Annual	$147,700.00	$0.00	$0.00	$147,700.00
Purchases	$169,894.00			$169,894.00
			μ=	0.87

5.8 Inventory turns

The supply chain inventory turns was the metric utilized to determine which warehouse was more reasonable to consolidate. The table below gives details of the calculated inventory turns for the seven warehouses. Inventory turns was defined as the average number of items kept in stock divided by the annual usage of the item. Please see Equation 5.1 below to compute inventory turns.

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

Equation 5.1

From the equation stated above, Table 9 below provides the inventory turn for each warehouse.

Table 9 Calculated Inventory turn for Warehouse 1 through Warehouse 7

Warehouse	**Inventory Receipts**	**Inventory Usage**	**Inventory Ending Balance**	**Inventory Turn Projected Rate**
Warehouse 1	$3,762.00	$43,965.00	$3,890.00	1.06
Warehouse 2	$13,153.00	$43,965.00	$14,242.00	3.88
Warehouse 3	$26,614.00	$43,965.00	$28,629.00	7.81
Warehouse 4	$4,858.00	$43,965.00	$5,086.00	1.38
Warehouse 5	$42,661.00	$43,965.00	$43,057.00	11.75
Warehouse 6	$36,324.00	$43,965.00	$39,725.00	10.84
Warehouse 7	$42,523.00	$43,965.00	$47,302.00	12.91

5.9 Friedman Rank Test

In inventory control, the supplies cost was important for warehouse management. For this reason the supplies cost for a one year period was collected from seven warehouses of a local healthcare provider. The distribution of the supplies costs was not known and the limitation in the number of data points warranted a non-parametric statistical analysis such as the Friedman’s rank test. In this test the values in each row is first ranked separately from low to high. The data in each column was then ranked. If the sums were very different, the P value would be small. Table 10 summarizes the rank of the warehouses based on supplies cost.

Table 10 Output of Friedman's Rank Test

Warehouses	**Rank**
WH1	1
WH4	2
WH2	3
WH3	4
WH6	5
WH5	6
WH7	7

From the above table it was evident that warehouse 1 had the least rank and warehouse 7 had the highest rank. Thus, warehouse seven was recommended for consolidation. Based on ranks of warehouses 1 and 4 further investigation was suggested to determine if closing or consolidating the warehouse is the appropriate suggestion.

5.10 Decision

The decision after calculating the carrying cost ratio for the seven warehouses was to consider consolidating warehouse number seven. This choice was validated from the inventory turns calculation. In Section 5.6 of the thesis it can be seen that the inventory turns ratio for warehouse seven is extremely high giving reason to believe that there is obsolete inventory on hand and consolidating this inventory evenly amongst the over six warehouses would be optimal. Also consolidating warehouse number seven, the organization reduces holding cost of inventory for that particular warehouse. This conclusion is also supported by the Friedman's rank test in section 5.7. Since warehouse, seven had the highest rank of the warehouses it is assumed that management should take a closer and in-depth analysis of this warehouse and consider consolidating for a lower inventory turn rate.

Chapter 6

Conclusion

Many organizations operate numerous warehouses in order to reduce overall cost. In a situation where inventory is not carefully monitored or effective inventory management system is unavailable, inventory has the opportunity to become very problematic and unmanageable. Unless managers check there inventory on a continuous bases the carrying cost has the potential to outweigh savings from procurement when purchasing inventory in mass quantities. However, decreasing the cost ratio support reasons in lowering overall cost of the supply chain. This is a very critical point for organizations seeking ways to reduce cost. The inventory turns analysis and Friedman's rank test displayed its value when trying to decide which warehouse or distribution center to close. It is envisioned that this analysis technique can be adopted to address such concerns.

6.1 Limitations

There are a few limitations to consider when working with the proposed model. First limitation is that this model does not have the capacity to be maximized in a large system. Utilizing this model in a large system would be very complex. This model is more suitable for smaller compact organizations with issues pertaining to their supply chain performance. There were also some constraints to the data set. Due to number of data points available limited statistical analysis could be performed. In the future, the goal is to obtain more data points to perform a strong statistical procedure.

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 the warehouse in terms of reducing inventory and avoiding the occurrence of obsolete inventory. The research model presents a carrying ratio that can be calculated easily from easy to access data. This model and methodology has the ability to assist management in determining which warehouse is performing the worse. Also, management then either decide to consolidate with other warehouse or eliminate the warehouse completely .The inventory turns and Friedman's rank test contributed significantly to determining which warehouse to consolidate and management can utilize the same tool. In closing, specific objectives, two and three were met. Further evaluation of Specific Objective One is needed to make decision if reaching this objective was achieved. In addition, Objective One will be met once other metrics are analyzed and then comparison of the metrics can be successfully carried out.

Chapter 7

References

1. La Londe, Bernard J., Lambert, Douglas. (1977). Methodology for Calculating Inventory Carrying Costs, International Journal of Physical Distribution & Logistics Management, **7(4)**, 193–231.
2. Caglar, D., Li, C.L., and Simchi-Levi, C. (2003). Two-echelon spare parts inventory system subject to a service constraint, IIE Transactions, **36**, 655-666.
3. Dong, Y., KXu, K. (2002). A supply chain model of vendor managed inventory, Transportation Research. Part E: Logistics and Transportation review, **38(2)**, 75-95.
4. Gossard, Gary. (2003). Best Practices for Inventory Reduction, Supply Chain market.13 Jan.2003 Web 23 Mar.2010.
5. Graves, S.C. (1985). A multi-echelon inventory model for a repairable item with one-for-one replenishment. Management Science, **31**, 1247-1256.
6. Holsenback, E. J., Henry J. McGill. (2007). A survey of inventory holding cost assessment and safety stock allocation. Academy of Accounting and Financial Studies Journal, **11(1)**, 111-120.
7. IOMA: Managing Logistics (2002). Inventory Carrying Costs: Is There a "Right' Way to Calculate Them?
8. Nicholson, L, Vakharia., Erenguc S. S. (2004). Outsourcing inventory management decisions in healthcare: Models and application, European Journal of Operational Research, **154**, 271–290.

9. Raghunathan, S., Yeh, A.B. (2001). Beyond Edi: Impact of continuous replenishment program (CRP) between a manufacturer and its retailer, Information Systems Research, **12(4),** 406-419.
10. REM Associates. (n.d.). Methodology of Calculating Inventory Carrying Costs. Princeton, New Jersey.
11. Richardson, Helen. (1995). Transportation & Distribution, Control Your Costs then Cut Them
12. Sherbrooke, C.C. (1968). METRIC: a multi-echelon technique for recoverable item control. Operations Research, **16**, 122-141.
13. Tony, Wild. (2002). Best Practices in Inventory Management. John Wiley & Sons, New York, NY.
14. Williams, Mark. (2009). 10 Keys to Inventory Reduction, The Williams Supply Chain Group, Inc, 18, Nov. 2009. Web. 23 Mar 2010.
15. Wang, Y., Cohen, M. A., & Zheng, Y.S. (2000). A two-echelon repairable system with the restocking –center-dependent depot replenishment lead times. Management Science, **46**, 1441-1453.
16. Schnetzler, M. J., A. Sennheiser, A., & Schonsleben , P. (2007). A Decomposition-based approach for the development of a supply chain strategy. International Journal of Production Economics **105**, 21–42.
17. Lee, C. B. (2003). Multi-echelon inventory optimization. Evant White Paper Series. http://www.stanford.edu/group/scforum/Welcome/white%20Papers/Multi-Echelon%20%Inventory720Optimization%20-%20Evant%20white%20paper.pdf. Accessed: August 30, 2007.

18. Johnson, J. C., Wood, D. F., Wardlow, D. L., and Murphy, P. R., Jr. (1999). Contemporary Logistics, 7th Edition. Upper Saddle River, NJ: Prentice Hall.
19. Nicole, D., Raman, A. (2008). Inventory Record Inaccuracy: An Empirical Analysis, Management Science, 54(4), 627-641.
20. Descioli, D, T., Byrnes, L, S., (2001). Differentiating the Hospital Supply Chain for Enhanced Performance, Master’s Thesis, Rutgers University, New Brunswick, NJ.
21. Rivard-Royer, H., Landry, S., Beaulieu, M. (2002). Hybrid stockless: A case study: Lessons for health-care supply chain integration. International Journal of Operations & Production Management, 22(4), 412.
22. Wilson, R.H. (1934). A Scientific routine for stock control. Harvard Business Review, 12, 116-128
23. Harris, F, H., (1913). How Many Parts to Make at Once. The Magazine of Management. 10, 135-136.
24. Tsubakitani, S., Rogers, D, F., (1991). Newsboy-Style Results for Multi-Echelon Inventory Problems: Backorders Optimization with Intermediate Delays," Journal of Operational Research Society, 42 (1), 57-68.
25. Sinha, D. and Matta, K. F. (1991). Multi-echelon (R, S) inventory model. Decision Sciences, 22 (3), 484-499.
26. Schonberger, E., Andriessen, L., (1982). The Apollonian Clockwork: Tempo (New Series), **3**, 3-21.

27. Talluri, S., Cetin, K. & A.J. Gardner, (2004). Integrating Demand and Supply Variability into Safety Stock Evaluations. International Journal of Physical Distribution & Logistics Management, 31(1), 62-69.

28. Larry, P.V., (1983). System to Maximize Inventory Performance in a Small Hospital. American Journal of Hospital Pharmacy, 40 (1), 70-73.

29. Ballard, Glenn and Gregory Howell (1995a). "Toward Construction JIT." Proceedings of the 1995 ARCOM Conference, Association of Researchers in Construction Management, Sheffield, England.

30. Mecca, S. (2000). As Sequences Flow: Proposal of Organizational Rules for Lean Construction Management. IGLC-&7 Proceedings, Brighton.

31. Tommelein, I. D., (1997). Discrete-event Simulation of Lean Construction process. IGLC-5 Proceedings, University of California, Berkeley, USA, 121-123.

32. Piasecki, D. (2001). Optimizing Economic Order Quantity. IIE Solutions.

33. Raghuram. INVENTORY METRICS. 6 April 2010

<http://www2.egr.uh.edu/~araguram/INVENTORY+METRICS-sachin1.htm>.Dr. 34.

34. Erick C. Jones and Tim Farnham "Obsolete Inventory Reduction with Modified Carrying Cost Ratio"(2006)