A SUSTAINABILITY BASED FRAMEWORK TO MAKE A STRATEGIC OUTSOURCING DECISION FOR WAREHOUSES IN THE ELECTRONICS INDUSTRY

by

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Dedicated to My Parents – Murugananthan & Bharathi

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ABSTRACT

A SUSTAINABILITY BASED FRAMEWORK TO MAKE
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Over the course of last decades, sustainability matured from an abstract concept to an important source of corporate legitimacy. Supply chain management plays an important role in shaping and framing sustainability, due to the high level of external value added in many industries (Hofmann, Busse, Bode, & Henke, 2013). It is critical to accurately monitor and determine inventory holding costs and its impacts on decision making as it can be a representation of almost half of the overall assets of an organization. The concept of outsourcing stems from the traditional make-or-buy and subcontracting questions that companies have dealt with for centuries. Research suggests that, instead of outsourcing functions or activities (tasks within a functional area) one by one, they should be outsourced in clusters if they are connected through flows of goods or information (Biehl & Prater, Outsourcing Multiple Business Functions: A Theory Building Investigation, 2003). Simultaneously with increased demands on strong economic performance based on the effectiveness of these supply chains, organizations are now held responsible for the environmental and social

performance of their suppliers and partners (Editorial, Sustainability and supply chain management - An Introduction to the Special Issue, 2008).

The goal of this research is to provide an economic and sustainability analysis on a decision criterion whereby organizations can determine whether to continue operations of their warehouse(s) or to close the warehouse(s) based on the carrying cost ratio. If a shutdown is determined as the best solution, then the benefits of outsourcing multiple functions of a supply chain together must be considered. This thesis provides a framework for outsourcing.

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INTRODUCTION

1.1 Sustainable Supply Chain Outsourcing

The concept of outsourcing stems from the traditional make-or-buy and subcontracting questions that companies have dealt with for centuries. In today's climate of economic uncertainty, companies that have relied on outsourcing in the past to curtail costs are increasingly "reeling in" their outsourcing decision to more appropriately balance supply chain risk and reward (Russell & Smith, 2009). Hence, outsourcing is a critical decision which should account for numerous tradeoffs based on a company's primary objectives (reduce cost or increase production). Outsourcing of a supply chain (SC) activity is a special instance of business process outsourcing (Tsay, 2010).

A recent study, 2012 Market Predictions, stated that as companies seek to elevate the roles of their procurement professionals to include more strategic business sustainability activities, outsourcing of transactional functions are expected to increase (Urlaub, 2011). Sustainability is good for a business. In many cases, a move towards a greener supply chain will actually reduce the organization's cost and make the supply chain leaner and more flexible (Donnelley, n.d.).

1.1.1 Problem Statement

In the 2000s, organizations headquartered in the developed nations realized that they could cut costs and improve the quality of their services by outsourcing. In the mid-2000s, sustainable development increasingly became an issue. Policy makers began to consider the social and environmental impacts of the jobs (outsourcing) on broader economic development, otherwise known as responsible innovation (Perera, Begley, & MacGillivray, 2009).

In the mid-2000s, outsourcing and sustainability began to go hand-in-hand with each other. By this time outsourcing was looked at as the primary option to increase profit by reducing cost, reducing time, and it was also seen as an opportunity to focus more/completely on the core competencies. Thus, outsourcing strategies and techniques evolved in order to answer *how to achieve sustainable long-term success*, besides trying to answer *how to work more efficiently*. The problem is much easier to solve for a large company willing to squeeze budgets to force outsourcing than it is for smaller companies looking to implement a lasting process change (Tate, 2010).

Most people are ignorant about the fact that there are significant costs associated with outsourcing. These costs are not always factored into the cost savings in the first year. But instead, they are divided over a number of years in order to keep the shareholders happy. On CFO Day 2011 (an event for financial leaders), most participating CFOs agreed on the statements like "outsourcing always has a significant effect on CO_2 performance" and "the sustainability agenda for outsourcing needs to look beyond CO_2 reduction" (Heiningen, 2011). Thus, there is a need to move on from blind cost-cutting to focusing on efficiency, sustainability, and long-term competitive advantage (Tate, 2010).

1.1.2 Research Significance and Broader Impacts

What would be the disadvantages of using any one of the traditional outsourcing theories (such as Transaction cost economics theory or core competency theory)? If either of the theories is applied to making a decision on outsourcing, then there is a tradeoff associated with it. For instance, if only TCE is considered, then the firm has to be ready to outsource any of its core activities, and vice-versa. Or a tradeoff between profitability and sustainability may be necessary. The significance of this research is to seek impacts of the coordinated outsourcing framework that supports operational sustainability and optimizes decision making at the strategic planning level of the supply chain. Furthermore, the broader impact of this research is that it will be relevant for current research on supply chain sustainability and the research can lead to better informed and higher quality outsourcing decisions with significant cost savings.

1.1.3 Research Question and Hypothesis

The industrial sector, especially high-tech industries, is striving hard to attain a balance between the tradeoffs, so that the organization can be responsibly innovative and at the same time make enough profit to stay in the market. Therefore, this research strives to answer the question of "Can an optimal coordinated strategic and operational outsourcing decision criterion be obtained that accounts for the tradeoff between profitability and sustainability"? The research hypothesizes that the outsourcing decision can be made based on the inventory in the facility, and also suggests grouping multiple functions of the supply chain together in order to be more economical.

1.2 Research Purposes

Almost all companies have the goal of increasing shareholders' value. Both past and current research agrees that optimizing the supply chain can increase the profit of an organization. But understanding the behavior of the supply chain and making decisions based on that understanding has always been a treacherous and critical task. As discussed above, outsourcing has become a buzzword that, most people believe to be synonymous with optimizing the supply chain and making profit.

1.2.1 Overall Research Objective

The highly competitive electronics manufacturing marketplace demands that suppliers provide low-cost, high-quality products to their customers in a timely fashion (Mason, Cole, Ulrey, & Yan, 2002). Traditional manufacturers have started focusing on their core competencies, such as product design and development, caused by shortened product life cycles and increasingly global competition, which made them to outsource the actual manufacturing of their products to contract manufacturers (Mason, Cole, Ulrey, & Yan, 2002). Although the decision to outsource can have both positive and adverse effects on key areas of the manufacturing supply chain, one positive effect is that the manufacturer's supply chain agility is increased (Mason, Cole, Ulrey, & Yan, 2002).

It is important that companies understand how the business models they adopt will affect their companies' sustainable competitive advantage. Previous studies show that as capital investment rose in the competitive semiconductor industry, more and more semiconductor integrated device manufacturers (IDMs) have benefited from moving towards a business model based on asset-light or pure manufacturing outsourcing (PMO), resulting in better operating performance and efficiency (Wen, Huang, & Cheng, 2012).

The overall research goal of this research is develop a framework for economic and sustainability evaluation to help supply managers make decisions on outsourcing business functions in a warehouse.

1.2.2 Research Objective and Specific Research Objectives

Increased globalization and continued outsourcing in various industries have caused industry and organizations to function on a supply chain or interwoven demand networking level. Simultaneously with increased demands for strong economic performance of these supply chains, organizations are now held responsible for environmental and social performance of their suppliers and partners (Editorial, Sustainability and supply chain management - An introduction to the special issue, 2008).

On the flip side, most people (including some organizations) have a misconception that taking a sustainability initiative will compromise the profitability of the organization. This is not true. The objective of this research is to investigate a coordinated framework which determines the optimal decision criterion for logical outsourcing of functions at the strategic levels of a supply chain. In order to meet this objective, three specific objectives are investigated below:

1. Evaluate a Transaction Cost Economics parameter determined by optimizing inventory related to a warehouse in a supply chain.

2. Evaluate the feasibility and benefits of grouping functions of a supply chain for the purpose of outsourcing.
3. Identify the impacts of a sustainability initiative on the outsourcing decision model in a supply chain.

CHAPTER 2

BACKGROUND

2.1 Introduction

According to a white paper on outsourcing the supply chain operations by HAVI solutions (HAVI Global Solutions, 2009):

> "In the supply chain arena, outsourcing has traditionally focused and thrived in the warehousing and logistics functions. Many companies today tap into expertise of third-party logistics providers to execute the transportation, physical handling and storage of products as they flow from the point of creation to the point of consumption. In many industries, the manufacturing process itself is commonly executed by outside partner companies."

In order to support the increasing need for outsourcing the supply chain operations, a framework for making a decision on outsourcing is necessary. As discussed in the previous chapter, companies often make a decision based on the economic value or make a tradeoff between profitability and sustainability. This brings up the issue of optimizing the decision making process. In this chapter, we discuss the importance of outsourcing and the significance of the metrics used in our decision making framework.

2.2 Research Question in Detail

The electronics industry is growing at a very rapid pace and is considered to be the most dynamic industry in the world. Electronics manufacturing has accounted for at least 30 per cent of the USA's Gross National Product (GNP) since the Second World War (Mason, Cole, Ulrey, & Yan, 2002). This industry calls for high speed innovation and product development. For instance, products that were developed a decade ago are already facing extinction. During the last decades, the electronics industry has seen intense research, as a result of which tremendous changes in technologies have been developed and electronics has become an integral part of every person's life. There are various reasons behind this technological burst up.

Figure 2.1 depicts a typical life-cycle of a product. In the current scenario, the life of a consumer electronic is two to five years.

The short life-cycle of the products in the electronics industry makes the supply chain one of the most complex in the world. Nowadays, even before a particular product is in the market development phase, the companies are in the concept development stage of a newer product or are considering an extension to the existing technology or product. For instance, history shows us that Apple, Inc. introduces a new iPhone model or an update surpassing the previous model within a year from the release of the previous model in the market.

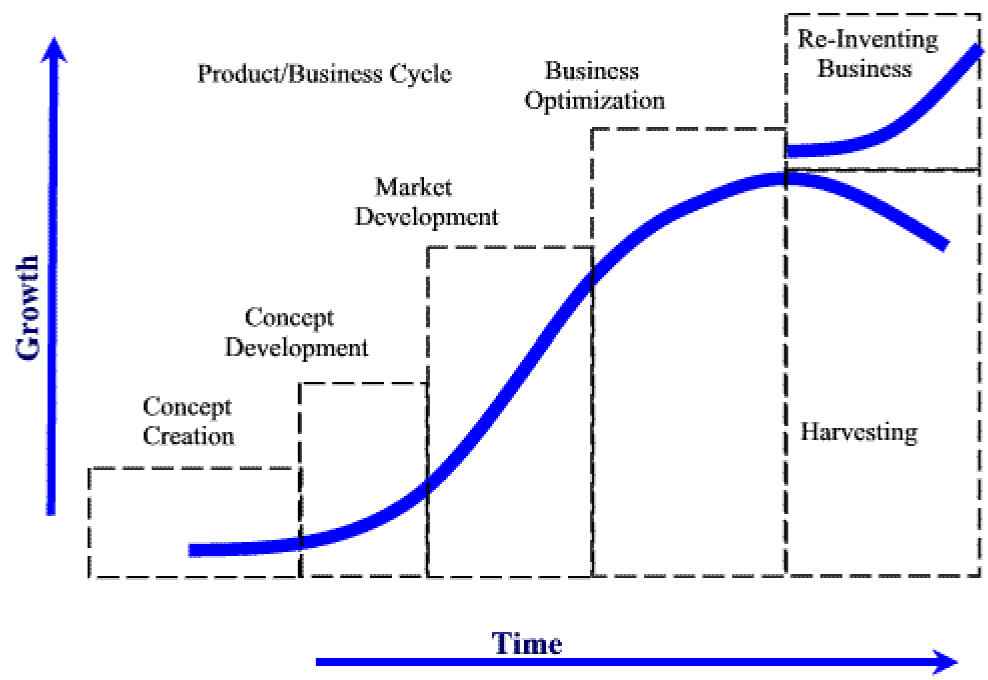

Figure 2.1 Product Life Cycle

A generic supply chain consists of:

1. Supplier
2. Manufacturer
3. Distributor
4. Customer

Figure 2.2 is an illustration of a generic supply chain. The end product manufacturer is called the focal firm. The direct suppliers of the focal firm are referred to as the first-tier supplier, and the direct customer of the focal firm is the first-tier customer. The suppliers of the first-tier supplier and the customer(s) in the first-tier customer position are referred to as the second-tier supplier(s) and second-tier customer(s) respectively (Wisner, Tan, & Leong, 2012). The number of tiers depends the type of the industry. In simple words, consider a computer manufacturer 'X' as the focal firm. Then, the manufacturers of the chip, display, etc. are X's first-tier suppliers and the mining company where the chip manufacturers get their raw materials from are the second-tier supplier to X. Likewise, the wholesale dealers of the computers are the first-tier customers and the people who buy the computers from the dealers are the second-tier customers of X.

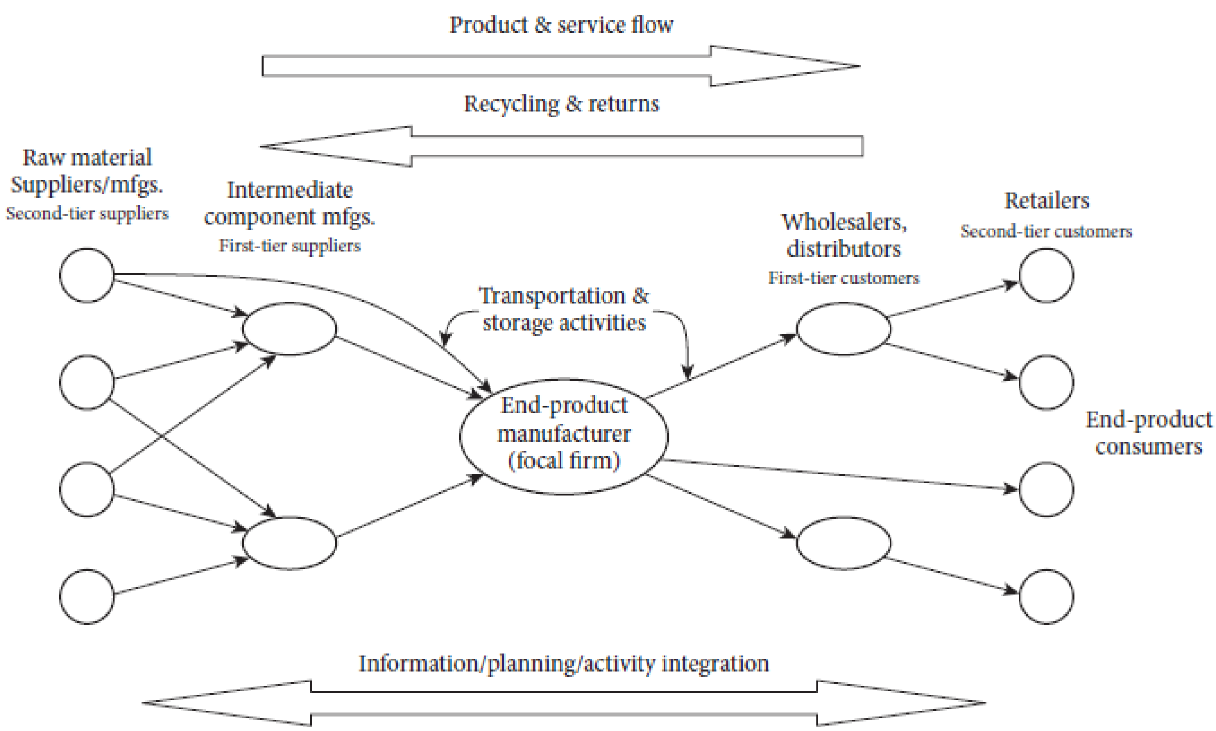

Figure 2.2 Typical Supply Chain

The supply chain illustrated above is one of the simplest of supply chains. There are numerous factors that make the supply chain more complex like:

- Quality
- Delivery time
- Inventory (safety stock, etc.)
- Demand
- Environmental Conditions
- Politics
- Cost
- Culture, etc.

These are just few factors that serve to increase the complexity of the supply chain.

The role of a distributor is the most difficult in a supply chain. This is because a distributor needs to forecast the demand for the product and ensure responsiveness through coordinating the logistics, maintaining optimum level of inventory to meet the demand and at the same time reduce costs, which includes transportation. In the current business scenario, product quality and customer responsiveness are the major determinants of a company's competitiveness in the market. Though the product quality cannot be altered by the distributor, customer responsiveness, almost, completely depends on the distributor. Despite the fact that demand cannot be determined with absolute certainty, the distributors are expected to meet the demand without losing even a minimal amount. Meeting the demand is very important because the competition in any industry is very close, and if demand is not met by a particular company, then there is a higher probability that the customer will tend to choose the competitors product and will never return. Thus, the obvious choice for distributors is to hold safety stocks and other types of inventory.

Holding inventory involves various costs associated with it. Inventory holding costs accounts for 25% to 30% of a company's overall assets (Thummalapalli, 2010). Thus, Inventory and Inventory Holding Cost (IHC) plays a significant role in the operation of a warehouse in addition to logistics, transportation and other supporting activities and associated costs. As inventory is the one single cost that accounts for most of the costs associated with the warehouse and distribution center, and any strategic decision must be based on the inventory holding cost.

The ‘Supply Chain Metrics’ report developed by Tompkins Supply Chain Consortium began with a survey which received responses from several major industries revealing some interesting facts about the high technology industry. According to the report, the high technology industry has the most number of Distribution Centers (DC). The figures of high technology industry are well above that of other industries. It is also to be noted that the high technology industry has the highest percentage of fully outsourced distribution centers (Supply Chain Consortium, 2012).

Outsourcing is a strategic decision that results in not only monetary benefits but also leads to other traits like focusing on the core business. As discussed earlier, decisions have to be made based on inventory holding costs in order to make accurate and economical decisions. In this research, inventory holding cost is used as the primary factor in the process of making the decision of whether or not to outsource the Distribution Center.

Table 2.1 Number of Distribution Centers (Supply Chain Consortium, 2012)

Industry	**Average**
Automotive	13
Consumer Products	16.5
Food & Beverage	19.5
High Technology	71.7
Industrial & Commercial	17.3
Pharmaceutical & Medical Devices	29
Retail	9.3
Service	1.8
LSP	25

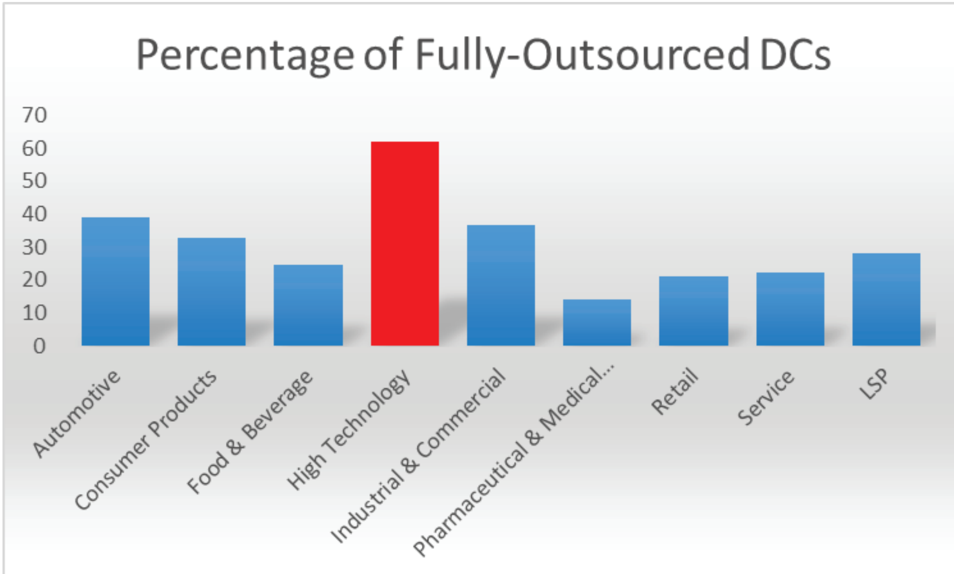

Figure 2.3 Percentage of Fully Outsourced DCs (Supply Chain Consortium, 2012)

2.3 Specific Objective #1

The idea of using Carrying Cost Ratio (CCR) for the purpose of making an outsourcing decision is based on previous works by Rama Thummalapalli (Thummalapalli, 2010) and Maurice Cavitt (Cavitt, 2010). In both reports, the carrying cost ratio was used as a metric to evaluate the efficiency of a supply chain or a ware house with particular attention paid to the health care industry.

2.3.1 Inventory Holding Cost

There are several manufacturing techniques like Just-in-time (JIT) and Lean manufacturing, which are available to attain or make the manufacturing process more efficient. Though the principles of each technique are different and unique, they eventually aid in reducing the inventory holding cost. For instance, the key driver to the success of just-in-time manufacturing is the minimization of work-in-process (WIP) inventory. The WIP inventory is minimized through an efficient matching of the manufacturing process and the rate of supply of components (Holsenback & McGill, 2007). Despite the fact that JIT was developed with a goal to reduce manufacturing time, JIT reduces the carrying cost while WIP is a type of inventory that incurs cost. This is true in the case of lean manufacturing also. Lean manufacturing systems are designed to minimize supply variability, thereby minimizing concerns associated with inventory holding cost and safety stock inventory (SSI) for raw materials and WIP (Holsenback & McGill, 2007). IHC and SSI are two very significant elements of inventory management. In many occasions, managers tend not to realize the importance of these two elements.

In the field of supply chain management (SCM), there exists various definitions for the term inventory holding cost, however, the widely accepted definition is “inventory holding cost (IHC) is the variable cost of keeping inventory on hand, and represents a combination of costs associated with opportunity costs, storage, taxes, insurance, shrinkage, and other variables” (Holsenback & McGill, 2007). In this research, as we focus only on the warehouses in a supply chain, from now on the inventory holding cost or carrying cost refers to the IHC of a warehouse and the term warehouse costs is used invariably with IHC as most of the costs associated with a warehouse will relate to the inventory held. From this point forward the term warehouse and distribution center are used interchangeably.

Speh categorizes warehouse costs as shown in Figure 2.4 (Speh, 2009). The definitions for each sub-category given by Speh holds good for this work.

1. *Handling***.** All expenses associated with moving product in or out of the warehouse should be included in the holding cost. The largest component is the labor used to handle the product that moves through the distribution center. It includes receiving, put-away, order selection, and loading. It may also include labor to re-warehouse, repackage, or refurbish damaged product.

   All costs associated with the equipment used to handle products in the warehouse, such as the depreciation of equipment cost, and the cost of fuel, or electricity to power the equipment may also be included in handling costs (Speh, 2009).

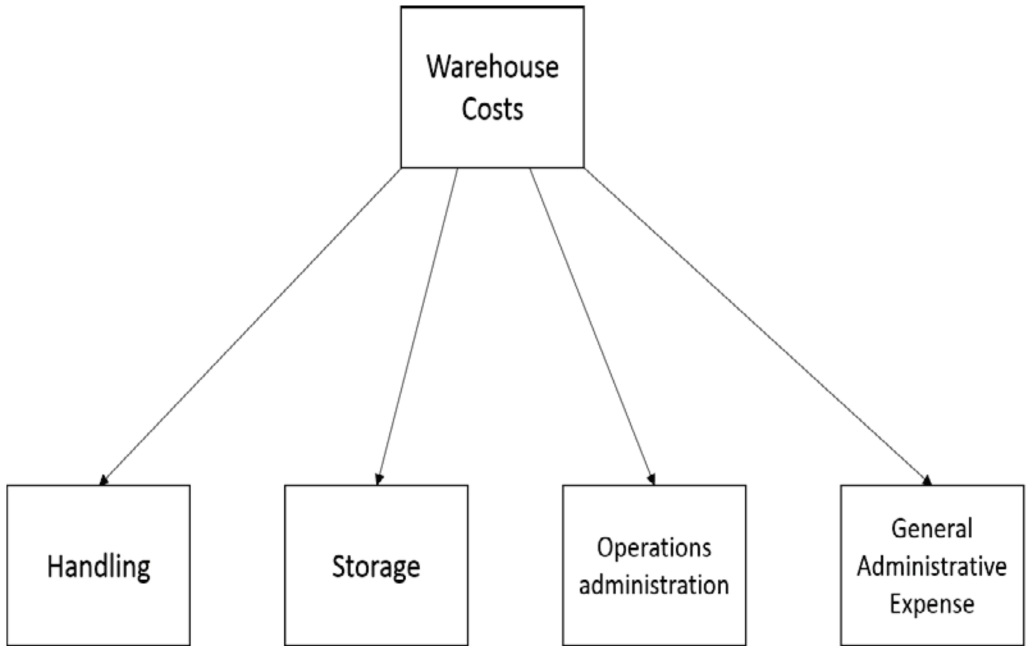

Figure 2.4 Warehouse Costs – Breakdown (Speh, 2009)

Other handling expenses are the detention of truck or rail cars, operating supplies, and trash disposal. In effect, handling includes all those costs that are associated with “goods in motion” (Speh, 2009).

2. *Storage.* Storage expenses are costs associated with “goods at rest.” These costs would be incurred whether or not any product ever moved. Because storage expenses are related to the cost of occupying a facility, and these costs are normally accumulated each month, storage is expressed as a monthly cost (Speh, 2009). “If an entire building is dedicated to an operation, storage expenses are the total occupancy cost for that facility” (Speh, 2009).

3. *Operations administration.* These expenses are incurred to support the operation of the distribution center. Closing the facility would eliminate these costs. Included are the costs for line supervision, supplies, insurance, and taxes (Speh, 2009).

4. *General administrative expenses.* Expenses not included for a specific distribution center (DC) are included in this category. General management, non-operating staff, and general office expenses are examples. This particular cost can be any cost except for inventory carrying cost.

Speh's categorization details and includes all the costs and expenses associated with a warehouse including salaries and compensation for labor and management. For our research, the only cost that needs to be focused on is the inventory holding cost. La Londe and Lambert categorize inventory carrying cost as follows (La Londe & Lambert, 1977).

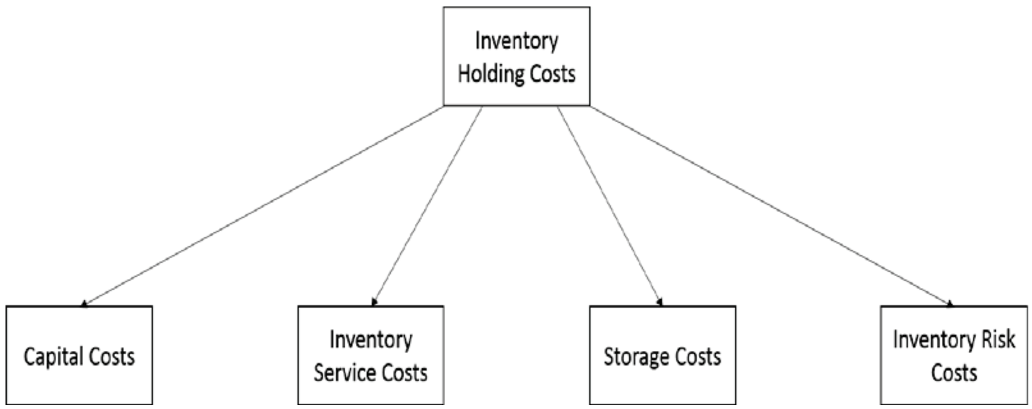

Figure 2.5 Inventory Holding Costs – Breakdown (La Londe & Lambert, 1977)

Despite the fact that all the expenses associated with the inventory are included in one of Speh's categories, it only makes sense to categorize them in detail.

2.3.1.1 Capital Costs

Capital costs are the costs that include all the funds used in order to acquire the inventory. This includes the funds that are generated internally within the organization and the funds generated from the investors (or externally), i.e., debts and equity. Consequently, the company's opportunity cost of capital should be used in order to accurately reflect the true cost involved (La Londe & Lambert, 1977).

1. *Inventory Investment.* Many managers consider that inventory is a relatively liquid and riskless investment. But the downside of investing in inventory is that the return on investment (ROI) is comparatively low with respect to investing in other sectors of the corporation. Unfortunately, the investment in inventory is critical to the operation of all sectors of the corporation. Therefore, the company's minimum acceptable rate of return (MARR) should be applied only to the variable costs directly associated with the inventory (La Londe & Lambert, 1977).

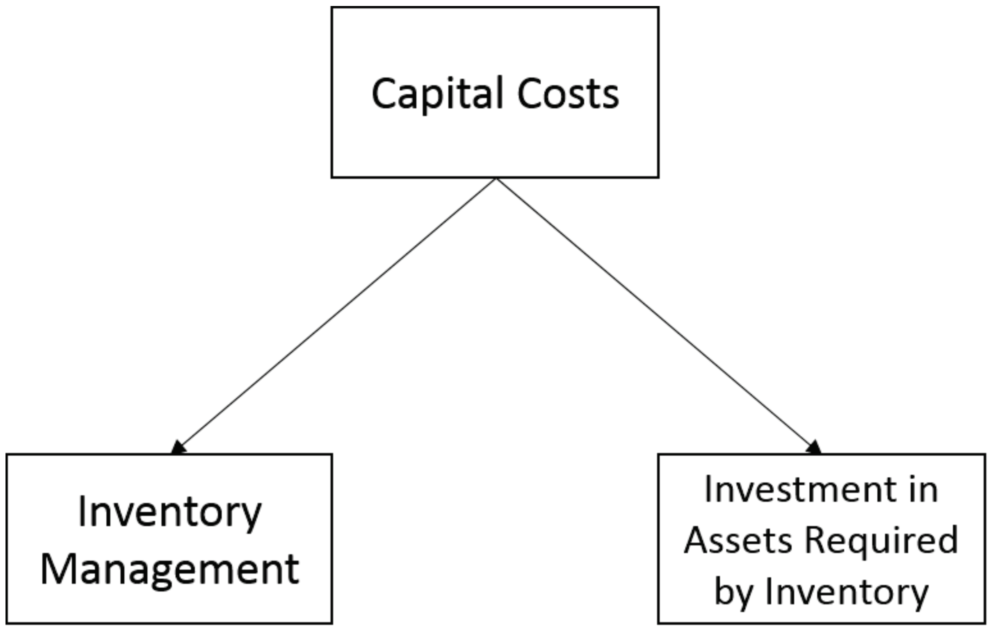

Figure 2.5 Capital Costs – Breakdown (La Londe & Lambert, 1977)

2. *Investment in Assets.* La Londe and Lambert concluded that capital costs should include investment in physical assets such as materials handling equipment if the amount of investment varies directly with the volume of inventory held and not the quantity of inventory shipped (La Londe & Lambert, 1977).

2.3.1.2 Inventory Service Costs

The inventory service costs are made up of:

1. *Taxes.* Taxes depend on the geographic location of the warehouse and the inventory levels. According to La Londe and Lambert, unless large changes in tax rates are expected or major changes in distribution have taken place affecting the inventory levels, the tax component can be calculated by using the actual taxes paid during the previous year over the average inventory value during that year (La Londe & Lambert, 1977).
2. *Insurance.* Unlike the tax component, insurance is not directly proportional to the inventory levels. Therefore, the insurance rates may be considered variable with inventory levels. Insurance rates depend on the materials used in construction of the building, its age, and

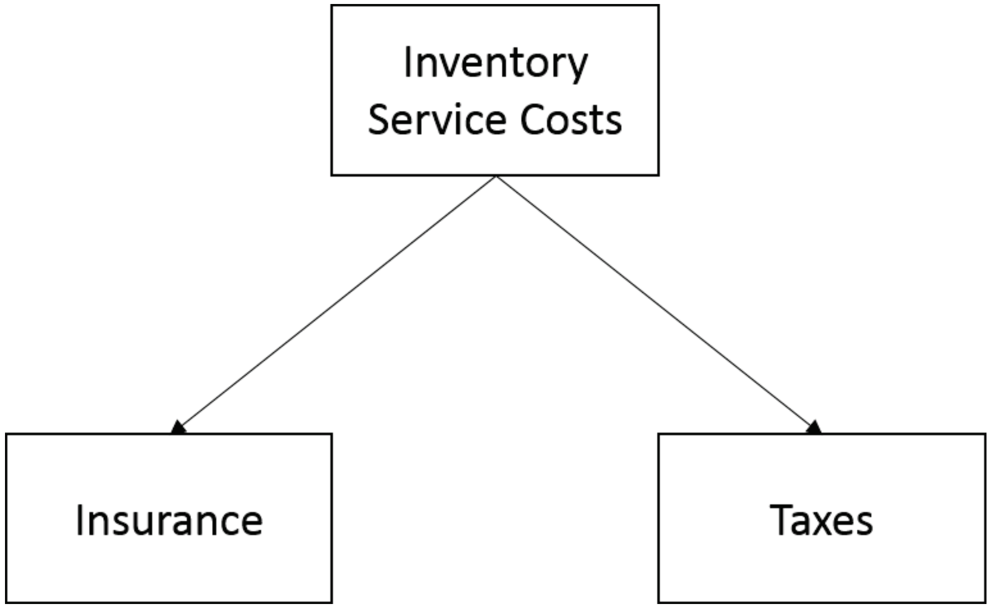

Figure 2.6 Inventory Service Costs – Breakdown (La Londe & Lambert, 1977)

considerations such as the type of fire prevention equipment installed (La Londe & Lambert, 1977).

2.3.1.3 Storage Space Costs

All the costs associated with the storage space i.e., warehouse is referred to as the storage space costs.

1. *Plant Warehouses.* In general, the costs associated with the plant warehouses are fixed in nature. The fixed charges and other allocated costs are irrelevant when making decisions on inventory policy unless the warehouse space could be rented or used for some a productive purpose, other than storing inventory (La Londe & Lambert, 1977).
2. *Public Warehouses.* The costs associated with public warehouses should be considered as throughput costs and only charges for recurring storage that are explicitly or implicitly included in the rental cost should be included in the carrying costs (La Londe & Lambert, 1977).

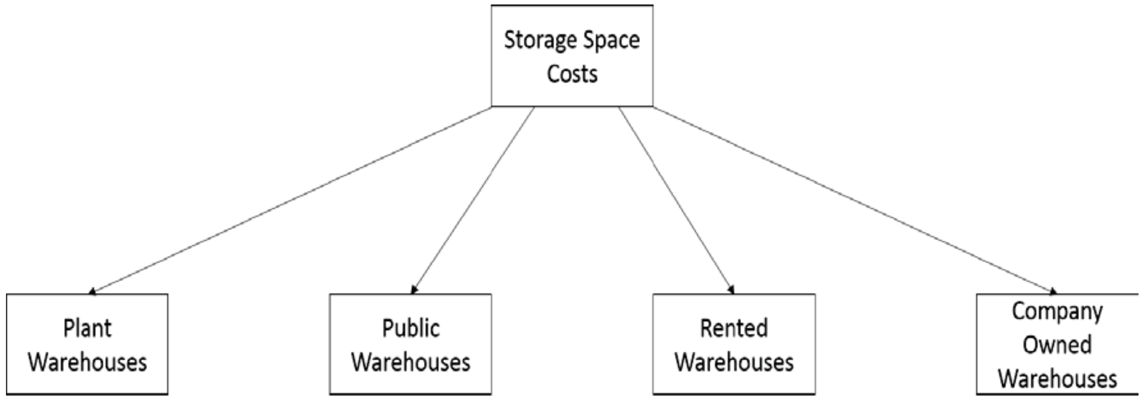

Figure 2.7 Storage Space Costs – Breakdown (La Londe & Lambert, 1977)

3. *Rented (Leased) Warehouses.* The rate of incurring warehouse rental charges does not fluctuate from day to day with changes in the inventory level, although the rental rates can vary from month to month (La Londe & Lambert, 1977).
4. *Company Owned Warehouses.* All operating costs that could be eliminated by closing the warehouse or net savings resulting from a change to public warehouses should be included in warehousing costs and not in inventory carrying costs (La Londe & Lambert, 1977).

2.3.1.4 Inventory Risk Costs

1. *Obsolescence.* Obsolescence cost is of great significance especially in the high technology sector where products have a shorter life cycle (discussed earlier in this chapter) due to the rapid and continuous innovation process. It is the difference between the original cost and the salvage value (La Londe & Lambert, 1977).
2. *Damage.* The probability of damage is higher in the high technology industry, and it is also relatively higher in the high technology sector as most of the products are fragile and must be handled with care. Only damage that is directly attributable to the volume of inventory held should be included in this cost component (La Londe & Lambert, 1977).
3. *Pilferage or Shrinkage.* Shrinkage may be caused due to various reasons like theft, and, unfortunately, it is hard to control (La Londe & Lambert, 1977). This will be included in the security costs described by Speh.

4. *Relocation Costs.* As the name suggests, all the costs associated with transporting or transferring the inventory to one or more different stocking locations is referred to as relocation costs (La Londe & Lambert, 1977).

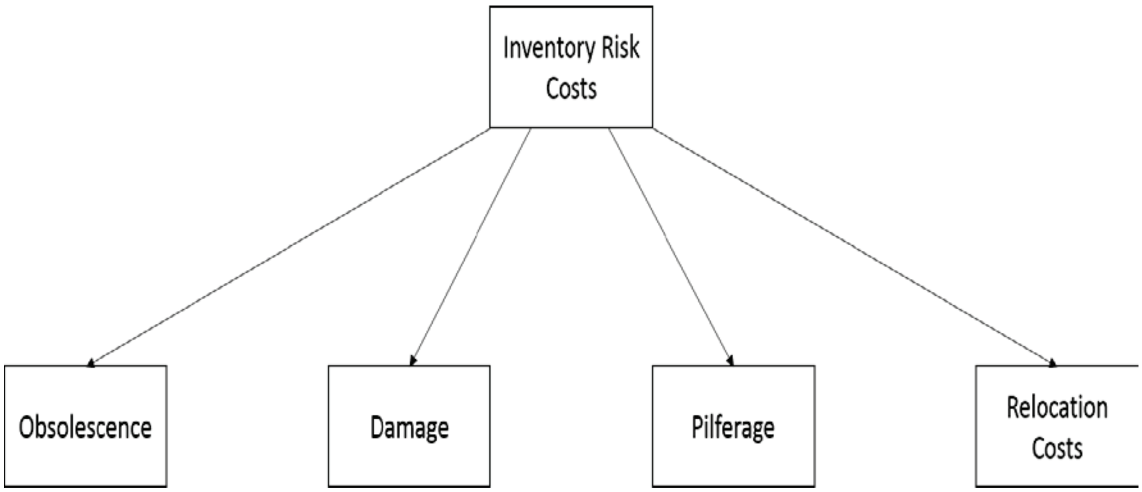

Figure 2.8 Inventory Risk Costs – Breakdown (La Londe & Lambert, 1977)

In the calculation of inventory holding cost, the costs can be classified into fixed costs and variable costs and it should be ideally divided into price-dependent and quantity-dependent components. Some relevant calculations published by Holsenback and McGill are listed below (Holsenback & McGill, 2007). To understand the calculations, the following must be considered:

The average inventory for a period = I_{avg};

The inventory floor plan rate, which is the cost of the capital = R;

The average inventory at a particular point of time = I_{cur};

The average monthly fixed overhead = O;

The average time that an item remains in inventory before sale = T;

Daily Interest Cost per Unit (C_{int}) = $\frac{(I_{avg}/365)}{I_{Cur}}$

Daily Fixed Overhead Cost per Unit (C_O) = $\frac{(O/30)}{I_{Cur}}$

Daily Holding Cost per Unit (DHC) = $C_{int} . C_O$

Inventory Holding Cost per Unit (IHC) = $DHC . T$

The equations above are generic equations and do not include the hidden costs.

It is extremely critical to accurately assess the inventory carrying costs. This is because this assessment is essential in making several distribution decisions including number of warehouses to be maintained, the configuration of these facilities, transportation, and inventory policy (Lambert & Mentzer, 1971). Lambert and Mentzer (1971) claim that it is highly unlikely that a company would choose a distribution policy that would maximize profits, without an accurate assessment of inventory carrying cost. According to Lambert and Mentzer the carrying cost assessment is used with 67% for cost trade-off analysis, 65% for setting FGI levels, 62% for EOQ analysis, and 57% for warehousing and distribution systems (Lambert & Mentzer, 1971). They also reported that the cost of money component of inventory carrying cost was less than 15%.

2.3.2 Warehouse

The major roles of warehouses include: buffering the material flow along the supply chain to accommodate variability caused by factors such as product seasonality and/or batching in production and transportation; consolidation of products from various suppliers for combined delivery to customers; and value-added-processing such as kitting, pricing, labeling, and product customization, which makes the warehouses a significant component of a supply chain (Gu, Goetschalckx, & McGinnis, 2007). Warehouses also provide a strategic service, in that it enables firms to store their purchases, work-in-progress and finished goods, in addition to performing break bulk and assembly activities (Wisner, Tan, & Leong, 2012).

Even though U.S. freight distribution systems move goods from manufacturers to end users in an increasingly efficient manner, the growth in demand for warehouse space has overcome this improved efficiency (Wisner, Tan, & Leong, 2012). Warehouses also ensure improved customer service, as finished goods inventory (FGI) is stored in warehouses facilitate shorter delivery times against the longer make-to-order manufacturing policies. In 2007, the average size of a warehouse in the U.S. was approximately 250,000 square feet. This figure has shown a growth of approximately 60% to 400,000 square feet in 2012 (Wisner, Tan, & Leong, 2012). Besides storing inventory, warehouses perform one of the most important functions of a supply chain i.e., distribution, which includes logistics and transportation. The inventory in warehouses is used to support purchasing, production and distribution activities (Wisner, Tan, & Leong, 2012).

The factors that have to be considered while discussing warehouse advantages and disadvantages are (Wisner, Tan, & Leong, 2012):

1. Safety stock and average system inventory
2. Responsiveness
3. Customer service to the warehouse
4. Transportation costs
5. Warehouse system capital and operating costs

The adoption of new management philosophies such as JIT or lean production improves efficiency, but at the same time, they bring new and tough challenges for warehouse systems, including tighter inventory control, shorter response time, and a greater product variety (Gu, Goetschalckx, & McGinnis, 2007). Fortunately, the improvements and development of new technologies in the field of information technologies (IT) like bar coding and radio frequency identification (RFID) have led to easier and more accurate tracking and managing of inventory (Gu, Goetschalckx, & McGinnis, 2007).

2.3.2.1 Inventory Turns

In spite of the availability of several key performance indicators of inventory management like throughput and sell through percentage, Inventory turnover/ inventory turns is widely accepted as the ideal indicator. It is a measure of operational efficiency in managing the materials/ inventory. In simple words, inventory turns is a measure that tells the managers how many times a particular set of inventory has been turned annually. This helps keep track of and/or eliminate obsolete inventory. Inventory turns is defined as the ratio of the average number of items in stock to the annual usage of the item (Cavitt, 2010).

$$T = \frac{Cost\ of\ goods\ sold\ (COGS)}{Average\ Inventory} = \frac{COGS}{(Beginning\ inventory + Ending\ inventory)/2}$$

Table 2.2 Research History

Original white paper by Dr. Erick Jones used at the city of Houston Health and Human services
Rama Thummalapalli used this model to reduce the obsolete inventory at the VA hospitals
Maurice Cavitt re-evaluated the city of Houston data to evaluate and compare to the EOQ and created a table to describe ratios for compare holding inventory against just in time orders for medical supplies and drugs

2.4 Specific Objective #2

Due to increasing competition and a changing business environment, corporations are pursuing different supply chain management strategies to fulfill a variety of customer requirements and improve profits. Under these circumstances, flexibility and adaptability become increasingly important (Wee, Peng, & Wee, 2010). Among the supply chain strategies used to overcome uncertainty, collaboration and outsourcing have become a mega trend, focusing on joint planning, co-ordination and process integration between suppliers and customers in a supply chain (Wee, Peng, & Wee, 2010). Historically, organizations have considered outsourcing supply chain functions for one or more of the following purposes (Tanowitz, Baritugo, & Harmon, 2009), all of which can be considered as advantages to outsourcing managers:

1. *Accelerated introduction of new devices and accelerated innovation of existing devices:* This allows the organization to focus its resources on product innovation, research and product development, regulatory compliance management and demand management.

2. *Decreased cost of goods sold driven by the outsourced manufacturer's expertise in securing manufacturing efficiencies and the ability of the outsourced partner to leverage material costs:* This allows a provider to aggregate raw materials, packaging and incidental materials as needed for customers that use similar materials—a key benefit in an industry where materials represent 60 to 70 percent of the total cost.
3. *Improved fixed assets performance and utilization:* This happens when a significant portion of a firm's manufacturing and logistics assets are no longer reflected in its balance sheets.

The drive for greater efficiencies and cost reductions has forced many organizations to specialize in a limited number of key areas. The immense pressure on industries to attain higher efficiency, coupled with the revolutionary growth of information technology has led organizations to outsource activities and services traditionally carried out in-house. A significant role taken by strategic outsourcing is determined by the tendencies for change in the operation of companies (Jarka, 2010). Although outsourcing decision has been in vogue for several years, organizations have always made decisions based on determining the boundaries of their organization (McIvor, 2009). However, rapidly developing product and service markets and developments in information and communications technologies have accelerated the growth in outsourcing to encompass almost every organizational activity (Aron & Singh, 2005). The research areas in outsourcing can be broadly classified into five categories, as shown in Figure 2.9.

Figure 2.9 Research Areas on Outsourcing (Lee, Huynh, Chi-Wai, & Pi, 2000)

In this research, the category of interest is the decision criteria. If an outsourcing decision has been made then it has to be evaluated by taking into consideration the adequate factors. The seriousness of in-house problems may not be known until the alternatives are investigated (Lee, Huynh, Chi-Wai, & Pi, 2000). Outsourcing which occurred due to a wrong decision can cause catastrophic economic and technological effect (Lee, Huynh, Chi-Wai, & Pi, 2000). Therefore, it is critical to investigate and evaluate all the alternatives available for a problem on hand.

The study of outsourcing has become a rich tapestry of theoretical and conceptual foundations, drawing on theories from a range of disciplines such as economics, business strategy, organization theory, and general management. There are several theories that are applied to explain or analyze a firm's outsourcing decision, process, and result. But, the two most important theories in the field of outsourcing research are:

1. Theory of Transaction Cost Economics (TCE), and
2. Core Competency Theory

From the literature on outsourcing research, according to transaction cost economics, organizations make decision on whether to internalize (insource) or externalize (outsource) the activity depending on relative transaction costs of conducting the activity. In contrast, according to the core competency theory, organizations must focus on what they can do best (core activities), and appropriately outsource activities that value chain partners can do best.

2.4.1 Theory of Transaction Cost Economics (TCE)

Economic approaches to the study of organization, transaction cost analysis included, generally focus on efficiency. The transaction cost economics has been applied at three levels of analysis: overall structure of the enterprise, operating parts, and manner in which human assets are organized (Williamson O. E., 1981). According to the TCE, the activities of the firm either will be internalized or market-mediated, depending on relative transaction costs of conducting the activities (Williamson O. , 1979). TCE is a combination of economic theory and management theory which aids in the determination of the ideal relationship a firm should develop in the marketplace. While most microeconomic theories regard the firm as an abstract construct, theory of transaction cost analysis, deliberately attempts to describe the firm as a set of internal (administrative) activities and external market (contract) relations. It defines the boundary of the firm as the limit of transactions governed by internal processes. The theory of transaction cost economics argues that factors determining transaction costs are:

- Asset specificity: Transactions that require high investments which are specific to the requirements of a particular exchange relationship (Williamson O. E., 1985).
- Uncertainty: Ambiguity as to transaction definition and performance can be further divided into two groups (Widener & Selto, 1999):
  (1) Environmental uncertainty – Expected variation in the demand for activities
  (2) Behavioral uncertainty – The inability to monitor activities
- Frequency: The volume or rate at which activities are conducted (Widener & Selto, 1999).

Theory of transaction cost analysis hypothesizes that firms seek to minimize costs of operations, which include transaction costs – the "costs of running the system" (Williamson O. E., 1981). According to Williamson the decision of whether or not to outsource, and the extent of outsourcing, depends on the transaction costs associated with outsourcing versus internalization. The two extremes of a sourcing decision are either vertical integration or outsourcing. The decision will always be made in relation to the scope for cost reduction and the importance of asset specificity (Williamson O. E., 1981). The hardcore of transaction costs theory is that the properties of the transaction determine the governance structure.

2.4.2 Core Competency Theory

Core competency theory suggests that activities should be performed either in-house or by suppliers. Activities which are not core competency should be considered for outsourcing with "best-in-world" suppliers. Some non-core activities may have to be retained in-house if they are part of a defensive posture to protect competitive advantage (Quinn & Hilmer, 1994). Outsourcing allows a company to streamline its operations and concentrate on what it does best.

Some researchers define the term "core competencies" as including only the skills and know-how possessed by an organization, perceiving them as just one of the resources possessed by an organization. This emerging school of thought, called the resource-based view, argues that it is important to examine all resources including competencies in order to determine the sources of the competitive advantage of an organization. Other researchers also define core competencies as pure skills, but emphasize that they are the determinant resources for a firm's competitive advantage.

When the two strategic approaches are properly combined, they allow managers to leverage their companies' skills and resources well beyond levels available with other strategies (Quinn & Hilmer, 1994). In this research, a framework for making an outsourcing decision based on a combination of both theory of transaction cost economics and the core competency theory has been developed.

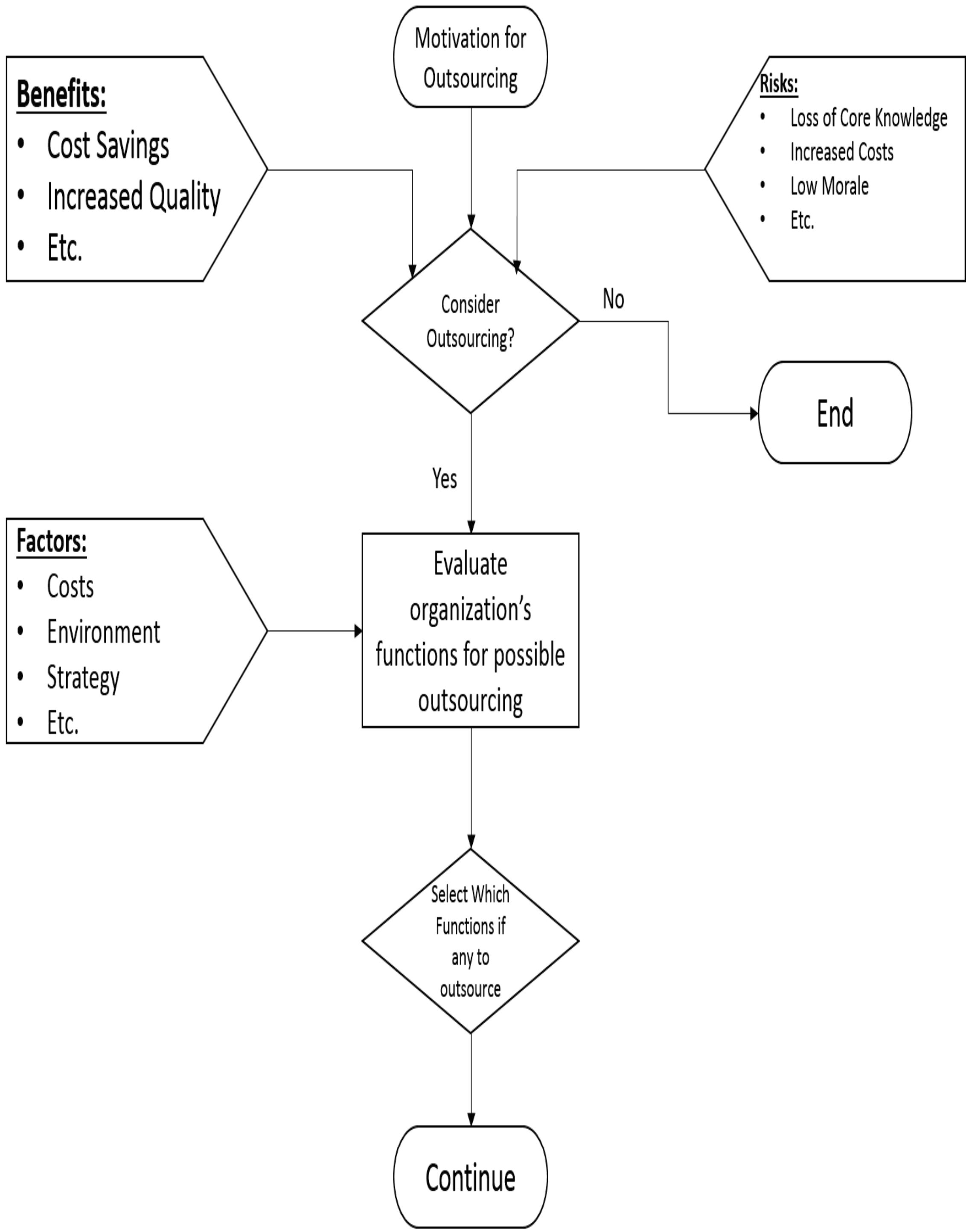

Figure 2.10 Outsourcing Decision

2.5 Specific Objective #3

Globalization and outsourcing have increased the complexity of supply chains. Concurrent with this trend, over the past few decades, the concepts of sustainability and sustainable development have emerged as humanity has become more cognizant of its increasing impact on the world (Hutchins & Sutherland, 2008). According to a UN Global compact summit (Lacy, Cooper, Hayward, & Neuberger, 2010), 66 percent of the attending executives identified climate change as one of the critical development issues for the future success of their business. About 68 percent of the Global250 firms generated a separate annual sustainability report in 2004; in addition 80 percent of these reports discuss supply chain related issues (Carter & Rogers, 2008). According to the CEOs who participated in the summit, the next era of sustainability is one where sustainability is not only a separate strategic initiative, but something fully integrated into the strategy and operations of a company (Lacy, Cooper, Hayward, & Neuberger, 2010).

In the supply chain management perspective, the term sustainability refers to an integration of social, environmental, and economic responsibilities (Carter & Rogers, 2008). Besides the fact that several governing organizations like the federal governments and the World Commission on Environment and Development (WCED) frame laws for companies to develop sustainable processes (example: Agenda 21 of the United Nations), the corporation executives by themselves have started to integrate sustainability measures into their mission which traditionally aimed for increased profits, as opposed to social responsibility. Seuring and Muller define sustainable development as “a development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Seuring & Muller, 2008). Though numerous definitions for the term sustainability exist, one central concept helping to facilitate sustainability is the triple bottom line approach, where a minimum performance is to be achieved in the environmental, economic and social dimensions (Seuring

Figure 2.11 Triple Bottom Line (Elkington, 2008)

& Muller, 2008). Most operations management literature has viewed sustainability from an ecological perspective without explicit incorporation of the social aspects of sustainability (Carter & Rogers, 2008).

2.5.1 The Triple Bottom Line

Figure 2.11 gives a graphical representation of 'the Triple Bottom Line'.

1. Economic Bottom Line (Elkington, 2008): The ultimate goal of any business in the world is to make money. A company's bottom line is the profit figure used as the earnings figure in the earnings-per-share statement.

2. Environmental Bottom Line (Elkington, 2008): Today, owing to the contributions of numerous environmental activists over the decades, people have become more environmentally responsible and several buzzwords like 'Go Green', 'Environmentally-Friendly', etc. go hand-in-hand with supply chain management as well. Many business people these days

feel happier being challenged on environmental issues than on social issues. This fact has had a marked impact on the way the sustainability agenda is defined by business.

3. Social Bottom Line (Elkington, 2008): Although the sustainable development community argues that sustainability has nothing to do with social, ethical, or cultural issues, the supply chain management community insists otherwise. Some of the indicators are media attention where headlines regarding industry violations call attention to human rights, irresponsible marketing, political contributions, wages and working conditions, women's rights, etc.

One of the principal challenges of sustainability is to make the Brundtland definition operational, i.e., use it to guide decisions (Hutchins & Sutherland, 2008). Until a few years ago, companies make decisions only based on the economic impacts of the decisions. Over the last decade, this trend has evolved as companies have started to consider the environmental impacts of making a decision, in addition to the economic perspective. It has to be noted that emphasis on the social perspective is little or nonexistent. But looking at the history of the evolution of sustainability, it is certain that it will not be too long until the social aspects of sustainability will be accounted for when companies are making a decision.

2.5.2 Indicators of Sustainability

From the above discussion, it is very clear that the indicators of sustainability must cover all three dimensions of sustainability. An indicator proposed by Unilever, relates environmental and economic performance in the approach known as Overall Business Impact Assessment (OBIA). The OBIA parameter measuring the performance of business or product group *j* in environmental impact category *i* is defined as:

$$\phi_{i,j} = \frac{Impact\ in\ category\ i/Value\ of\ business\ j}{Total\ anthropogenic\ contribution\ to\ impact\ category\ i/Total\ global\ economic\ activity}$$

where the environmental impact is evaluated over the whole life cycle and the "value" is taken as the total sales from the business. Econometrics like $\phi_{i,j}$ can be used to identify highly unsustainable activities-or to distinguish between discrete options or scenarios. The OBIA approach provides a means of screening products or business areas which should be targeted for environmental improvement or substitution (Clift, 2003).

2.6 Supply Chain Model

The layout of a supply chain was illustrated earlier in this chapter with the product flow from manufacturers, distributors, retailers, and finally to the customer. Demand for a product from an end-user is considered to be the starting point of any supply chain and the delivery of the product to the end-user is considered to be the end of the supply chain. As explained above, in order to deliver the product to an end-user, the product goes through various stages of a supply chain, like manufacturing, distribution, etc. Each stage is referred to as an echelon.

As discussed earlier in this chapter, there are different manufacturing techniques that assess the effectiveness of a supply chain based on levels of uncertainty within the supply chain. In simple words, minimizing uncertainty will maximize the effectiveness of a supply chain. Unfortunately, minimizing the uncertainty of a supply chain is not as simple as it seems. This is because, the uncertainty in a supply chain depends on several factors ranging from the customer's end expectations, like demand fluctuation, to the manufacturer's end expectations, like innovation. The increase in the number of echelons will only increase the level of uncertainty in a supply chain. Though the supply chain of high-technology industry is regarded as one of the most complex supply chains in the world, this thesis is limited to a two-echelon supply chain.

2.6.1 Two-Echelon Model

Previous studies have developed a number of supply chain models. For the purpose of this thesis, the model proposed by Caglar (2004) is used in this analysis as 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 (Cavitt, 2010). The emphasis of inventory holding costs has made the model more relevant for this research. Caglar's model is a two-echelon multi-

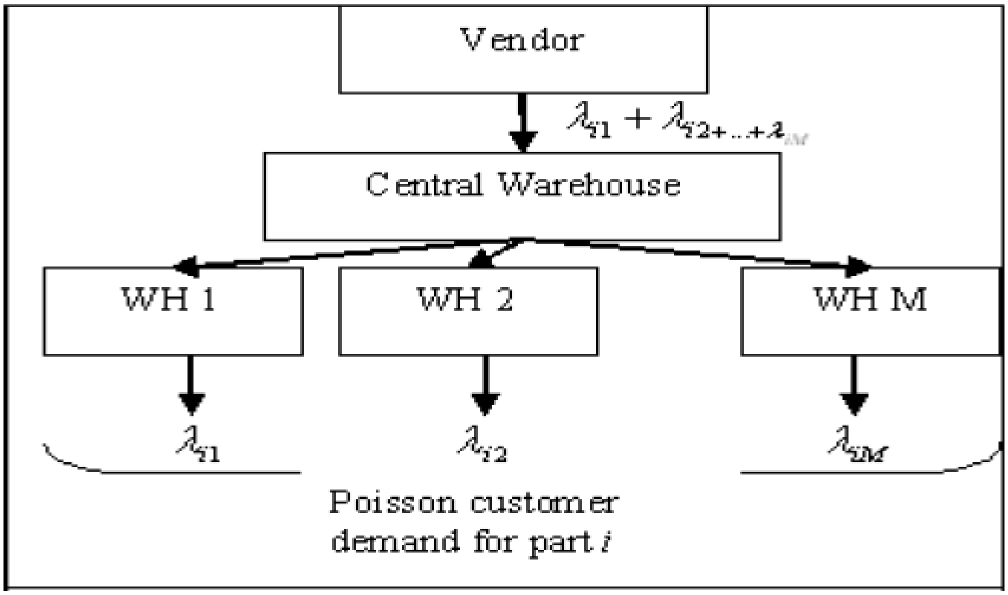

Figure 2.12 Two-Echelon Supply Chain Model (Cavitt, 2010)

consumable goods inventory system consisting of a central distribution center and multiple customers (Cavitt, 2010).

According to Thummalapalli, each secondary warehouse acts as a smaller warehouse. These secondary warehouses in turn supply many customers and maintain a stock level S_{iM} for each item (Thummalapalli, 2010). 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 (Thummalapalli, 2010).

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 percent reduction in inventory carrying costs (Holsenback & McGill, 2007).

The 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 used to determine proper stocking levels at each of secondary and primary warehouses (Caglar, Li, & Simchi-Levi, 2004).

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,

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

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

τ_j = customer expectation for maximum expected response time and W_j is calculated using response time equation and Little's law (Caglar, Li, & Simchi-Levi, 2004).

According to Little's law in queuing theory of stochastic processes, L = λW, where L is the mean number in the system and W_j is the mean response time. Even though this model holds well at optimizing a two-echelon supply chain, it requires a large amount of data and assumptions, as it was developed by Caglar to provide an approximate distribution for inventory on-hand and also provide information on backorders at each depot for a two-echelon system (Thummalapalli, 2010).

CHAPTER 3

RESEARCH OBJECTIVES

3.1 Introduction

As mentioned earlier in chapter 1, the significance of this research is to seek impacts of the coordinated outsourcing framework that supports operational sustainability that optimizes decision making at the strategic planning level of the supply chain. This research strives to answer the research question: “Can an optimal coordinated strategic and operational outsourcing decision criterion be obtained, that accounts for the tradeoff between profitability and sustainability?” This research hypothesizes that the facility has to be outsourced if the inventory held in the facility will not impact the profitability.

The overall objective is to develop a framework for economic and sustainability evaluation to make decisions on outsourcing business functions in a supply chain. The objective of this research is to investigate a framework which determines the optimal decision criterion for making a decision on outsourcing the functions of a supply chain.

3.2 Specific Objectives

The specific objectives are investigated as follows:

(1) Evaluate a Transaction Cost Economy (TCE) parameter determined by optimizing inventory related to a warehouse in a supply chain.

(2) Evaluate the feasibility and benefits of grouping functions of a supply chain for the purpose of outsourcing.

(3) Identify the impacts of a sustainability initiative on the outsourcing decision model in a supply chain.

It is hypothesized that the outsourcing decision can be made based on the inventory in the warehouse, and also suggests that grouping multiple functions of the supply chain together is more economical.

3.3 Intellectual Merit

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

- A new inventory control metric that will also serve as a decision criteria for making a decision on the feasibility of outsourcing the warehouse,
- The model is the result of combining principles of theory of transaction cost economics and the core competency theory,
- The proposed model is a model that demonstrates the tradeoffs between sustainability and supply chain profit that can be expanded to other nations.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Notations

The research methodology aims at developing a framework for making an outsourcing decision based on the inventory held at a warehouse in a supply chain of a high technology industry. The decision criterion is based on the prices/costs associated with procurement and holding of the inventory from stocking to delivering the products to the customer. This research is an extension of previous research, by Cavitt and Thummalapalli, on using the carrying cost ratio to make a decision on which warehouses should be shut down in a health care supply chain (Cavitt, 2010) (Thummalapalli, 2010). Therefore, the assumptions made by these authors can be used for this research as well.

The assumptions used for this research (same as the assumptions used by the previous authors) are 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.
- Every item was crucial for the customers (to function properly).
- 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 assume K_j, 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 $\lambda_{ij} = K_j I_i$. However, this assumption is typically violated whenever an order is made by the customer, and it is common when dealing with machine failure.

The notations used by Cavitt and Thummalapalli also hold good for this research.

Table 4.1 Notations for CCR Calculation (Thummalapalli, 2010)

Notations	**Description**
Aw	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;
J = {1, 2, …, M}	Set of Offices;
K_j	Customer at Office *j*;
I_i	Demand rate of item *i;*
L_{JITij}	JIT lead time for an expedited order of item *I* at office *j;*
$\lambda_{ij} = K_j I_i$	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* at office *j;*
W_j	Waiting time for a customer ordering at office j;

4.2 Supply Chain Model

As discussed in Chapter 2, the supply chain model for this research is a two-echelon supply chain model developed by Caglar. According to this model, each service center in this two-echelon model acted as a smaller warehouse because the service rate came from customers that are receiving supplies. In addition, the level of stock for 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 (Thummalapalli, 2010).

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 store. 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 (Cavitt, 2010).

Using the notations listed above, a model for the cost of operating a warehouse and implementing a JIT system was derived (Cavitt, 2010). This information can be used for determining if the warehouse needs to be outsourced for greater economic benefits. Material management in a warehouse is comprised of both fixed costs and variable costs. Fixed costs include cost of racking, utilities, labor, vehicle fleet maintenance, property depreciation, and a lease or any tied up capital (Thummalapalli, 2010). Therefore, the annual fixed cost (A_W) is

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

The annual fixed cost (A_W), in addition to the item-associated costs, makes up the total cost of having a warehouse in operation (Cavitt, 2010). When the procurement managers decide what level of quantities to purchase, most of the costs listed above are frequently overlooked (Thummalapalli, 2010). Shrinkage in the form of lost items, stolen items, or damaged items, obsolescence, and the cost of capital on the inventory is typically among these hidden costs. These costs can be modeled as a percentage of the total inventory on hand (Cavitt, 2010).

4.3 Model Description of Carrying Cost Ratio

This research is an extension of the Carrying Cost Ratio model proposed by Cavitt and Thummalapalli. The Carrying Cost Ratio (CC_R) compares the total cost of the purchased inventory to the amount of money spent holding in warehouses and shipping to customers (Thummalapalli, 2010). The validity of this model was evaluated utilizing a sample data set consisting of warehouse costs generated as random numbers. This evaluation is discussed in Chapter 5.

Although the results obtained from the carrying cost model can be interpreted and used for different applications, the results primarily suggest the cost incurred on a warehouse by evaluating the inventory associated with the warehouse. The merits of determining these inventory costs include (Thummalapalli, 2010)

- Understanding the cost of each item,
- An in-depth knowledge of the costs associated with the operations of a warehouse, and
- Planning preventive measures to minimize the cost/dollar spent ratio.

The total cost of a warehouse is the sum of the annual fixed cost (A_W) and the cost of inventory (C_I).

$$Total\ Warehouse\ Cost\ (TWC) = A_W + C_I$$

Once the costs associated with a warehouse are all determined using the equations discussed above, then the carrying cost ratio can be used in order to determine which warehouses need to be outsourced. The carrying cost ratio can be calculated by dividing the total warehouse cost by the total purchase price of inventory.

$$CC_R = \frac{TWC}{\sum_{i \epsilon I} C_{Wi}}$$

The decision criterion for outsourcing the warehouse based on the value of the carrying cost ratio is shown as follows:

Table 4.2 CCR Decision Criteria

Range	Decision
< 0.1	Check for errors in Calculation
0.1 - 0.25	Best Possible Value
0.25 - 0.35	Ideal Value
0.35 - 0.6	Needs minor improvements
0.6 - 0.9	Needs Major Improvements
> 1	Not worth consolidating

The ideal value of the carrying cost ratio is estimated to be in the range 0.25 to 0.35. This is because literature suggests that a warehouse in the supply chain of the electronics industry should turn their inventory at least thrice annually. If the CC_R is less than 0.1, then the performance of the warehouse is too good to be true. That is, a lesser the value of CC_R implies lesser inventory holding costs, and a value as low as < 0.1 suggests that there might be lost sales. In other words, the warehouse does not have the inventory to meet demand. Another possibility is that a value this low could be the result mathematical error. Either way, it is not good for the system. The value between 0.1 and 0.25 is the most desirable value. The other values are self-explanatory from the Table 4.2. A CC_R value of >1 implies that the performance of the warehouse is very poor, and that it is not worth consolidating. After the CC_R is calculated it is compared to the corresponding inventory turns ratio, in order to validate the model.

4.3.1 Iterations for CC_R

In previously published research on the carrying cost ratio (CC_R), the model for the calculation of CC_R was developed and carrying cost ratios were calculated. In the first case (Cavitt, 2010), the author calculated the CC_R once and concluded that the performance of a particular warehouse was poor and that the warehouse should be shut down. This is not true in the real time where, if a particular warehouse in a supply chain is shut down, then it affects the performance of the other warehouses, if not the performance of the whole supply chain. For instance, consider a supply chain with five warehouses. After investigating the carrying cost ratios, a decision is made to shut down Warehouse 4. Then, the performance of the other warehouses could not be improved because of shutting down Warehouse 4. In fact, there is a significant chance that the performance of the supply chain will deplete. This is because, once Warehouse 4 is shut down, the operations and inventory will be redirected to the other warehouses in the supply chain. This puts an extra load on other warehouses as the capacity of the other warehouses will still remain the same. It is to be noted that the other warehouses yielded a better carrying cost ratio because they were operating well within their current inventory and capacity. At this point it has to be noted that conducting an iterative calculation can only give an optimal solution.

In the second case (Thummalapalli, 2010), iterations of the carrying cost ratios of the warehouses were carried out. But, the author uses a 'Trial and Error' method. This method will not be very efficient when the manager of a warehouse tries to make a decision or track the performance of the warehouse. Therefore, an efficient and accurate method is needed for the purpose of iterating the values of the carrying cost ratio determined by using the previously discussed equations.

The act of replicating a process with an aim to achieve the desired goal (in our case, it is attaining an optimal solution) is called an iteration. For the purpose of conducting an iterative calculation, in this thesis, software assistance was used. The software used for iterations is 'Matlab'. Iterations can be conducted using Microsoft Excel also, but the reason for choosing Matlab is that it is more robust and quicker than MS-Excel. It can also handle large sets of data efficiently. The Matlab program written for iterating the carrying cost ratio is discussed in Chapter 5.

4.4 Outsourcing Back-Office Functions:

After analyzing the carrying cost ratio calculations, if the management decides to outsource the functions based on the performance of a particular warehouse, then it has to be decided which functions of the warehouse can be outsourced to make the supply chain more economical. As discussed in Chapter 3, organizations tend to outsource based on the transaction costs of the functions/processes or by evaluating the functions/processes to determine if they are core functions for their business.

Core functions are usually comprised of core competencies that take a long time to build (through continuing organizational learning) and that competitors cannot easily duplicate (Biehl & Prater, Outsourcing Multiple Business Functions: A theory building Investigation, 2003). When a function is outsourced, the accompanying loss of personnel and their expertise exposes the firm to the risk of losing the ability to continue innovation in the outsourced function. If that function was the source of competitive advantage, the firm may lose the knowledge upon which it had previously built a competitive advantage (Biehl & Prater, Outsourcing Multiple Business Functions: A theory building Investigation, 2003). Especially in complex supply chains like the ones in the electronics industry, the pressures from markets has driven companies to concentrate on core competency and outsourcing other functions (Helo, 2004). Determining the core competencies of a firm depends on the type of firm, the firm's environment, and the firm's strategy. The core of the electronics industry is design and Research and Development (R&D). For instance, Apple Inc. does all its design of the products and the research and development of new products in the United States, but the manufacturing of its products has been outsourced to FoxConn in Taiwan and China. Companies like FoxConn are referred to as electronics contract manufacturers (EMS), and they do not have own product design or marketing divisions, but perform well in manufacturing and logistics (Helo, 2004). After outsourcing its manufacturing and logistics, Apple Inc. has claimed to have achieved the following benefits:

- Reduced Cost – Cost of manufacturing in China and Taiwan is significantly low, when compared to manufacturing in the United States due to cheap labor and other political reasons.
- Non-Core Function – As the non-core functions like manufacturing are outsourced, Apple Inc. can now concentrate only on design of the products without worrying about manufacturing. In other words, it can do what it does best and the manufacturing can be better performed by firms whose core business is manufacturing: thereby producing better quality in manufacturing.

For whatever reasons firms outsource initially, they tend to outsource other functions later. As organizations expand their use of outsourcing, they move along the continuum and begin to outsource more strategic activities viewed as ever closer to the core of their business (Biehl & Prater, Outsourcing Multiple Business Functions: A theory building Investigation, 2003). This raises the question of how to make a 'reasonably good' decision of what to outsource. Biehl and Prater suggest that firms may outsource *clusters* of non-core activities that share "highly specialized operational skills, physical assets, processes, technologies, and transactional information enabling the achievement of economics of scale" (Venkatesan, 1992). On average, nine activities are outsourced with a tendency to outsource administrative and support functions instead of value-creating activities (Biehl & Prater, Outsourcing Multiple Business Functions: A theory building Investigation, 2003).

Before we go further with the discussion of outsourcing the functions together, the word 'together' has to be defined to make the meaning of the word vivid. In the context of this research, 'outsourcing together' means that when the outsourcing decision is made, the firms decide to eventually outsource all those functions, but they may not be outsourced at the same time. Biehl and Prater have termed the firms that outsource functions together as *'integrative outsourcers (IOs)'* and the firms that do not outsource functions together as *'non-integrative outsourcers (NIOs)'*.

When making the outsourcing decision, two parameters matter the most (Biehl & Prater, Outsourcing Multiple Business Functions: A theory building Investigation, 2003):

1. Whether the functions considered for simultaneous outsourcing are core or non-core to the firm, and
2. Whether it makes managerial sense to outsource these functions at the same time.

As several firms have begun to integrate their value chains and focus on processes rather than functional silos, it is critical for the research to identify how the business functions are related to each other. The formulated hypothesis is as follows (Biehl & Prater, Outsourcing Multiple Business Functions: A theory building Investigation, 2003):

H1: *Firms outsource functions that represent or contain core capabilities to a lesser degree than non-core functions.*

H2a: *Integrative outsourcers outsource functions simultaneously if they are connected through flows of goods or information.*

H2b: *Non-Integrative outsourcers outsource sets of functions that are connected through flow of goods or information only by chance.*

Biehl and Prater developed a questionnaire and, to establish construct and internal validity, got it pre-tested by managers involved in outsourcing decisions and pursuing MBA and incorporated the feedback in the questionnaire. The questionnaire was structured to provide mostly qualitative data but also some quantitative data. The structure of the questionnaire developed by Biehl and Prater (Biehl & Prater, Outsourcing Multiple Business Functions: A theory building Investigation, 2003) is discussed in this section. In the questionnaire, outsourcing was defined in accordance with the definition adopted in the first section. Then, the functions that were outsourced and the degree to which they were outsourced were determined. The degree of outsourcing was measured on a scale of 0 to 4 where 0 means 0% outsourced and value 4 means 100% outsourced activities within the function. For qualitative information, the authors asked about the decision process (reasons, timing, etc.) as well as informational and physical connections between the outsourced functions.

The authors also suggest that, in order to be able to differentiate between outsourcing practices and their results on firms that conform to our process-oriented theory versus those that do not, the information obtained from the managers have to be qualitatively analyzed. This helps us classify the firms into two categories: Integrative outsourcers and Non-integrative outsourcers.

The information obtained from the questionnaires were analyzed using non-parametric correlation analysis, cluster analysis, and perpetual mapping.

Table 4.3 Analysis for Grouping the Business Functions

Analysis	**Purpose**
Non-Parametic Correlation	To establish bivariate outsourcing relationships The correlation coefficients also represent similarities (proximities) between the pairs of functions
Cluster Analysis	To Identify functions that are typically outsourced together
Perceptual Mapping	To display the similarities in a two or three dimensional grid

4.5 Sustainability Analysis:

As discussed in the previous chapter, companies need a way to estimate the eco-efficiency in the view of meeting the environmental standards and still make a profit. Most of the businesses have a misconception that the sustainability efforts can only be undertaken at the expense of the firm's profit margin. Fortunately, this is not true. In fact, sustainability efforts bring in more profits. Although sustainability will have an insignificant cost associated with it at the time of implementation, in the long run, the businesses can make more money as it will eliminate unnecessary costs. It can also be viewed as a lean approach in the economic perspective of a company.

In this thesis, the sustainability indicator used is commonly referred to as the Overall Business Impact Assessment (OBIA) developed by Unilever. At this point of the thesis, it has to be reemphasized that OBIA is based on the triple-bottom line approach. Hence, the firms need not worry about the economic downslide with respect to sustainability efforts. The OBIA ($\Phi_{i,j}$) can be undertaken using the following equation:

$$\phi_{i,j} = \frac{Impact\ in\ category\ i/Value\ of\ business\ j}{Total\ anthropogenic\ contribution\ to\ impact\ category\ i/Total\ global\ economic\ activity}$$

This equation can be used to identify highly unsustainable activities, or to distinguish between discrete options or scenarios (Clift, 2003). It has to be kept in mind that the overall business impact assessment will not eliminate the unsustainable process or activity. Using the results of the OBIA the firm can identify unsustainable processes or activities and the firm itself has to take measures to make the process sustainable. The OBIA along a supply chain is schematically illustrated in the Figure 4.1. The “environmental impact” ordinate refers to the quantified contribution to one of the impact categories such as global warming potential, ozone depletion potential, human toxicity, etc. or some other category such as solid waste. Thus Figure 4.1 is a projection of a multi-dimensional surface in the different environmental categories, to avoid reducing the categories to a single metric (Clift, 2003). Again, this is just a generic representation, and the convexity may be understated in Figure 4.1 when considering

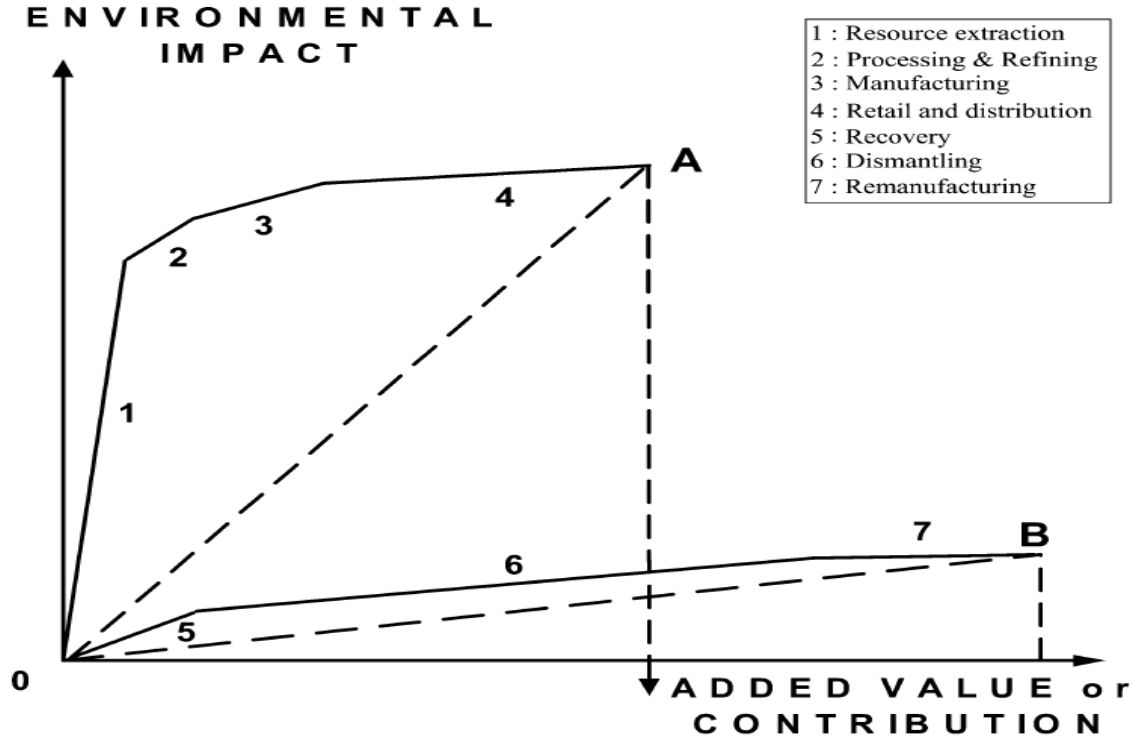

Figure 4.1 Accumulation of Environmental impact and Economic value along the supply Chain (Clift, 2003)

the electronics industry where the quantity of solid waste produced per kg of final product is of order 200 kg in extraction, processing and refining and 20 kg in manufacturing (Clift, 2003). Thus, Clift concludes that the convexity of the supply chain is an indicator of unsustainability for equity along the supply chain, i.e., equitable distribution of impacts and benefits, in which case the curve should be essentially straight. In our case, we are only concerned about the warehouses of a supply chain and the segments like resource extraction and manufacturing which can be replaced by the functions of the warehouse.

The use of OBIA for the purpose of screening or identifying the unsustainable activities can be illustrated by the following Figure 4.2. The $\Phi_{i,j}$ value that are close to unity implies that the activity is sustainable and otherwise, and any value that is much less than unity is unusually good (Clift, 2003). For example activity 1 is highly sustainable while activity 7 is very unsustainable.

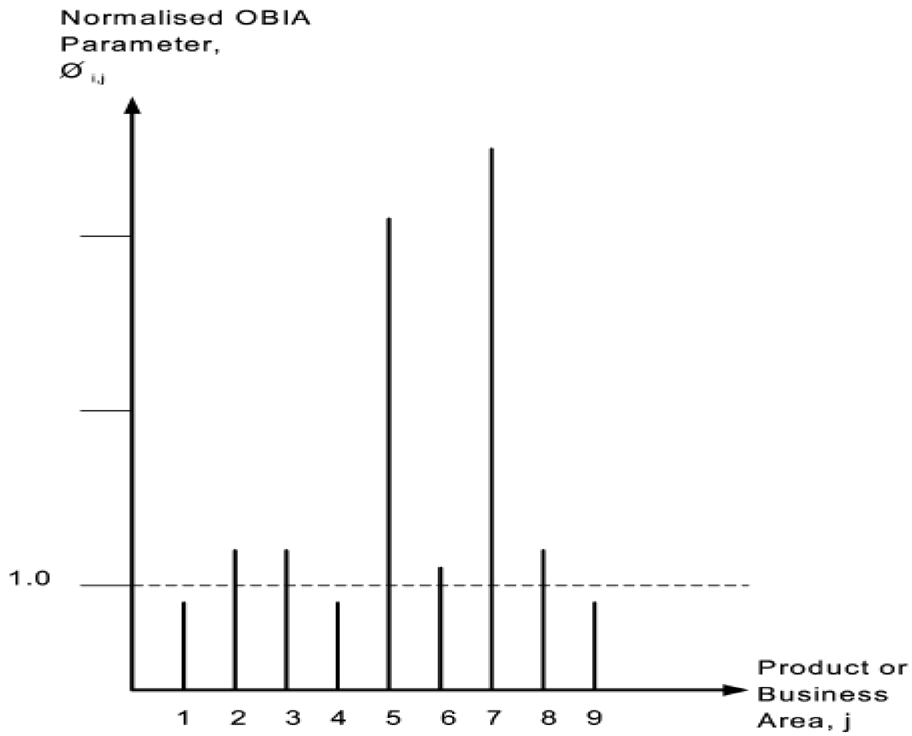

Figure 4.2 Use of OBIA normalized metric to identify least sustainable business areas (Clift, 2003)

CHAPTER 5

CASE STUDY

5.1 Case Study: Description

Cavitt and Thummalapalli validated their model using the data from the department of health and human services (C0XHHS) of a large city in the United States. But in this thesis, a dataset based on the previous research is generated using random numbers. Cavitt's and Thummalapalli's dataset is not relevant to this research because, as stated earlier, their dataset is based on a healthcare supply chain while the supply chain of interest for this research is a supply chain of a high-technology or electronics industry. Therefore, the dataset generated should be close to the values that would have been obtained if the data collection was done in those industries. We base the data collected by the previous authors in an attempt to make it more realistic.

For this thesis, the data has to be obtained from a supply chain of electronics industry

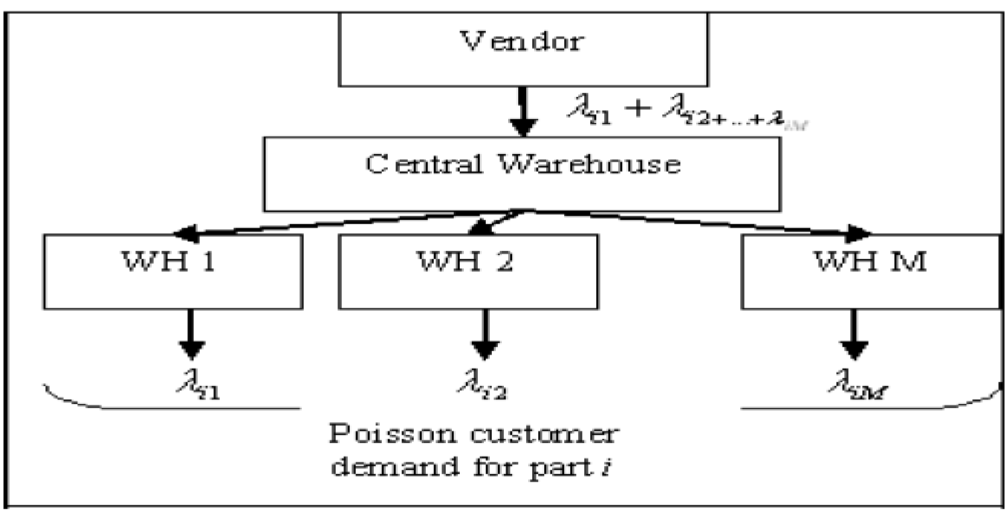

Figure 5.1 Two-Echelon Supply Chain Model (Cavitt, 2010)

that follows a two-echelon supply chain inventory model. A two-echelon supply chain model is discussed in the literature review. The reason for a choosing a two-echelon model like the one illustrated in Figure 5.1 is to make the initial analysis of the model simple.

Some of the assumptions and guidelines for the model were the same as those made from Thummalapalli's model. The decrease in percentage of obsolete inventory was chosen as the performance metric. The best industry practice is to have excessive inventory in the range of 3% to 6% of total inventory (Thummalapalli, 2010). Inventory turns was chosen as the secondary performance metric for the supply chain and the best practice in the industry is for inventory turns to be over 1.2 (Thummalapalli, 2010).

The expected results of this research were that the carrying cost ratio model will help managers make decisions on outsourcing, and at the same time the managers attain knowledge about the obsolete inventory they are holding. Reducing the obsolete inventory will reduce the inventory which in turn reduces the inventory holding cost of the supply chain. The data was generated assuming that the electronics supply chain has seven secondary warehouses. This framework can be beneficial when the warehouse manager has to investigate the performance of the warehouses in a supply chain and carry out outsourcing measures.

5.2 Data Generation

The definitions of the notations described in Chapter 4 are used for the calculation of the carrying cost ratio. The addition of space allocation costs for storage and procurement costs of products will yield the value of holding costs.

The costs related to utilities, labor (picking, packing, and shipping) are included in Space Costs (C_S) (Thummalapalli, 2010).

$$Holding\ Costs = C_S + C_P$$

$$Space\ cost = C_S$$

The cost of items, inbound trucking delivery to warehouse, and opportunity cost of tied up money would be included in the procurement costs. The fleet maintenance costs, cost of delivery (such as cost per mile for pick-up or use of courier services such as UPS) would be included in customer service or service costs (C_d).

As mentioned earlier, the data for this research is generated based on the dataset from previous research and the carrying cost breakdown put-forth by Richardson (Richardson, 1995).

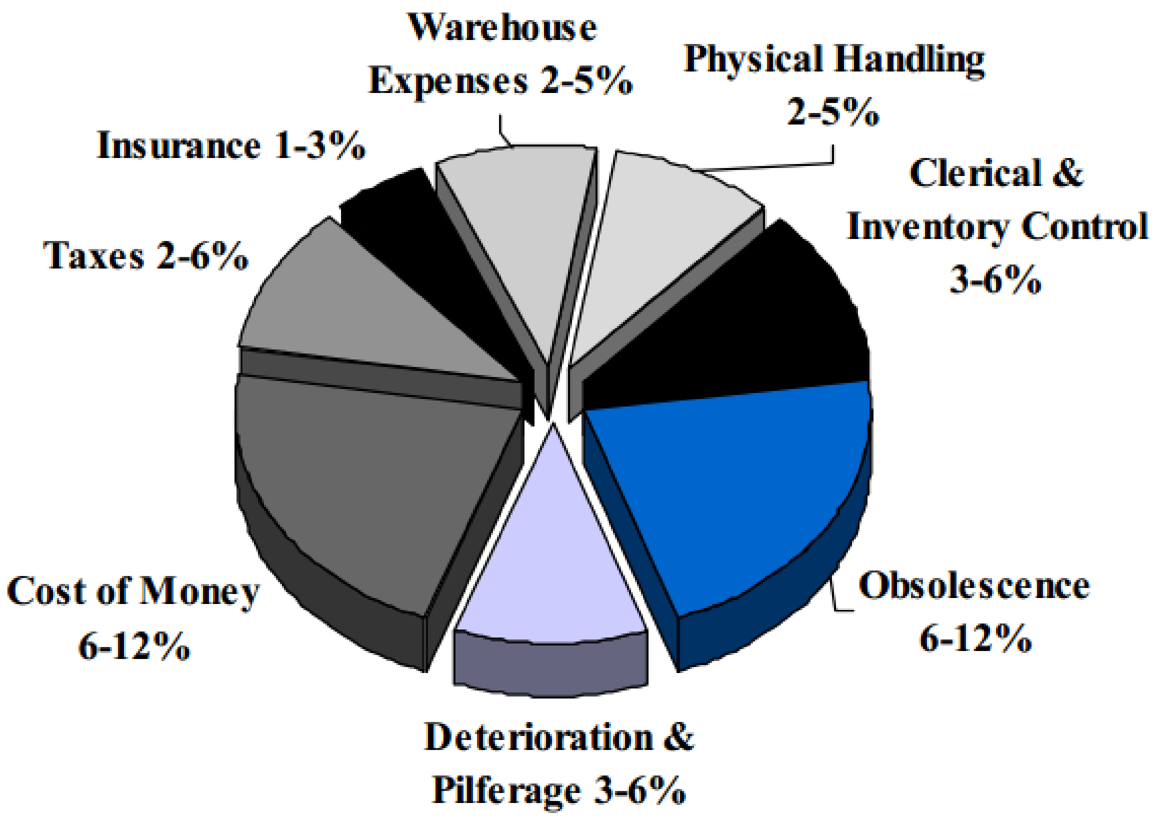

Figure 5.2 Inventory Holding Costs – Breakdown (Richardson, 1995)

The breakdown of the inventory holding costs is shown in the Figure 5.2. A sample of the generated data is shown in the following Table 5.1.

Table 5.1 Sample Data

MONTH	WAREHOUSE EXPENSES 2-5%	PHYSICAL HANDLING 2-5%	CLERICAL & INVENTORY CONTROL 3-6%	OBSOLESCENCE 6-12%	DETERIORATION & PILFERAGE 3-6%	COST OF MONEY 6-12%	TAXES 2-6%	INSURANCE 1-3%
Jan	$379	$726	$558	$1,100	$658	$1,825	$870	$809
Feb	$517	$792	$596	$1,233	$616	$1,400	$503	$394
Mar	$387	$585	$882	$1,095	$604	$1,709	$947	$911
Apr	$635	$433	$864	$1,417	$619	$1,910	$461	$475
May	$429	$755	$820	$1,522	$626	$1,258	$776	$473
Jun	$684	$788	$913	$1,700	$991	$1,871	$454	$905
Jul	$407	$812	$745	$1,988	$858	$1,602	$887	$769
Aug	$733	$777	$761	$1,413	$849	$1,353	$419	$451
Sep	$638	$388	$933	$1,160	$776	$1,799	$338	$718
Oct	$380	$691	$694	$1,579	$968	$1,648	$631	$395
Nov	$705	$621	$990	$1,676	$947	$1,976	$489	$671
Dec	$402	$336	$570	$1,080	$572	$1,671	$642	$791

The sum of all the costs and expenses listed in Table 5.1 provide the total annual inventory carrying cost of a particular warehouse. The generated data for other warehouses is presented in the appendix of this thesis. Once the costs are listed, then the calculation of inventory turns and more importantly, the carrying cost ratio is carried out. These calculations can be done using any spreadsheet (here, MS-Excel is used). As mentioned above the supply chain under consideration consists of seven warehouses.

Table 5.2 Carrying Cost Ratio

WAREHOUSE	**INVENTORY HOLDING COST**	**Receipts**	**Carrying Cost Ratio**
1	$85,970.00	$48,060.00	0.56
2	$57,515.00	$57,060.00	0.99
3	$104,236.00	$34,536.00	0.33
4	$126,069.00	$59,400.00	0.47
5	$70,065.00	$72,000.00	1.03
6	$84,215.00	$54,000.00	0.64
7	$110,672.00	$36,000.00	0.33

For instance, the inventory holding cost of Warehouse1 is calculated by summing all the individual costs for the year. The annual report of each warehouse will provide the value of receipts.

$$IHC = 6{,}636 + 6{,}975 + 9{,}438 + 18{,}141 + 9{,}144 + 18{,}688 + 7{,}700 + 9{,}248 = \$85{,}970$$

$$CC_R = \frac{Receipts}{IHC}$$

$$CC_R = \frac{48060}{85970} = 0.56$$

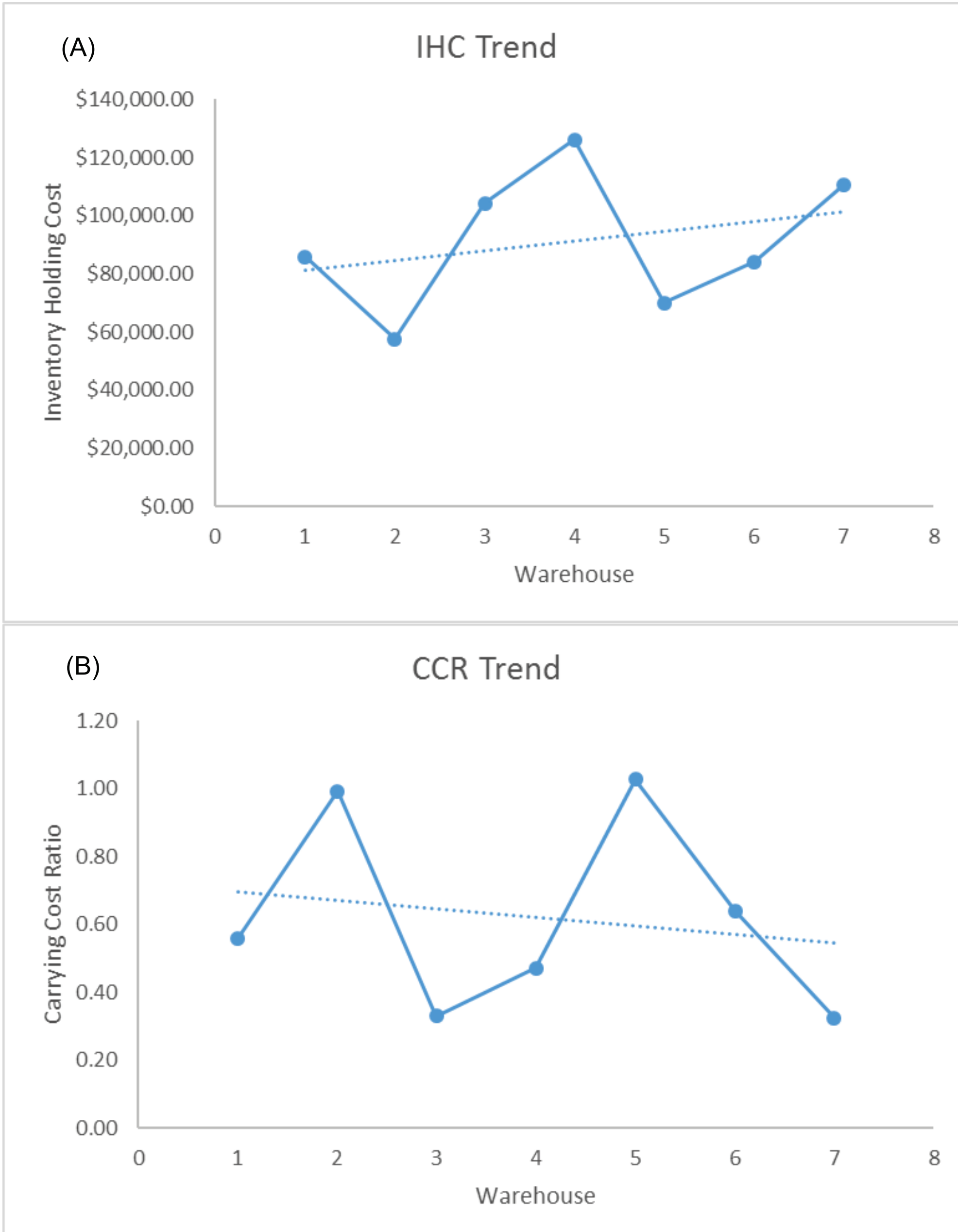

Figure 5.3 (A) Trend of Inventory Holding Cost
(B) Trend of Carrying Cost Ratio

From Figure 5.3, it can be noted that the inventory holding cost and the carrying cost ratio are almost perfectly inversely proportional to each other.

$$IHC \propto \frac{1}{CC_R}$$

As discussed earlier in CHAPTER 4, the ideal value of CC_R is 0.25-0.35. Therefore, iterations have to be run in order to attain an optimum value and eliminate the warehouses with higher carrying cost ratios.

5.3 Iterations for Optimum value

In order to run the iterations of the carrying cost ratio to yield optimum values 'Matlab' is used. The Matlab program is written in such a way that it eliminates any warehouse whose carrying cost ratio is over 1. When a warehouse is eliminated because the value of the carrying cost ratio is 1, the values of the other fields of the warehouse like the inventory holding cost and receipts are moved to the warehouse with the lowest carrying cost ratio. In other words, the inventory held in the lowest performing warehouse is moved to the warehouse with the highest performance. In this way, a balance in performance of the warehouses, if not the supply chain, can be attained. The iteration keeps running until it reaches a point where further movement of inventory between warehouses or optimizing is not possible. The Matlab program is presented in the appendix of this thesis. The results of the iteration are as follows:

```
IHC =
    85970
    57515
   104236
   126069
    70065
    84215
   110672
Receipt =
    48060
```

57060

34536

59400

72000

54000

36000

Initial_CCR =

0.5590	0.9921	0.3313	0.4712	1.0276	0.6412	0.3253

CCR =

0.5590	0.9921	0.3313	0.4712	0.6412	0.3253

CCR =

0.5590	0.9921	0.3313	0.4712	0.6412	0.6928

CCR =

0.5590	0.9921	0.5663	0.4712	0.6412	0.6928

CCR =

0.5590	0.9921	0.5663	0.6344	0.6412	0.6928

CCR =

0.7326	0.9921	0.5663	0.6344	0.6412	0.6928

CCR =

0.7326	0.9921	0.6780	0.6344	0.6412	0.6928

CCR =

0.7326	0.9921	0.6780	0.7197	0.6412	0.6928

Final_CCR =

0.7326	**0.9921**	**0.6780**	**0.7197**	**0.6412**	**0.6928**

From the values of carrying cost ratio after the iteration is done, outsourcing decision can be made. For example, the warehouse with a value 0.9921 should be outsourced without further thought because from the decisions based on the CC_R values, any warehouse with a carrying cost ratio more than 0.9 is performing very badly, hence, it only makes sense to outsource that particular warehouse instead wasting in-house resources on trying to optimize that warehouse or keep it in operation. Likewise, the decisions regarding the other warehouses can be made based on the respective carrying cost ratios.

CHAPTER 6

CONCLUSION

Although the primary reason behind operating warehouses in a supply chain is to store and distribute inventory, most firms operate warehouses in order to reduce costs and increase service by lowering the delivery and/or response time for the demand. But, if the warehouses are not managed carefully, they can become a liability rather than an asset to the firm. This is because there is reasonable probability that if the inventory is not maintained properly, additional inventory holding costs can easily consume 25% - 30% of the company's overall costs. Thus the inventory in the warehouse should be constantly monitored and the performance of the warehouses must be analyzed periodically using indicators like the Carrying Cost Ratio.

Decrease in carrying cost ratio demonstrates consolidating commodities into fewer facilities will lower costs and allow cost justification and priority qualification to determine which facilities should be eliminated and in what order (Thummalapalli, 2010).

The framework for outsourcing the operations of a warehouse gives warehouse managers a quick and accurate model for outsourcing to the top management. The case study using the sample data validates the model. The differences between this research and previous models of carrying cost ratio by Cavitt and Thummalapalli are illustrated in the Table 6.1.

Table 6.1 Comparison of this Thesis and previous Similar Works

	Cavitt	**Thummalapalli**	**This Thesis**
Purpose	To evaluate the performance of the warehouses	To evaluate the performance of the warehouses	To make an Outsourcing Decision
Industry	Health Care	Health Care	Electronics
Iterations	NO	YES	YES
Type of Iteration	NA	Trial and Error	Matlab
Other Analysis	Friedman's Rank Test	ABC Analysis	NA
Ideal CCR Value	0.2 to 0.4	0.2 to 0.4	0.25 to 0.35

6.1 Limitations and Future Work

In spite of the benefits of the framework, there are some limitations to the model. One of the limitations to this model is that it does not consider capacity constraint, which must be dealt with when moving the inventory to other warehouses. The data used in this thesis is generated using random number generators, therefore it is not the actual representation of the real time validity of the model. The grouping of the business functions for outsourcing and the sustainability parameter are not validated.

Future research which would supplement and enhance the work done here is as follows:

- Data should be collected using Speh's "warehouse cost calculation form" (Speh, 2009). [see appendix]

- A capacity parameter should be included in the equation to calculate the carrying cost ratio.
- The grouping of business functions for ‘integrative outsourcing’ should be validated.
- The sustainability indicator – Overall Business Impact Assessment (OBIA) should be validated and included using the Matlab program.
- According to the conception of the framework, results must be robust enough to support accurate investigation for the whole supply chain.

6.2 Contribution to the Body of Knowledge

This model is a combination of principles of Industrial Engineering, Engineering Economics, and Operations Management. It can be used as literature for future research on sustainable supply chain, for which the availability of published research is relatively limited. In the view of industrial implementation, it will act as a quick and accurate framework for the managers of warehouses. This type of research will also aid in the effort to reduce the carbon footprint of supply chain management and make the business operations and inventory processes more eco-friendly.

APPENDIX A

DATA GENERATED USING EXCEL BASED ON THE DISTRIBUTION OF WAREHOUSE COSTS

WAREHOUSE	**MONTH**	**WAREHOUSE EXPENSES**	**PHYSICAL HANDLING**	**CLERICAL & INVENTORY CONTROL**	**OBSOLESCENCE**	**DETERIORATION & PILFERAGE**	**COST OF MONEY**	**TAXES**	**INSURANCE**	**INVENTORY HOLDING COST**	**Receipts**	**Carrying Cost Ratio**
		2-5%	**2-5%**	**3-6%**	**6-12%**	**3-6%**	**6-12%**	**2-6%**	**1-3%**			
	Jan	$361.00	$576.00	$770.00	$1,566.00	$659.00	$1,294.00	$958.00	$909.00	$7,093.00	$4,005.00	$0.56

	Feb	$353.00	$784.00	$841.00	$1,092.00	$862.00	$1,795.00	$956.00	$653.00	$7,336.00	$4,005.00	$0.55
	Mar	$704.00	$734.00	$735.00	$1,337.00	$830.00	$1,318.00	$934.00	$377.00	$6,969.00	$4,005.00	$0.57
	Apr	$406.00	$609.00	$722.00	$1,854.00	$679.00	$1,447.00	$486.00	$378.00	$6,581.00	$4,005.00	$0.61
	May	$503.00	$757.00	$946.00	$1,981.00	$963.00	$1,326.00	$845.00	$858.00	$8,179.00	$4,005.00	$0.49
1	Jun	$616.00	$401.00	$819.00	$1,578.00	$697.00	$1,252.00	$875.00	$389.00	$6,627.00	$4,005.00	$0.60
	Jul	$467.00	$364.00	$815.00	$1,229.00	$735.00	$1,845.00	$929.00	$835.00	$7,219.00	$4,005.00	$0.55
	Aug	$768.00	$362.00	$726.00	$1,161.00	$525.00	$1,228.00	$761.00	$606.00	$6,137.00	$4,005.00	$0.65
	Se	$772.	$412.	$686.	$1,14	$536.	$1,79	$831.	$585.	$6,76	$4,00	$0.5

	p	00	00	00	5.00	00	7.00	00	00	4.00	5.00	9
	Oct	$794.00	$640.00	$923.00	$1,696.00	$656.00	$1,246.00	$782.00	$523.00	$7,260.00	$4,005.00	$0.55
	Nov	$431.00	$360.00	$597.00	$1,933.00	$731.00	$1,466.00	$846.00	$526.00	$6,890.00	$4,005.00	$0.58
	Dec	$624.00	$475.00	$612.00	$1,327.00	$981.00	$1,011.00	$662.00	$697.00	$6,389.00	$4,005.00	$0.63
	TOTAL	**$6,799.00**	**$6,474.00**	**$9,192.00**	**$17,899.00**	**$8,854.00**	**$17,025.00**	**$9,865.00**	**$7,336.00**	**$83,444.00**	**$48,060.00**	**$0.58**
	Jan	$446.00	$250.00	$617.00	$1,210.00	$367.00	$927.00	$245.00	$668.00	$4,730.00	$4,755.00	$1.01
	Feb	$391.00	$469.00	$372.00	$1,001.00	$375.00	$989.00	$255.00	$483.00	$4,335.00	$4,755.00	$1.10
	Ma	$340.	$234.	$455.	$738.	$495.	$925.	$375.	$377.	$3,93	$4,75	$1

	r	00	00	00	00	00	00	00	00	9.00	5.00	.21
	Apr	$548.00	$534.00	$523.00	$754.00	$554.00	$1,180.00	$578.00	$352.00	$5,023.00	$4,755.00	$0.95
	May	$383.00	$345.00	$543.00	$826.00	$410.00	$813.00	$624.00	$450.00	$4,394.00	$4,755.00	$1.08
2	Jun	$376.00	$258.00	$648.00	$788.00	$496.00	$1,067.00	$462.00	$508.00	$4,603.00	$4,755.00	$1.03
	Jul	$244.00	$274.00	$366.00	$1,337.00	$525.00	$893.00	$233.00	$493.00	$4,365.00	$4,755.00	$1.09
	Aug	$346.00	$503.00	$603.00	$1,261.00	$481.00	$821.00	$310.00	$278.00	$4,603.00	$4,755.00	$1.03
	Sep	$451.00	$257.00	$626.00	$712.00	$390.00	$1,219.00	$506.00	$664.00	$4,825.00	$4,755.00	$0.99
	Oct	$305.00	$418.00	$543.00	$1,220.00	$470.00	$857.00	$255.00	$364.00	$4,432.00	$4,755.00	$1.0

												7
	Nov	$364.00	$339.00	$608.00	$1,162.00	$655.00	$1,128.00	$479.00	$385.00	$5,120.00	$4,755.00	$0.93
	Dec	$316.00	$371.00	$572.00	$882.00	$543.00	$1,061.00	$268.00	$450.00	$4,463.00	$4,755.00	$1.07
	TOTAL	**$4,510.00**	**$4,252.00**	**$6,476.00**	**$11,891.00**	**$5,761.00**	**$11,880.00**	**$4,590.00**	**$5,472.00**	**$54,832.00**	**$57,060.00**	**$1.04**
	Jan	$698.00	$670.00	$695.00	$1,820.00	$1,176.00	$2,313.00	$635.00	$1,071.00	$9,078.00	$2,878.00	$0.32
	Feb	$816.00	$605.00	$1,011.00	$1,940.00	$1,021.00	$2,181.00	$472.00	$930.00	$8,976.00	$2,878.00	$0.32
	Mar	$705.00	$845.00	$1,139.00	$1,455.00	$863.00	$1,947.00	$1,151.00	$957.00	$9,062.00	$2,878.00	$0.32
	Apr	$871.	$715.	$878.	$1,69	$760.	$1,71	$1,11	$500.	$8,24	$2,87	$0

		00	00	00	6.00	00	0.00	5.00	00	5.00	8.00	.35
	May	$556.00	$772.00	$791.00	$2,382.00	$1,160.00	$2,203.00	$537.00	$587.00	$8,988.00	$2,878.00	$0.32
3	Jun	$727.00	$915.00	$1,017.00	$2,178.00	$891.00	$1,753.00	$529.00	$1,078.00	$9,088.00	$2,878.00	$0.32
	Jul	$909.00	$511.00	$1,054.00	$1,973.00	$1,189.00	$1,377.00	$592.00	$1,025.00	$8,630.00	$2,878.00	$0.33
	Aug	$741.00	$650.00	$1,145.00	$1,649.00	$730.00	$1,571.00	$828.00	$1,186.00	$8,500.00	$2,878.00	$0.34
	Sep	$731.00	$555.00	$726.00	$1,903.00	$1,086.00	$1,329.00	$506.00	$1,148.00	$7,984.00	$2,878.00	$0.36
	Oct	$982.00	$782.00	$968.00	$2,044.00	$1,117.00	$1,235.00	$1,026.00	$1,146.00	$9,300.00	$2,878.00	$0.31
	Nov	$480.00	$562.00	$1,096.00	$1,417.00	$803.00	$1,436.00	$1,056.00	$515.00	$7,365.00	$2,878.00	$0.3

												9
	Dec	$813.00	$796.00	$881.00	$1,741.00	$696.00	$1,352.00	$627.00	$998.00	$7,904.00	$2,878.00	$0.36
	TOTAL	**$9,029.00**	**$8,378.00**	**$11,401.00**	**$22,198.00**	**$11,492.00**	**$20,407.00**	**$9,074.00**	**$11,141.00**	**$103,120.00**	**$34,536.00**	**$0.33**
	Jan	$1,218.00	$604.00	$971.00	$2,728.00	$1,402.00	$2,240.00	$709.00	$800.00	$10,672.00	$4,950.00	$0.46
	Feb	$946.00	$962.00	$759.00	$1,799.00	$1,441.00	$2,611.00	$1,345.00	$795.00	$10,658.00	$4,950.00	$0.46
	Mar	$1,210.00	$658.00	$918.00	$2,874.00	$1,049.00	$2,779.00	$1,428.00	$1,084.00	$12,000.00	$4,950.00	$0.41
	Apr	$1,072.00	$908.00	$845.00	$2,937.00	$892.00	$1,934.00	$786.00	$941.00	$10,315.00	$4,950.00	$0.48
	Ma	$909.	$880.	$1,25	$2,64	$1,36	$2,03	$960.	$1,11	$11,1	$4,95	$0

	y	00	00	4.00	7.00	1.00	2.00	00	2.00	55.00	0.00	.44
4	Jun	$731.00	$779.00	$1,008.00	$2,309.00	$1,043.00	$2,211.00	$1,178.00	$1,489.00	$10,748.00	$4,950.00	$0.46
	Jul	$1,228.00	$1,057.00	$1,346.00	$2,146.00	$1,433.00	$2,179.00	$1,251.00	$1,236.00	$11,876.00	$4,950.00	$0.42
	Aug	$634.00	$1,069.00	$1,090.00	$2,091.00	$856.00	$2,177.00	$896.00	$1,385.00	$10,198.00	$4,950.00	$0.49
	Sep	$787.00	$592.00	$877.00	$2,010.00	$1,420.00	$1,599.00	$1,324.00	$1,073.00	$9,682.00	$4,950.00	$0.51
	Oct	$820.00	$1,006.00	$934.00	$2,485.00	$1,083.00	$1,925.00	$1,449.00	$1,215.00	$10,917.00	$4,950.00	$0.45
	Nov	$522.00	$1,122.00	$1,391.00	$2,213.00	$1,126.00	$2,720.00	$1,421.00	$889.00	$11,404.00	$4,950.00	$0.43
	Dec	$1,254.00	$1,183.00	$1,334.00	$2,083.00	$1,412.00	$2,658.00	$1,340.00	$1,444.00	$12,708.00	$4,950.00	$0.3

												9
	TOTAL	**$11,331.00**	**$10,820.00**	**$12,727.00**	**$28,322.00**	**$14,518.00**	**$27,065.00**	**$14,087.00**	**$13,463.00**	**$132,333.00**	**$59,400.00**	**$0.45**
	Jan	$645.00	$622.00	$451.00	$880.00	$426.00	$928.00	$487.00	$591.00	$5,030.00	$6,000.00	$1.19
	Feb	$567.00	$435.00	$759.00	$871.00	$585.00	$1,252.00	$506.00	$806.00	$5,781.00	$6,000.00	$1.04
	Mar	$381.00	$647.00	$757.00	$1,390.00	$582.00	$1,146.00	$769.00	$527.00	$6,199.00	$6,000.00	$0.97
	Apr	$425.00	$450.00	$778.00	$1,119.00	$540.00	$1,620.00	$705.00	$623.00	$6,260.00	$6,000.00	$0.96
	May	$522.00	$359.00	$572.00	$1,393.00	$643.00	$1,037.00	$571.00	$509.00	$5,606.00	$6,000.00	$1.07
5	Jun	$341.	$389.	$783.	$1,31	$517.	$1,60	$591.	$689.	$6,23	$6,00	$0

		00	00	00	8.00	00	7.00	00	00	5.00	0.00	.96
	Jul	$394.00	$344.00	$784.00	$1,489.00	$632.00	$1,162.00	$282.00	$353.00	$5,440.00	$6,000.00	$1.10
	Aug	$646.00	$522.00	$613.00	$952.00	$626.00	$1,003.00	$584.00	$765.00	$5,711.00	$6,000.00	$1.05
	Sep	$466.00	$537.00	$820.00	$990.00	$541.00	$1,363.00	$689.00	$509.00	$5,915.00	$6,000.00	$1.01
	Oct	$359.00	$677.00	$509.00	$1,083.00	$822.00	$1,559.00	$568.00	$606.00	$6,183.00	$6,000.00	$0.97
	Nov	$498.00	$374.00	$592.00	$942.00	$511.00	$1,586.00	$684.00	$701.00	$5,888.00	$6,000.00	$1.02
	Dec	$399.00	$330.00	$618.00	$1,324.00	$620.00	$1,508.00	$783.00	$569.00	$6,151.00	$6,000.00	$0.98
	TO	**$5,64**	**$5,68**	**$8,03**	**$13,7**	**$7,04**	**$15,7**	**$7,21**	**$7,24**	**$70,3**	**$72,0**	**$1**

	TAL	**3.00**	**6.00**	**6.00**	**51.00**	**5.00**	**71.00**	**9.00**	**8.00**	**99.00**	**00.00**	**.02**
	Jan	$734.00	$792.00	$789.00	$1,903.00	$520.00	$1,770.00	$600.00	$861.00	$7,969.00	$4,500.00	$0.56
	Feb	$616.00	$500.00	$992.00	$1,824.00	$652.00	$1,575.00	$645.00	$388.00	$7,192.00	$4,500.00	$0.63
	Mar	$507.00	$398.00	$972.00	$1,047.00	$734.00	$1,639.00	$821.00	$733.00	$6,851.00	$4,500.00	$0.66
	Apr	$823.00	$762.00	$855.00	$1,516.00	$992.00	$1,807.00	$844.00	$808.00	$8,407.00	$4,500.00	$0.54
	May	$779.00	$800.00	$651.00	$1,482.00	$575.00	$1,633.00	$896.00	$861.00	$7,677.00	$4,500.00	$0.59
6	Jun	$765.00	$821.00	$531.00	$1,720.00	$970.00	$1,509.00	$449.00	$708.00	$7,473.00	$4,500.00	$0.60
	Jul	$511.	$588.	$843.	$1,96	$733.	$1,88	$916.	$977.	$8,42	$4,50	$0

		00	00	00	7.00	00	6.00	00	00	1.00	0.00	.53
	Aug	$434.00	$581.00	$1,002.00	$1,263.00	$896.00	$1,433.00	$635.00	$916.00	$7,160.00	$4,500.00	$0.63
	Sep	$425.00	$760.00	$546.00	$1,343.00	$596.00	$1,175.00	$741.00	$923.00	$6,509.00	$4,500.00	$0.69
	Oct	$645.00	$585.00	$869.00	$1,710.00	$535.00	$1,857.00	$861.00	$377.00	$7,439.00	$4,500.00	$0.60
	Nov	$779.00	$555.00	$760.00	$1,894.00	$553.00	$1,936.00	$509.00	$640.00	$7,626.00	$4,500.00	$0.59
	Dec	$352.00	$796.00	$707.00	$1,298.00	$567.00	$1,499.00	$823.00	$895.00	$6,937.00	$4,500.00	$0.65
	TOTAL	**$7,370.00**	**$7,938.00**	**$9,517.00**	**$18,967.00**	**$8,323.00**	**$19,719.00**	**$8,740.00**	**$9,087.00**	**$89,661.00**	**$54,000.00**	**$0.60**

	Jan	$507.00	$547.00	$1,214.00	$1,565.00	$1,193.00	$1,949.00	$1,132.00	$1,297.00	$9,404.00	$3,000.00	$0.32
	Feb	$731.00	$454.00	$1,001.00	$2,651.00	$937.00	$1,697.00	$1,186.00	$796.00	$9,453.00	$3,000.00	$0.32
	Mar	$737.00	$972.00	$841.00	$1,523.00	$697.00	$1,465.00	$779.00	$1,181.00	$8,195.00	$3,000.00	$0.37
	Apr	$716.00	$1,116.00	$687.00	$2,226.00	$913.00	$1,867.00	$793.00	$1,207.00	$9,525.00	$3,000.00	$0.31
	May	$525.00	$583.00	$1,086.00	$1,422.00	$981.00	$2,606.00	$751.00	$870.00	$8,824.00	$3,000.00	$0.34
7	Jun	$1,041.00	$1,014.00	$1,044.00	$2,647.00	$787.00	$2,096.00	$724.00	$525.00	$9,878.00	$3,000.00	$0.30
	Jul	$596.00	$1,104.00	$1,144.00	$2,105.00	$782.00	$1,658.00	$704.00	$657.00	$8,750.00	$3,000.00	$0.34
	Au	$961.	$882.	$1,16	$1,70	$1,27	$1,38	$526.	$590.	$8,48	$3,00	$0.3

	g	00	00	1.00	3.00	3.00	9.00	00	00	5.00	0.00	5
	Sep	$742.00	$1,053.00	$796.00	$2,006.00	$1,248.00	$1,501.00	$1,115.00	$860.00	$9,321.00	$3,000.00	$0.32
	Oct	$917.00	$744.00	$1,060.00	$2,055.00	$786.00	$2,357.00	$1,298.00	$1,208.00	$10,425.00	$3,000.00	$0.29
	Nov	$960.00	$1,099.00	$1,161.00	$1,399.00	$1,240.00	$2,356.00	$470.00	$606.00	$9,291.00	$3,000.00	$0.32
	Dec	$543.00	$935.00	$1,301.00	$1,846.00	$850.00	$2,342.00	$970.00	$941.00	$9,728.00	$3,000.00	$0.31
	TOTAL	**$8,976.00**	**$10,503.00**	**$12,496.00**	**$23,148.00**	**$11,687.00**	**$23,283.00**	**$10,448.00**	**$10,738.00**	**$111,279.00**	**$36,000.00**	**$0.32**

APPENDIX B

MATLAB PROGRAM FOR ITERATION OF CARRYING COST RATIO

```
clc
clear all
IHC = xlsread('Carrying Cost Ratio.xlsx',3,'J:J');
IHC
Receipt = xlsread('Carrying Cost Ratio.xlsx',3,'K:K');
Receipt
for i = 1:size(IHC,1)
    a(i) = Receipt(i)/IHC(i);
end
Initial_CCR = a;
Initial_CCR
f = a;
d = [];
g = [];
y = [];
z = [];
CCR = a;
p = IHC;
q = Receipt;


for i = 1:size(CCR,2)
    [d,maxindex] = max(CCR);  %Max of CCR
    [g,minindex] = min(CCR); %Min of CCR
    if d > 1
        p(minindex) = p(maxindex) + p(minindex);
        q(minindex) = q(maxindex) + q(minindex);
```

```
        e(minindex) = q(minindex)/p(minindex);
        p(maxindex) = [];
        q(maxindex) = [];
        CCR(maxindex) = [];
        i = i-1;
    elseif d > 0.33
        p(minindex) = p(maxindex) + p(minindex);
        q(minindex) = q(maxindex) + q(minindex);
        CCR(minindex) = q(minindex)/p(minindex);
    end
    CCR
end
Final_CCR = CCR;
Final_CCR
```

APPENDIX C

WAREHOUSE COST CALCULATION FORM (Speh, 2009)

A FORM FOR WAREHOUSE COST CALCULATION

I. HANDLING

A. Labor

1. Direct payments:
   a. Wages . . . . $________
   b. Overtime . . . . $________
2. Fringe benefits
   a. Health insurance . . . . $________
   b. Pension . . . . $________
   c. Life insurance . . . . $________
   d. Uniforms . . . . $________
   e. Other . . . . $________
3. Compensated time off
   a. Vacation . . . . $________
   b. Holidays . . . . $________
   c. Sick leave . . . . $________
   d. Jury duty . . . . $________
   e. Funeral leave . . . . $________
   f. Other . . . . $________
4. Taxes
   a. FICA . . . . $________
   b. Workers compensation . . . . $________
   c. Unemployment compensation . . $________
   d. Other . . . . $________
5. Temporary labor
6. Development costs
   a. Training . . . . $________
   b. Education allowances . . . . $________
   c. Other . . . . $________

B. Handling equipment

1. Lift trucks and attachments
   a. Rental . . . . $________
   b. Depreciation and interest . . . . . . $________
   c. Maintenance . . . . $________
   d. Motor fuel or electricity . . . . . . $________
2. Conveyors
   a. Depreciation and interest . . . . . . $________
   b. Maintenance . . . . $________
   c. Electric power . . . . $________
3. Pallets
   a. Purchase or replacement costs . . $________
   b. Repair . . . . $________

C. Other handling expenses

1. Detention/demurrage
2. Recouping damaged product
3. Trash and/or snow removal
4. Maintenance of loading docks and related equipment

II. STORAGE

A. Facility

1. Rent, or depreciation and interest . . . $________
2. Taxes . . . . $________

II. STORAGE (continued)

3. Insurance . . . . $________
4. Building maintenance . . . . $________
5. Other . . . . $________

B. Grounds

1. Lawn and landscaping maintenance . $________
2. Parking lot maintenance . . . . $________

C. Storage equipment (racks and/or shelving)

1. Depreciation and interest . . . . $________
2. Maintenance . . . . $________

D. Utilities

1. Heat and/or temperature control . . . . $________
2. Lighting . . . . $________

E. Security

1. Sprinkler and other fire protection systems . . . . $________
2. Electronic burglar alarms . . . . $________
3. Guard service . . . . $________

F. Pest control

G. Other facility expense

III. OPERATING ADMINISTRATIVE EXPENSE

A. Supervisory salaries . . . . $________

B. Clerical salaries . . . . $________

C. Labor purchased from staffing services . . . . $________

D. Office and data processing equipment

1. Depreciation and interest . . . . $________
2. Software . . . . $________
3. Maintenance . . . . $________
4. Training . . . . $________

E. Office maintenance . . . . $________
F. Communications costs . . . . $________
G. Legal and professional . . . . $________
H. Taxes and licenses . . . . $________
I. Travel . . . . $________
J. Insurance and claims . . . . $________
K. Losses due to damage, shortages and errors . . . . $________

IV. GENERAL ADMINISTRATIVE EXPENSE

A. Executive salaries . . . . $________
B. Executive office expenses . . . . $________
C. Selling and advertising expenses . . . $________

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BIOGRAPHICAL INFORMATION

Chendur Murugananthan Anand, also known as Chendur M. Anand, has a Bachelor's degree in Mechanical Engineering from Amrita School of Engineering, India. Immediately after his undergraduate program, he came to the University of Texas at Arlington (UTA) to pursue his education. As a graduate student in Industrial Engineering he was involved in some research activities in the University. His area of specialization is inventory management and logistics. He was a part of the Radio Frequency and Auto Identification (RAID) labs associated with UTA's Industrial and Manufacturing Systems Engineering (IMSE) department. He started off as a graduate research assistant at the lab where he was involved in some projects on RFID and inventory control. In the summer of 2012, he also served as the interim manager of RAID Labs where Chendur submitted few papers for journals like International Journal of Production Research (IJPR). Later, during the fall semester, in recognition to his work, Dr. Erick Jones (Director, RAID Labs) gave him the responsibility of heading the research team at the RAID Labs. He was also passively involved in the activities of Institute of Supply Management (ISM) Fort Worth chapter. He has a certification in Six Sigma Green Belt. After completing his Master's program he is planning to work as a technical consultant at Intrigo Systems, Inc, CA. He is very motivated in getting a doctoral degree in the near future after gaining some work experience.