An Engineering Approach to Improving Hospital Supply Chains

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Abstract

This thesis explores supply chain management practices that have been implemented, and have improved supply chains in industries outside of healthcare. The presented supply chain practices have been selected because they have the potential to improve efficiency, reduce costs and improve patient safety within hospitals. Due to the diverse nature of hospitals and a unique product profile, there is no "one size fits all" supply chain solution that can be implemented. Therefore, product specific characteristics are discussed that can be used by hospitals in order to develop segmentation policies. Supply chain best practices from outside of the healthcare industry are presented for each category of segmented products. The culmination of this thesis is the presentation of a supply chain that will enable the hospital to significantly reduce inventory storage space, on hand inventory value, and time spent by nurses managing inventory. The proposed supply chain model is patient specific and involves the delivery of items from an offsite warehouse directly to the patient's bedside. In order to successfully implement a new supply chain solution in a hospital setting, change management is a critical part of the process. Methods are presented that have resulted in successful implementations of complex systems within hospitals. Three areas must be considered when managing change in this type of setting, the healthcare environment, the hospital's internal management and operational aspects of the hospital supply chain. Using simulation models, we show that implementation of the proposed supply chain for appropriately segmented products will result in significant supply chain cost savings and boost the revenue.

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Dedications

Scott would like to dedicate this thesis to his parents, Rong-Jan Cheng and Su-Chen Huang, and his girlfriend, Christy Tzu-Yun Kuo. Without support from his parents, Scott would not have been able to attend MIT and receive the MLOG degree. Christy has consistently been an angel, lighting the way and making everything easier.

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Biographical Notes

Scott Hsiang-Jen Cheng is a 2008 candidate for the MLOG degree. Scott will work as a McKinsey consultant in the Greater China office after graduation. Prior to attending MIT, he worked as a Project Manager for Taipei Smart Card Corporation, a start-up RFID and IT service provider in Taiwan. Scott received his M.S. degree in Transportation and B.S. degree in Civil Engineering, both in National Taiwan University.

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1 Introduction

Acute Care Hospitals, as defined by the US Department of Health and Human Services, are hospitals that provide inpatient medical care and other related services for surgery, acute medical conditions or injuries. The medical care offered by these hospitals is usually for a short term illness or condition. Acute Care Hospitals not only operate with high inpatient volume but also deal with the challenges of increasing supply chain management costs within the healthcare industry.

Over the past decade, most hospitals have been facing the challenges of rising costs. For over seven years, the cost of healthcare has been increasing at a much faster rate than inflation (McKone-Sweet 2005). From the year 2000 through 2005, inflation has rose by 18%, while healthcare premiums increased by 87%. Supply chain management practices are some of the problems driving these continually increasing costs.

It can be argued that as hospitals in the US look to improve margins through revenue enhancement and cost containment, they regard enhancing the hospital's procurement and logistical supply chain as an opportunity to control cost, improve patient safety, and optimize staff time. Hospitals are seeking ways to optimize how they both procure and then move medications and medical supplies through their hospitals in the safest, most cost effective manner. Many hospitals, having for years relied on manual processes, are looking to cutting edge technologies and processes both in and outside of the healthcare arena to choose the best strategy to move forward.

Practices such as hording, over ordering, and leaving inventory management up to nurses within hospitals are some of the factors that have contributed to the current problems (DeScioli 2005). Nurses horde because of the relationship that exists between the doctors and nurses within hospitals. It is often that nurses are reprimanded when there are stock outs. Over ordering occurs because many of the systems hospitals use to track inventory are manual and outdated. In order to reduce holding costs and stock out occurrences, hospitals may need to update their inventory policies to benefit from the advances made over the past decade in the consumer products industry.

1.1 Research Scope and Objectives

The primary focus of this research will be to develop roadmaps and strategies that have been useful in other industries and can be transferred into the healthcare industry. The new procedures will help reduce inventory, and also reduce stock outs for any items that are used within a hospital setting.

The question the authors intended to answer with this thesis is: “What supply chain management techniques have been successfully implemented in industries outside of healthcare that may be applicable within the healthcare industry?” The first step in answering this question was to analyze hospital supply chains, uncover the problems currently experienced by hospitals and benchmark specific characteristics of hospital supply chains.

Once an in depth understanding of hospital supply chains was achieved, the next step was to find industries that had supply chains with similar characteristics. If supply chains could not be found that were similar enough to the hospital supply chain, then segments of the hospital supply chain would be compared with segments of supply chains outside the hospital setting. Once the correlation between internal and external supply chains was made, then intent was then to develop procedures that could be implemented in the hospital to reduce supply chain costs.

1.2 Research Methodology

We followed a mixed method approach to investigate the supply chain issues experienced in hospitals. Both qualitative and quantitative data were collected. Qualitative data were gathered through literature reviews and interviews with supply chain professionals within the hospitals, nurses, materials management professionals from outside the hospital setting, and supply chain specialists outside the healthcare industry.

In particular, we studied three hospitals to obtain the current practices in different supply chain development stages at Northeast Hospital (NEH), Public Midwest Hospital (MWU) and Private Midwest Hospital (MWR). The study included interviews with various hospital staff at each location as well as HCD employees and experienced professionals outside of healthcare industries to develop a roadmap and guidelines for hospitals to improve procurement processes and logistical systems and also to move toward more optimized supply chain systems. The purpose of these interviews was to gain a better understanding of the problems experienced within the hospital setting and discuss possible solutions to the problems. The interviews within the hospitals were conducted at MWU, MWR and NEH.

Once we determined the specific types of data that were needed for simulations to replicate certain aspects of the hospital supply chain, we requested the data from participating hospitals. The data that we received were APU system transaction data representing medical/surgical items at NEH. Data analysis was completed in order to illustrate the potential advantages or disadvantages of the proposed solution to the supply chain issues present in hospitals. Specifically, we examined the benefits of inventory reductions, increased service levels, reclamation of hospital real estate and savings of nurse's and pharmacist's time. Similarly, we also examined various costs, such as transportation costs associated with the personalized kit supply chain.

1.3 Thesis Outline

Chapter 2 reviews the research that has been done in the past related to hospital supply chains, as well as supply chain best practices in other industries, in order to create a framework for the subsequent sections. Chapter 3 explains the methodology used in order to complete the research for this thesis, and the data collection is also discussed. Chapter 4 discusses various approaches that can be taken in order to segment the items within a hospital. Some segmentation criteria are more appropriate than others with respect to MWU, MWR and NEH, but the needs of all hospitals are different, and therefore segmentation of products should be done differently for each hospital. Chapter 5 presents a new approach to supply chain management within hospitals, and the potential benefits of implementing the new supply chain management strategy. Chapter 6 presents guidelines that should be used in order to ensure the highest likelihood of success when implementing any major changes in supply chain management within hospitals. Conclusions are presented in Chapter 7 reached from the research conducted, and areas that should be investigated further in the future.

2 Literature Review

In order to determine supply chain best practices outside the healthcare industry that are applicable within the healthcare industry required research in three main categories. These are "Existing Hospital Supply Chains", "Supply Chain Best Practices Outside the Healthcare Industry", and "Implementation of Supply Chain Modifications".

2.1 Existing Hospital Supply Chains

Hospitals require medications, medical consumables, and surgical products to be provided to patients. Each of these categories of products is commonly handled differently by the staff within the hospital, and therefore requires separate supply chain practices. Each of these categories is regularly broken up into sub-categories that must also be handled differently (DeScioli 2005). Although each supply chain requires different consideration, there are some practices that are common across hospitals and products.

It is a common practice among hospitals to have a central inventory for medical consumables within the hospital (Duclos 1993). This central inventory is where backup inventory is held for each of the units of the hospital. Inventory is generally received at the receiving dock, the shipments are broken down, and then the individual products are transferred to central inventory.

The first step in the supply chain process is the receipt of the product at the loading dock of the hospital in the morning. The products arrive on carts or on pallets. If the distributor has been directed to package products for specific units within the hospital on one cart, then these carts are brought to the wards within the hospital to stock the storage spaces within the wards. Many hospitals do not have this type of arrangement, and instead materials management professionals transport the products to central storage locations.

Once the product arrives in the central warehouse, the boxes are opened and the products are brought to their specific stock locations. Next, the materials management professionals replenish the inventory and manually take note of any discrepancies in the inventory levels. This process is performed daily and may take several hours to complete.

Items from central inventory are used in order to replenish material that has been used in each of the hospital's wards. Minimum and maximum inventory levels are set for products held at the central inventory warehouse, and items that are stored within each of the wards are managed by the nurses assigned to the wards. In most cases, nurses determine when to order products by "gut feel" and through experience with the specific items. As expected, this type of inventory management practice leads to a large amount of excess inventory in most hospitals and a large number of the products may be unavailable at any given time (Rivard-Royer, H., Landry, S., Beaulieu, M. 2002). The primary responsibility for nurses is patient care, and as an extension of this responsibility, they get involved in materials management. A lack of familiarity with basic inventory management techniques causes frequent stock out conditions, because nurses generally order more than they need at any given time to ensure that they never run out of product.

2.1.1 Vendor Managed Inventory

Recently, many hospitals have begun to transition to vendor managed inventory (VMI), which are arrangements to manage the inventory on behalf of the customer. This is a management practice that allows the supplier to position employees within the hospital (Terech 2007). These employees perform all of the purchasing and warehousing of the materials in the central stores area. This arrangement is designed to decrease the amount of unaccounted for inventory that resides in the hospital, thus reducing material costs (Sjoerdsma 1991). In this type of arrangement, the vendor has significant incentive to optimize the supply chain within the hospital through determining optimal ordering quantities and safety stock levels.

There are two main issues that are not improved with the implementation of VMI policy. Firstly, the amount of space that is occupied by non-critical inventory within the hospital is not reduced, and therefore the hospital must maintain a large amount of floor space dedicated to the storage and management of inventory (Harrison 2003). The second aspect of the supply chain that is not significantly impacted is the inventory that is held within each of the units. Hording of inventory by the nurses within each unit is a common practice across nearly all hospitals. This excess inventory is accounted for, but adds to the cost of the hospital's supply chain. In order to resolve these two issues, a system must be introduced that removes all non-critical inventory from hospitals, and delivers necessary items directly to patients.

2.1.2 Automated Point of Use (APU) Systems

The most advanced hospitals are currently using APU systems in order to track some of their medical consumable products and their pharmaceutical products. This type of inventory management system allows the user to log into the system to take an item from stock. Once the user identifies the needed item, the door opens in the location of the item allowing the nurse to take the number of items that they need. The user indicates how many of each item they are taking, and then the inventory levels within the tracking system are automatically updated.

This type of an inventory management system requires that the users, who are generally nurses, accurately input any inventory that they take or replace. Nurses are incentivized to perform these actions accurately because they are identified upon logging on to the machine. From an audit point of view, with less than ten minutes effort, it is generally possible to determine who is responsible for any inventory inaccuracies (Marino 1998). Another incentive to maintain accurate inventory counts is to ensure that proper stock levels are maintained, which in turn help nurses provide the best possible care for their patients.

One drawback to using APU systems is the limited amount of space that is available in the systems relative to the large amount of space hospitals utilize for central inventory. The result of this lack of space is a lower level of safety stock, and the inability to risk pool. This restriction leaves the wards unable to fulfill uncertain demand that can increases at an unexpected rate, even 300% in a 24 hour period (Duclos 1993). Typically, these machines are kept in each of the wards, so in the event that one does run out of inventory, the nurses have the option to go to another ward and attempt to obtain the desired product in another machine. If the inventory level drops below the par level, then an automatic order is sent to the distributer. If the orders are placed prior to midnight, distributors generally have agreements set up that require them to fill the orders the following day.

2.2 Best Practices outside the Healthcare Industry

One of the many challenges that exist in the surgical supply chain is keeping an accurate record of inventory. Once a surgical parts supplier is informed that a set of parts is needed for an upcoming surgery, the set is sent from the supplier's distribution center to the hospital. This is generally done by the large freight services companies such as Federal Express or UPS.

Surgical kits may contain over 100 different parts, of which only 10 are used during the procedure. The remaining parts must then be inventoried and returned to the vendor. Currently the procedure that is carried out in order to determine which parts have been used is manually performed. A worker uses a barcode scanner to scan every box, and the boxes that are not present indicate the parts that have been used for the procedure. This process is error prone, and may take over 20 minutes to complete (Collins 2006).

Despite the inaccurate nature of this task, the procedure assumes that the set of surgical parts in the box at the start of the surgery is complete. If any of the parts were missing prior to the start of surgery, the level of service that the patient receives will be reduced, and the hospital will be charged for the missing part or parts.

An intermediate step between the current status of hospital inventory management and removal of inventory from hospitals is a standardization of bar codes associated with these products. This poses another challenge for the materials management professionals in hospitals since there is a lack of standardized bar codes (Terech 2007).

2.2.1 Warehouse Management Best Practices

Dell has implemented a strategy that allows them to keep less than two hours of inventory on hand at any time. The reason they use this type of strategy is that the components that are used in their computers can lose anywhere from 0.5 to 2.0 percent of their value in one week (Kapuscinski 2004).

Dell has successfully decreased their inventory turnover by implementing offsite warehouses called revolvers. A revolver is a small warehouse that is managed by the companies that supply Dell. Three times a week, the suppliers will visit the warehouse to add stock to the inventory on hand in the revolvers (Kapuscinski 2004). Dell indicates what they would like for target inventory levels to these supplies, and the different vendors are scored against these goals. Several different suppliers of the same substitutable products generally keep their products in the inventory of the revolvers, so it is possible for Dell to switch to another supplier any time they decide their current supplier is not meeting their requirements.

Every two hours, materials management professionals from Dell travel from the manufacturing facility to the revolvers to retrieve the items that will be needed within the next few hours. This type of materials management practice has not been attempted in hospitals. An obvious difficulty of implementing this type of practice in the healthcare industry is the diversity of the products that would have to be packaged within minutes of receiving an order (Lovell 2005).

Useful insight can be obtained from Amazon's warehouse model that allows products of different shapes and sizes to be packaged and shipped within hours of receiving an order. This complicated logistics task is possible with the use of extensive conveyor belts that traverse the length of the warehouse. Under this regime, items are automatically picked from their stocking locations and transferred to the conveyor belts. Once the items have been moved to the belts, they are then moved to a merging site where all of the products for an order are merged, and transferred to the totes. The medical products portion of the healthcare industry is not currently using this method of warehouse management, but this method is used to pick items in warehouses that store drugs, groceries, toys, home wares and apparel (Wang 2006).

2.2.2 RFID Implementation in Surgical Supply Chains

It has been suggested that Radio Frequency Identification (RFID) technology could significantly improve the efficiency and accuracy of surgical supply chains within hospitals. There are no known large scale implementations of RFID within hospitals in the United States, but small scale testing has been going on for nearly a decade.

The small scale testing of RFID has produced promising results (Collins 2006). Suppliers have been able to show an inventory accuracy rate of greater than 99%, and the time to inventory the parts has been reduced by approximately 95%. The greatest difficulty with RFID technology, however, is in the implementation of the new procedures and processes. We will not cover this topic in great detail as there are no large scale implementations in the healthcare industry to study.

2.3 Implementation of Supply Chain Enhancements

The primary function of hospitals is not inventory or supply chain management, and this is possibly what has caused the lag between implementation of supply chain best practices in other industries and in the healthcare industry (Nicholson 2004). Historically, and some continue to operate this way, hospitals would manage their inventory using educated guesses and experience. However, it is critical that hospitals manage the inventory, in central inventory and in the units, in such a way that they do not stock out. Although inventory management has been seen as a secondary priority, a stock out condition can lead to a fatality.

In order to implement materials management changes within the hospital, it is necessary to understand the motivations and incentives of each of the stake holders involved in the change at all levels. A common mistake, when attempting to affect change in a hospital, is to place the ownership on just one or two levels of employees within the organization (Grol 2003). In reality, any planned changes must involve all of the employees that are involved in any aspect of the supply chain, from receiving employees to upper management. Another important aspect to consider when attempting to implement a change are the incentives of each of the individuals involved in the change. There must be sufficient incentive for each of the individuals in the supply chain to alter their current practices and risk taking on a new way of completing each part of the supply chain.

3 Case Studies and Data Collection

In order to probe into the hospital practices, the authors worked closely with HCD, Inc. (HCD), a disguised name of a fortunate 500 medical wholesaler/distributor. HCD has developed several long-term collaborative pharmaceutical and medical/surgical sourcing relationships with hospitals in the United States. HCD provides a vendor managed inventory (VMI) service and stockless inventory arrangement for the pharmaceutical and medical/surgical items they sell. HCD also assists in managing the inpatient pharmacy of these hospitals and installs automatic point of use (APU) systems to manage the supply of medication and medical surgical products. A key objective of implementation of these systems is to enhance the hospital's procurement and logistical supply chain. The relationship between the hospitals and HCD is viewed by both parties as an opportunity to control cost, improve patient safety, and optimize staff time (Hospital Executive 01/23/2008).

3.1 Midwest Public Hospital

MWU is a public local medical teaching center, has a high percentage of indigent patients, and relies heavily on government programs to help cover the financial burden of patients that are unable to pay for their visits. 50% of the patients at MWU are considered indigent, who do not pay for their care, compared to approximately 10% of the patients at other hospitals in the area that are considered indigent; the other 35% of the patients are compensated by Medicare/Medicaid, and 15% are covered through private insurance. MWU partners with HCD on its inpatient pharmacy by instituting a VMI stockless solution coupled with Automated Point of Use (APU) systems and its pharmacy management service. On the outpatient pharmacy side of operations, MWU employs their own staff and HCD serves as a major distributor. On the other hand, MWU is purchasing medical supplies from both the group purchasing organizations (GPOs) and another regional distributor. Some general statistics on MWU can be seen in Table 1.

Number of Beds	200
Inpatient Admissions (2006)	2,923
Total inpatient days (2006)	16,627
Emergency Visits (2006)	31,164
Outpatients (2006)	81,600
Number of Employees	1,034
Inpatient Pharmacy prescriptions (Dec., 2007)	133,000 monthly
Outpatient Pharmacy prescriptions (Dec., 2007)	200,000 monthly
Annual Medical Supplies Demand	$18,263,340

Table 1: 2006 – 2007 MWU Summary Statistics

MWU relies on both manual operation and assistance of the APU for the medication supply chain. One inventory specialist forecasts the demand according to historical experience for the inpatient pharmacy and outpatient pharmacy, respectively, and places the orders with HCD Medications are replenished three times a week plus some emergency deliveries. Medications for the inpatient pharmacy and outpatient pharmacy are manually unpacked and stored in a central warehouse but are physically separated on different shelves. Inpatient medication is then replenished in the APUs throughout the hospital. Outpatient medications are processed in the outpatient pharmacy. Medical supplies are handled manually and replenished to 35 par carts in different units throughout the hospital. All inventories are manually reviewed daily by eyeballing the stock.

3.2 Midwest Private Hospital

MWR started in 1907 and is a private hospital with a prestigious Cancer Center and Heart Hospital. MWR is a customer of HCD's VMI-pharmacy solution coupled with APU systems. HCD distributes other pharmaceutical and medical supplies from other suppliers for MWR as well. Some general statistics on MWR can be seen in Table 2.

Number of Beds	159
Inpatient Admissions (2006)	21,865
Outpatients (2006)	70,200
Inpatient Pharmacy prescriptions (Dec., 2007)	28,000
Operating Rooms	15

Table 2: MWR Summary Statistics

MWR manages its medications in two ways. HCD helps manage about two-thirds of the frequently-used medications while hospital staff manages the rest of the medications. There are 66 APUs located throughout the units within the hospital and medications are replenished in these systems six times a week, Monday through Saturday. The demand of hospital-managed medications is forecasted by an inventory specialist. Most of the orders are placed automatically by an electronic system three times a week by this specialist. A small number of the medication orders are placed by nurses through paper-based or internet-based orders.

Medical supplies are also purchased through GPOs and managed by the materials management department of MWR. All of the hospital-managed items, including one-third of the medications and medical supplies, are stored in a central warehouse and then distributed to over 100 stocking locations throughout the hospital. The daily review process is completed by utilizing hand held barcode scanners. Data from the handheld scanners is then input into the inventory management system manually.

3.3 New England Hospital

NEH is a private, nonprofit group practice teaching hospital. This medical center has an ambulatory care center and an American College of Surgeons verified Level II Trauma Center. This hospital is consistently cited in U.S. News & World Report as one of "America's Best Hospitals", specifically in the area of treating urological diseases. There are several sub specialty areas at NEH that attract doctors and patients from around the world to practice and be cared for. Some general statistics on NEH can be seen in Table

Number of Beds	317
Inpatient Admissions (2007)	20,866
Total inpatient days (2007)	98,758
Emergency Visits (2007)	53,006
Outpatients (2007)	693,648
Number of Employees (Includes FT and PT)	5,127
Inpatient Surgical Cases (2007)	8,335

Table 3: 2006 – 2007 NEH Summary Statistics

NEH has selected to have HCD deliver a vast majority of the medical surgical products that are stocked within the hospital's units and also within NEH's central inventory. NEH has APU systems throughout the hospital that submit orders automatically once the inventory level has dropped below the reorder point. Items that are ordered prior to 9:00pm come from a regional distribution center one hour away and are dropped off at the loading dock of NEH the following morning at approximately 5:30. Most of the orders arrive on unit specific U-boats, which are U shaped carts that can be rolled directly to the units that ordered the inventory. The internal NEH materials management employees are responsible for transporting the materials around the hospital once HCD has dropped off the items at the loading dock. Both NEH and HCD have one senior level manager onsite with the responsibility of supply chain management.

3.4 Interviews with MWU, MWR, and NEH

The purpose of the interviews conducted at MWU, MWR, and NEH was to gain a better understanding of the problems facing hospitals that have different patient mixes[1]. The three hospitals were purposefully selected in order to gain an understanding of the variation of problems that face hospitals whose patients are largely indigent people, as opposed to other hospitals whose clientele are generally covered by their own insurance. MWU is a public hospital with a high percentage of indigent patients, MWR is a private hospital with a much lower percentage of indigent patients, and NEH is a not for profit hospital with many specialty physicians.

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[1] Patient mixes will be discussed in more detail in section 4.3.2

Individuals interviewed at the hospitals included pharmacists, materials management directors, materials management staff, nurses and IT engineers. At the distributor sites, we conducted interviews with employees in the integrated service department and distribution center staff. Interviews were conducted in open and semi-open formats. These formats were selected due to the author's limited knowledge related to hospital supply chains. These methods enabled the authors to extract as much information as possible in the time available to them. Many of the interviews were conducted in-situ and the authors were participant observers during the time of the interviews.

3.5 Data from NEH

The data provided by NEH came from 107 APU systems throughout the hospital. The data represent 2,483 Medical/Surgical items (Item-SKU's), and 7,518 Station-SKU's (Table 4). Station-SKU's represent unique APU system, Item-SKU combinations. For example, two identical items may be located in different APU systems, and therefore they will be identified as different Station-SKU's.

NEH Data Points	
Data Points	**Quantity**
Item – SKU's	2,483
Station – SKU's	7,518
Station-SKU's with Inventory/Demand/Transactions	97,734
Item-SKU's with Inventory/Demand/Transactions	32,279

Table 4: NEH Data Points

Prior to creating the models, the data were cleaned to prevent inaccuracies from impacting the results. Some of the data that was provided was not used, because of a problem that exists at MWU, MWR and NEH. Personnel in all three of these hospitals indicated that a lack of standardized barcodes has led to duplicate items in the hospital. This duplication occurs when two different hospital specific item IDs are given to one product, or similarly, two different item names are given to one product.

In order to minimize the amount of data cleaning necessary to create an accurate model, a three month timeframe of transaction data was selected. The three month timeframe, from October 1st, 2007 through December 31st, 2007 was chosen because this three month period minimizes the number of items that were added or removed from the inventory management system, and the unit cost of the items has not changed during this time period. Another advantage of using data from one quarter is that the inventory policy of the hospital has not changed during this time period.

Once the data was sufficiently cleaned, it was put into a spreadsheet. The rows of the spreadsheet represented characteristics of one item in one week from one APU station (see Appendix 1). The columns of the spreadsheet were broken up in the following manner:

- Transaction Time – Indicates the start date and end date that the transaction took place
- Item ID – Indicates the identification number the hospital has given the item
- Point Of Use System Name – Indicates the name the hospital has given the system

- Item Name – Indicates the name the hospital has given the item
- Unit Cost – Indicates the hospital's cost for this item
- Number of Picks – Indicates the number of times a hospital employee has gone to this specific APU system and taken this item within one week. This parameter is independent of the number of items that were taken during each of the picks.
- Volume Per Pick – Indicates the average number of items taken per pick during one week
- Reorder Point – Indicates the inventory level at which the system will automatically place an order for the item
- Order up to Point – Order up to Point minus the Reorder Point equals the order quantity
- Average Inventory – Indicates the average number of this specific item that are in the system throughout the week
- Days Without Inventory – Indicates the number of days in a week that the system is in a stock out condition for the specific item
- Stockout Event – Indicates the number of times a hospital employee has attempted to retrieve this item within one week, but the employee was unable to obtain the item because the system did not have this item in stock

4 Segmentation

In simple terms, segmentation is to discriminate items into several groups. The homogeneity of the segmented groups allow the standardization of supply chain techniques and reduce the processing costs. Segmentation also helps map the demand and supply channel in a systematic way and lays the foundation for further supply chain optimization.

In this chapter, the segmentation concept as applied in the supply chain domain will be first introduced, followed by a review of the successful segmentation approach of various industries will then be reviewed. Indeed, the complexity and sensitiveness of hospitals would not allow application of these successful approaches directly. To this end, we will discuss potential segmentation variables to facilitate applicability to hospitals. Furthermore, segmentation approach for every hospital may vary and leverage different variables. The case study of NEH's medical/surgical supply chains will demonstrate the practical use of our proposed integrated segmentation solution.

4.1 Segmentation in Supply Chain Management

Segmentation has made important contribution to the efficiency of supply chains in various industries. Since there is no one-size-fits-all supply chain. In today's complex environment, most firms or business units operate multiple supply chains. As expected, different supply chains require different techniques for each aspect of supply chain management, such as demand planning, procurement, inventory management, warehousing, transportation, and customer service.

While segmentation discriminates the heterogeneous characteristics among groups and creates homogeneity within each group, the value of segmentation emerges from the standardization of each group. With standardization, the system efficiency can be improved and the benefit of risk-pooling among homogeneous items may emerge. Successful segmentation serves as the foundation for taking the next-step in a company's supply chain strategy. The problems of each segmented group in this hospital supply chain will be uncovered and contrasted throughout this section.

In the hospital industry, the inefficiencies of pharmacy inventory management account for anywhere between 17% and 35% of a hospital's total revenue (Nathan and Trinkus 1996, Danas and Ketikidis, 2000). A segmentation based approach to improving the pharmacy inventory management is discovered by Danas et al. (2006). Another researcher (DeScioli 2005), has also argued that current, aggregate and "one-size-fits-all," strategies are inappropriate and discussed the importance of adding more attributes to the product master files to enable further supply chain enhancements.

4.2 Segmentation Practices in Other Industries

Segmentation in supply chain management can be product-oriented, customer-oriented, or supplier-oriented. Recently, developments in this field are moving the industry toward a combination of these three dimensions. Because the hospital industry is moving toward sourcing from one supplier or distributor, product-oriented and customer-oriented segmentation will be discussed in this section.

The healthcare industry is a service-oriented industry. Customer service and satisfaction are an important pursuit within the entire industry. Therefore, segmentation by markets or customers is a vital step toward developing the appropriate supply chain strategy for the target customer. Svensson (2000) believes that there is a necessity for supply chain integration. He also believes that such integration must be undertaken from the end customer perspective. Childerhouse and Towill (2006) presented four levels of market-oriented supply chains: 1) individual consumer pull, where product details are specified by the end customer; 2) aggregate market pull, where marketplace demand 'pulls' specific products; 3) market-orientated push, where value stream inventories reflect market research; and 4) product orientated push, where supply is determined by value stream inventories.

Thirteen value streams from eight different companies have been classified using a four by four matrix, which is composed of these four levels of market-oriented supply chains versus four stages of organizational integration. The products of these eight companies, separated into standard products and customized products, include computers, carpets, bikes, building sector electrical machines, precision mechanized products and lighting products.

Storbacka (1997) analyzed the customer-oriented supply chains of two Nordic retail banks, from which he proposed that the classification variables in these cases were volume, profitability, relationship volume, and relationship profitability. Relationship volume and relationship profitability are defined as historical records in terms of volumes and historical records in terms of profitability, respectively. These customer oriented supply chains may be applied to the hospital industry, meaning that the historical medical records of patients may be another potential dimension that can be used for segmentation.

Product-oriented view is the easiest way to start segmenting a supply chain to start segmenting. Fisher (1997) proposed that different demand patterns of products should lead to different kinds of supply chains. Under his categorization by *product innovation, demand volume stability, product life cycle duration*, and *make-to-order lead time*, the products could be separated into two categories as functional products and innovative products. For functional products, an efficient supply chain is desirable to reduce the supply chain cost. With the aid of Electronic Data Interchange (EDI) links with its retailers, Campbell Soup can better forecast demand, which enables them to cut inventories and also to reduce the replenishment lead time. For innovative products, a responsive supply chain could help shorten lead times as well as to react to forced markdowns, stock-outs, and obsolete inventory.

National Bicycle, a Japanese bicycle manufacturer, runs a pure make-to-order business for high profit margin, customized bicycles. The customer first orders at licensed bicycle retailers. The manufacturer then receives the electronic order, makes the bicycle and delivers the bicycle to the customer within two weeks. World Company, a leading Japanese apparel manufacturer, produces its basic styles in low-cost Chinese plants but keeps production of high-fashion styles in Japan, where the advantage of being able to respond quickly to emerging fashion trends more than offsets the disadvantage of high labor costs. Sport Obermeyer, based in Aspen Colorado, designs and manufactures fashion skiwear and distributes this apparel to 800 specialty retailers. An annual conference with the 25 largest retailers half a year ahead of the introduction of new product helps Sport Obermeyer reduce the uncertainty of demand, which allows them to further adjust their production volume and variety (Byrnes 2005). Brynes (2005) also proposed that having more than one supply chain may be just what you need to meet the needs of your best customers.

Christopher and Towill (2002) found out that a taxonomic approach with three dimensions, leading to eight possible configurations, could help the selection of the right supply chain strategy. Three key dimensions that can be used to determine how products are segmented are product characteristics, demand characteristics, and replenishment lead-time. In order to address different segmentation demands, agile supply chain and lean supply chain practices should align with the pipeline design. Griffin Manufacturing Company in the apparel industry was analyzed and three pipelines were proposed based on a match of commonality of specialty products with the volatility of demand: 1) innovative agile pipeline in US; 2) top-up agile pipeline in US; and 3) high volume lean pipeline in Honduras.

Childerhouse et al. (2002) suggested five key variables that influence decision making in the design of pipeline to market needs: *duration of life cycle, time window for delivery, volume, variety,* and *variability*. A case study of a major UK lighting manufacturer was analyzed and four clusters were presented: make-to-order, make-to-stock, postponed assembly process, and design-and-build. After having conducted the product segmentations, the lighting company matched the products to each of the four appropriate clusters and there was a resultant reduction in product development time of 75%; manufacturing cost reduction of up to 27%; and up to 95% reduction in delivery lead times.

There are four groups of variables that could influence supply chain segmentation: *product, market, source,* and *geographic and commercial environment*. By comparing the effect of the variables driving each subset of supply chain costs, Lovell et al. (2005) concluded that *throughput, demand variability*, and *product value density* are the three key variables. The product value density denotes the product value divided by the chargeable transportation unit, either by volume or weight or a combination of both. Two supply chain strategies were adapted and analyzed: centralization of inventory and a faster transportation mode. The benefits of centralization include 1) removal of replenishment inventories between different echelons; and 2) risk pooling of safety stock. The reduction in warehouse and trucking costs actually offset the increase in local delivery costs giving a net saving even before inventory reductions were taken into consideration. A case study in which the two strategies above were implemented, Sony

Broadcast and Professional Europe, resulted in an overall supply chain cost reduction of 25 percent from costs incurred in 1997.

Inventory management of spare parts inventory for production machines was found to have similarities with the management of pharmaceutical stock within the hospital pharmacy. Danas et al. (2006) proposed a criticality analysis based on logic trees to segment the medication inventory. In a Greek hospital case, the criticality was determined via dozens of interviews with the doctors, pharmacists, and nurses. The details of the considered variables are listed in table 5. According to the logic tree, every drug could be assigned to one of the four categories and setup with different inventory policies, namely *hospital safety stock, virtual pharmacy inventory systems (VPIS), clinic safety stock,* and *JIT with no safety stock*. The VPIS system is an information system within a hospital that virtually pools all of the inventory within every pharmacy inside the hospital.

Sequence	Variable categories	Variables
1	Patient treatment criticality	o Danger of loss of life o Quality of treatment o Replacement with other treatments
2	Supply characteristics	o Lead time o Number of potential suppliers o Replacement
3	Inventory problems	o Price o Space required o Special inventory condition o Expiry date
4	Usage rate	o Over stocking o Demand frequency

Source: Danas et al. (2006)

Table 5: Segmentation Variables of Pharmaceutical Supply Chain

The segmentation variables and responsive strategies above are summarized in table 6.

Authors	Segmentation Variables	Industry/company	Responsive strategy
Storbacka (1997)	o Volume o Profitability o Relationship volume o Relationship profitability	o Two retail banks in Nordic countries	NA
Fisher (1997)	o Product innovation o Demand volume stability o Product life cycle duration o Make-to-order lead time o Product variety o End-of-sale mark down	o Sport Obermeyer o Campbell Soup o National Bicycle	o Functional product-oriented o Innovative product-oriented
Christopher (2002)	o Product characteristics o Demand characteristics o Replenishment lead-time	o Griffin Manufacturing Company in the apparel industry	o Lean supply chain o Agile supply chain
Childerhouse et al. (2002)	o Duration of life cycle o Time window for delivery o Volume o Variety o Variability	o UK lighting company	o Make-to-order o Make-to-stock o Postponed assembly process o Design-and-build
Lovell (2005)	o Throughput o Demand variability o Product value density	o Sony Broadcast and Professional Europe (Broadcast systems, Digital video systems, and Security systems)	o Centralized inventory o Faster transportation mode
Danas et al. (2006)	o Patient Treatment criticality Supply characteristics o Inventory problems o Usage rate	o Pharmaceutical supply chain in a Greek hospital	o Hospital safety stock o Virtual pharmacy inventory systems o Clinic safety stock, JIT with no safety stock

Table 6: Segmentation of demand/supply chains within the literature

4.3 Current Situation in Hospitals

This section discusses the unique nature of current hospital supply chains. The characteristics of pharmaceutical supply chains and medical/surgical supply chains will be discussed to illustrate their peculiarities relative to supply chains in other industries. Furthermore, even among different hospitals, there are significantly different supply chain needs, which require supply chains that have been custom built for the specific hospital. The combined characteristics indicate the challenges for creating a universal system to segment hospital supply chains.

4.3.1 Characteristics of Hospital Supply Chains

In the hospital, criticality is an important consideration both on the patient-side and item-side. On the one hand, every patient is equally critical. The stock-out cost may be very large because sometimes a stock-out could be life-threatening. On the other hand, some items themselves are critical to certain operations; some items themselves are not critical but necessary to a process. For example, if one item is missing from an examination kit, the procedure could not be performed, so the item is critical to the procedure and should be considered as a critical part of a complete package. These criticalities are the first priority when dealing with hospital supply chains.

Low demand is another issue with hospital supply chains. Unlike the manufacturing industry and retailers, the majority of SKUs (Store Keeping Units) are low demand. At NEH, more than half of the SKUs have a demand of less than one unit per day. Some SKUs do not even have demand over periods of months, but the hospitals have to keep the inventory for emergency situations. Further analysis of this type of demand will be presented in the following sections.

The security of the supply chain is important as well. In particular, some narcotics and controlled substances require specific treatment throughout the distribution process. Sometimes it is necessary to keep the supply chains of these items separate from other items. In addition, there are some items managed in both the medication and medical/surgical supply chains that have extremely high unit prices, while there are many more items that have a much lower unit cost. The difference between the first quartile and the third quartile may be several thousand dollars. This discrepancy raises the issue of security of the hospital supply chains, and also implies that there is a complexity that must be understood in order to efficiently manage these two different categories of items.

Another issue that adds complexity to the management of hospital supply chains is that the information indicating the demand and quantity on hand for many products may not be correct or reliable. One of many reasons for such inaccuracies is the return of an item that has been borrowed from another ward. These types of issues result in a unique supply chain management environment in hospitals. For example, when nurses are attempting to help save a life in the emergency room, the nurse may grab a bunch of items at one time instead of picking the items one by one and documenting each action. Once the emergency situation has been stabilized, there may be unused items, and in many cases these items are not entered back into the system accurately. These actions increase the difficulty of capturing a true representation of demand for each product, and therefore increase the complexity of planning for the demand because inaccurate data cannot be used to create accurate forecasts.

Another factor that adds complexity to the supply chain is that, the hospitals staff involved in the processes are generally not trained to manage supply chains. The technicians, nurses, and pharmacists may be involved in demand forecasting, ordering, or inventory management. They may not have a clear forecasting method, and instead order according to their experiences and historical knowledge. In order to avoid stock-out events, these individuals tend to order more than necessary and sometimes store items in personal hiding places. In some hospitals, such as MWU, there is only one staff responsible for forecasting demand and ordering. This individual has been in the same position for many years and will not be able to be replaced without spending a significant amount of time training another employee. If this individual unexpectedly leaves the hospital, there will be disruptions to the hospital's supply chain.

When dealing with hospital supply chains, these factors indeed increase the complexity of and sensitivity of the system. The unique hospital environment makes it difficult to find a typical model that has been successful in other industries to directly apply in the hospitals. Hospital supply chains require special considerations to address these issues and to develop a dedicated approach to manage these complexities.

4.3.2 Uniqueness and Peculiarity of Individual Hospitals

Even among hospitals, there are generally many differences in the products needed and the supply chain design used to support the demand. Reimbursement schemes are a key driver of hospitals' behaviors. The source of funds, ranging from government budgets to insurance companies to Medicare, tends to restrict choices and ordering volume. Some hospitals will adapt themselves to fit certain regulations and strive for the subsidies. The Group Purchasing Organization (GPO) also divides hospitals into two groups with different kinds of ordering patterns.

Case mixes of patients also differentiates hospitals. For example, MWU diagnoses nearly ten percent of their patients as having mental disorders. In contrast, mental disorders are not in the top nine diagnoses at MWR and NEH. This indicates that the quantity and variety of medications and medical supplies be needed at each of the hospitals is different. Table 7 shows that there are significant differences in case mix between MWR and the other two hospitals the authors researched. Only the top nine diagnoses at each hospital are displayed in the table. Pediatric hospitals and general hospitals require different medications and even different sizes of the same item. The specialization of each hospital also leads to a specific arrangement of wards; for example, cancer-research-oriented wards will order many more cancer-related drugs and will show a different demand pattern from other hospitals.

MWU		MWR		NEH	
Disease or Disorder	**Percent of Diagnoses**	**Disease or Disorder**	**Percent of Diagnoses**	**Disease or Disorder**	**Percent of Diagnoses**
Mental	9.17%	Circulatory System	9.24%	Circulatory System	11.62%
Respiratory System	2.09%	Respiratory System	5.54%	Musculoskeletal System & Conn Tissue	4.99%
Circulatory System	1.78%	Musculoskeletal System & Conn Tissue	4.16%	Respiratory System	4.53%
Endocrine Nutritional & Metabolic	1.03%	Digestive System	4.01%	Digestive System	4.18%
Alcohol/Drug Use & Induced Organic Mental Disorders	0.89%	Nervous System	2.64%	Nervous System	3.29%
Digestive System	0.79%	Kidney & Urinary Tract	2.41%	Kidney & Urinary Tract	3.25%
Injuries Poisonings & Toxic Effects of Drugs	0.48%	Endocrine Nutritional & Metabolic	1.39%	Hepatobiliary System & Pancreas	1.28%
Musculoskeletal System & Conn Tissue	0.48%	Infectious & Parasitic Diseases	1.02%	Infectious & Parasitic Diseases	1.04%
Kidney & Urinary Tract	0.44%	Hepatobiliary System & Pancreas	0.82%	Endocrine Nutritional & Metabolic	0.92%

Table 7: Patient Mix with Respect to The Percent of Diagnoses That Fall Into Different Categories

The economic scales, in terms of number of beds, inpatient admissions, emergency visits, and outpatients, also reflect on different scales of demand and change organizational behaviors inside hospitals. In addition, a large number of hospitals have managed and will continue to manage their supply chains based on empirical methods for years. The self-developed systems partially determine the different natures of each hospital.

In summary, it is not only difficult for hospitals to apply a successful model from other industries, but also difficult to develop a universal system suitable for every hospital. A systematic approach to tailor the supply chain to different segmentation variables is a better strategy than creating one fixed model for each specific kind of hospital.

4.4 Potential Segmentation Variables

Based on the variety among hospitals, it is difficult to develop a universal segmentation model to apply to every hospital. In other words, a segmentation approach with the flexibility to tailor the supply chain to each hospital would be a more feasible way to attack the complexities of hospital supply chains. A list of segmentation variables suitable for hospital supply chains, combined with a systematic screening process to pick out only a few variables for each hospital, is a more efficient way to address the peculiarities of each hospital and to fulfill its special requirements and demands.

Lovell et al. (2005) have summarized a great number of variables for segmentation and separated these variables into four categories: product, market, source, and geographic and commercial environment. Lovell et al. (2005) addressed the variables more from the supplier's perspective rather than the customer's perspective. From the customer's perspective, Danas et al. (2006) adopted variables to segment the medications and set up classification criterion for the hospital pharmacy. All potential segmentation variables are summarized in table 8 with our assessment of their applicability indicated in the third column.

In the product category, *Unit Price* is the fundamental variable when considering the inventory holding cost, which is a large financial burden to the wholesaler/distributor and also for many hospitals. *Physical Size and Weight* and *Handling Characteristics* are relevant to the distribution cost and hospital storage space; these variables also affect the material handling time and costs for all medical staff. *Shelf Life (Expiry Date)* is an important consideration for all the medication and some of the medical/surgical items. When designing the supply chain policies that should be reviewed every couple years, *Life Cycle* may be less relevant, and, *Variety within Product Group* and *Product Type* may not even be taken into consideration.

Market segment or customer category is very important for the hospital industry. *Criticality* and *Expected Service Level* are two of the most vital variable that will be discussed in the next section. *Demand Location/Dispersion* represents how the points of use for certain items are stocked in the wards throughout the hospital. *Demand Level*, *Demand Frequency* and *Demand Variability* are necessary variables to describe the demand patterns of any of the items.

When most American hospitals join GPOs, the hospital's source of items becomes less relevant since these hospitals have contracted one or several distributors. The *Number of Potential Suppliers* and *Economies of Scale* are already limited, while *Production Flexibility* and *Limitations on Raw Material* do not even need to be considered. *Lead-Time* is not an issue because most of the distributors replenish everyday or every two days; few hospitals even require more than one delivery per day. Although some medications are patented and irreplaceable; the nurses can usually find most items in other parts of hospital. Hence *Replacement* will not be taken into account at this stage.

Hospitals are mostly served by regional distributors, so the geographic factors or commercial environment are not relevant. All of the above-mentioned variables are listed in table 8 and the applicability to hospitals is also described in table 8. Segmentation discussed in the following sections will only be based on these "High Applicability" variables.

Category	Variables	Applicability for hospital
Product	o **Unit price**	High
	o **Handling characteristics**	High
	o **Physical size** and weight	High
	o **Shelf life** (Expiry date)	High
	o Life cycle	Medium
	o Variety within product group	Low
	o Product type: functional or innovative	Low
Market/customer	o **Criticality**	High
	o **Demand location/dispersion**	High
	o **Demand level**	High
	o **Demand frequency (Number of transactions)**	High
	o **Demand variability**	High
	o **Expected service level**	High
Source	o Limitations on raw material	Low
	o Number of potential suppliers	Medium
	o Replacement	Medium
	o Production flexibility	Low
	o Lead-time	Medium
	o Economies of scale	Low
Geographic and commercial environment	o Existing infra-structure	Low
	o Transport mode availability	Low
	o Customs/duties/trade areas	Low
	o Legislation	

*Partial information are cited from Danas et al. (2006) and Lovell et al. (2005)

Table 8: Summary of Potential Segmentation Variables

4.5 Segmentation and Supply Chain Strategy

In the previous section, nine potential variables for hospital supply chains were selected: *Criticality, Unit Price, Demand Level, Demand Frequency, Demand Variability, Demand Dispersion, Handling Characteristics, Physical Size and Weight,* and *Shelf Life (Expiry Date)*. In this section, the usefulness of these variables will be discussed. If a segmentation variable is determined to be suitable for developing a hospital supply chain management strategy around it, a corresponding supply chain strategy or a recommendation for the hospital will be presented. Less-suitable variables will not be used in this stage of segmentation decision-making but they may be useful for more detailed hospital supply chain designs. The significance of each variable may vary from one hospital to another. Management within each individual hospital should determine how many variables should be considered when segmenting the supply chain and also the significance of each individual segmentation variable.

The discussions in sections 3.5.1 through 3.5.10 are based on interviews with staff at BLH, MWH, and NEH during January 2008 and February 2008, and medical/surgical data from NEH. The interviewees include the nurses, pharmacists, inventory technicians, and materials management staff. These data of medical/surgical items were collected from October 1, 2007 through December 31, 2007 at NEH. The data are composed of a weekly average of a 2,283 SKUs.

4.5.1 Criticality

Different from other industries, criticality is very clearly defined in the hospital setting and is the most important factor that should be considered in a supply chain. However, conversations with the medical staff at all three hospitals visited, revealed that none of the three hospitals made this distinction in designing inventory policy and establishing expected service levels; rather all products are treated equally.

Criticality can be expressed with three attributes: *Danger of Loss of Life, Quality of Treatment*, and *Replacement with Other Treatments* (Danas et al. 2006). The weights and the grading of these three attributes should be obtained via interviews with medical staff at each individual hospital. Among the hospitals included in this research, the weights are different from one hospital to another. This observation coincides with the need for customized supply chain policies for each hospital. Similarly, the expected service level can be customized to each ward and hospital. Stock-outs for high criticality items should either be measured separately or weighted differently in an aggregate analysis.

In a sophisticated, segmented hospital supply chain, a ward-oriented (customer-oriented) approach would be more practical than a product-oriented approach. While most items are treated with different distribution and inventory policies, some of the wards are extremely critical and therefore should own their own safety stock for emergency use. Examples of areas that would benefit from holding their own safety stock are emergency rooms (ER), operating rooms (OR), and some intensive care units (ICU). The composition of wards varies from one hospital to another. The geographical locations of wards will vary as well. These variances will affect the allocation of safety stock and should be considered separately when designing the supply chain policy for each hospital.

4.5.2 Unit Price

Unit price is defined as the value of a drug or medical/surgical item per package. However, the packaging method may vary for items that have different uses and may be used in different frequencies among hospitals. Therefore, packages that have different quantities of the same item are treated as different Item-SKUs.

Figure 1 shows a total of 2,483 SKUs of medical/surgical items on the plot of average weekly demand versus the unit price. While segmenting the items both by *unit price* and by *demand*, it can be clearly observed that there are very few items in quadrant 1 and relatively small numbers in quadrant 4. The items in quadrant 4 have high unit prices with low demand. Their unit-values are above US $100 but weekly demand is less than 14 units. Though the number of units may not be high, their aggregate values are substantial. High unit value items cause much of the high inventory holding costs experienced by stock holders in the supply chain. The stock holders may be either the hospital or in a VMI system it will be the vendor. This inventory may be a heavy financial burden and may also represent a great opportunity cost. In order to eliminate this inventory in the supply chain, a flexible supply chain, responsive to orders could resolve the problem.

Make-to-order or assemble-to-order is a responsive supply chain strategy used to minimize the impact of uncertainty (Lewis and Slack, 2003). *Agile supply chains* could further decrease the supply chain cost. High value electronics are a good analogy for this segment, such as SONY broadcast systems and digital video systems products (Lovell et al., 2005). While risk and returns are linked, the company should first accept that there is an uncertainty to the demand of its products instead of blaming errors in the forecast as a cause for the uncertainty. In the hospital setting, uncertainty could be minimized by decreasing lead times and increasing the supply chain's flexibility so that it can pack to order or at least pack the product at a time closer to when the demand materializes and can be accurately captured. Faster transportation and centralized inventory could also help to lower the inventory level (Lovell et al., 2005). In the hospital supply chain, the distributor could apply concepts from *assemble-to-order* to *pack-to-order* and implement *faster transportation* or more *frequent distributions* to achieve increased service levels. Centralized inventory could then reduce inventory levels and create value from cost-savings. The IT infrastructure in the hospital enables the visibility of the entire supply chain and provides fundamentals for further improvement.

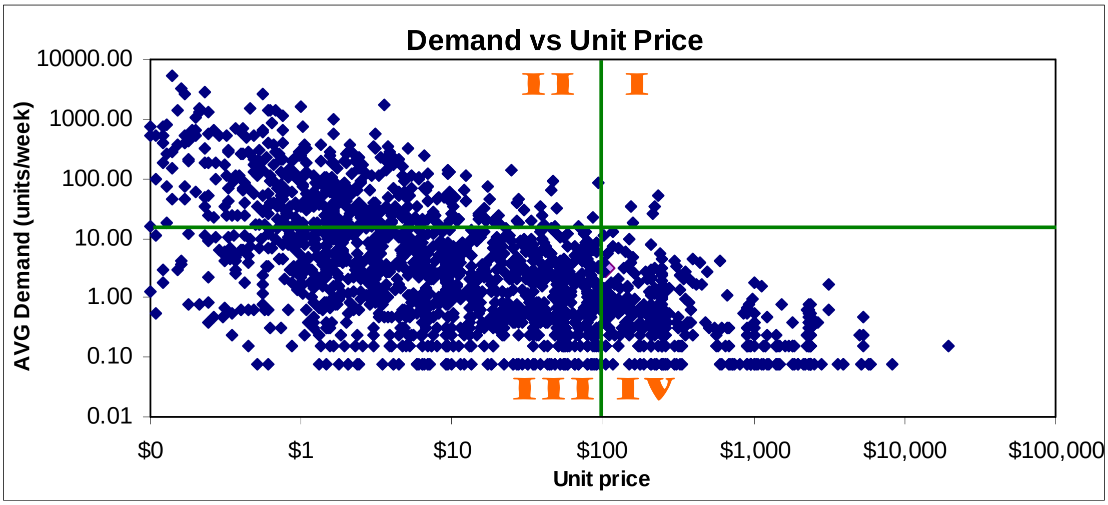


Figure 1: Demand vs Unit Price

4.5.3 Demand Level

Demand level is a classic and important factor used to describe the flow of goods in the supply chain system. When designing the supply chain, the total demand level determines the necessary capacity of the pipeline system, including the warehouse (storage space), distribution volume, distribution frequency, modes of transportation, and picking/handling capacity. Demand level is often described in units per duration, such as units per week.

In the hospital, medication demand and medical/surgical-item demand are relatively slow-moving. Figure 1 shows the distribution of demand level. The weekly demands of these items vary drastically, from 5,200 units per week to zero demand during the observation period. Specifically, some of the items have zero-demand but the hospitals must still hold safety stock in order to make sure they are ready for emergency situations. In figure 1, the high-demand items lie only in quadrant 2. The high-demand items are all relatively low value.

Instead of treating these items with a one-size-fits-all policy, it is more efficient to segment the low cost items from quadrant 3 and quadrant 4. A *lean supply chain* will be a good solution here. The lean supply chain is a commonly used supply chain management practice in manufacturing and commodity supply chains.

Where demand is expectedly stable, periodic replenishments with fragmented inventory could be a feasible implementation of a lean strategy in hospitals. Though there might be an induced increase of storage space needed in the hospital, the savings from staff effort and transportation costs should be able to offset the increase in the cost of storage space. On the other hand, by setting up a cross-functional supplier association, it would be necessary to enable supplier-customer coordination and development. It would also be necessary to raise awareness among players involved in on-going benchmarking where change is required. Some of the VMI parameters that would need to be benchmarked are due date performance, and stabilized scheduling (Taylor & Brunt 2001).

Some of these practices have already been implemented in the healthcare industry. Along the supply chain, the VMI system allows the distributors to have visibility into the supply chain and put a great deal of effort into coordination of the supply chain. EDI systems also increase visibility and improve ordering efficiency. However, supply chains in hospitals are the last-mile of the healthcare supply chain. The order starts from the doctor’s prescription, while the end user in the supply chain is the patient. The coordination process from the distributor to the material management staff to the nurse is necessary and crucial.

4.5.4 Demand Frequency

Demand frequency is another important factor that may be used to capture the demand pattern of medication and medical/surgical items and is also a good variable for segmentation. Researchers have found that spare part demand patterns for production machines in large industrial plants are similar to the case of the hospital pharmacy (Danas et al. 2006). DeScioli (2005) also noted that the hospital industry should be focusing on spare parts industries for developing its inventory policies and simulated the demand of medical/surgical items by using Croston’s (1972) intermittent demand method. Demand frequency and demand size are two elements used to describe an inventory pattern where there are many periods with no demand and a few periods with either small or large demand. In this section, the demand frequency is used to characterize the product demand.

Demand frequency is the number of transactions over a unit period. A transaction is defined as the action of a nurse or a pharmacist going to the point of use system and attempting to access the items he/she wants, even if the items are not in stock. Figure 2 shows the average weekly number of transactions versus the total average weekly demand of each item. It is clear that there is a group of items with high demand frequencies and with a high demand level. Among these items, the average demand frequencies are above 140 units per week, namely 20 units per day. Relative to other slow-moving items, these items are moving much faster in the hospital. The inventory behaviors of these items are similar to *fast moving consumer goods* and can be compared to make an analogy to develop a specific supply chain strategy.

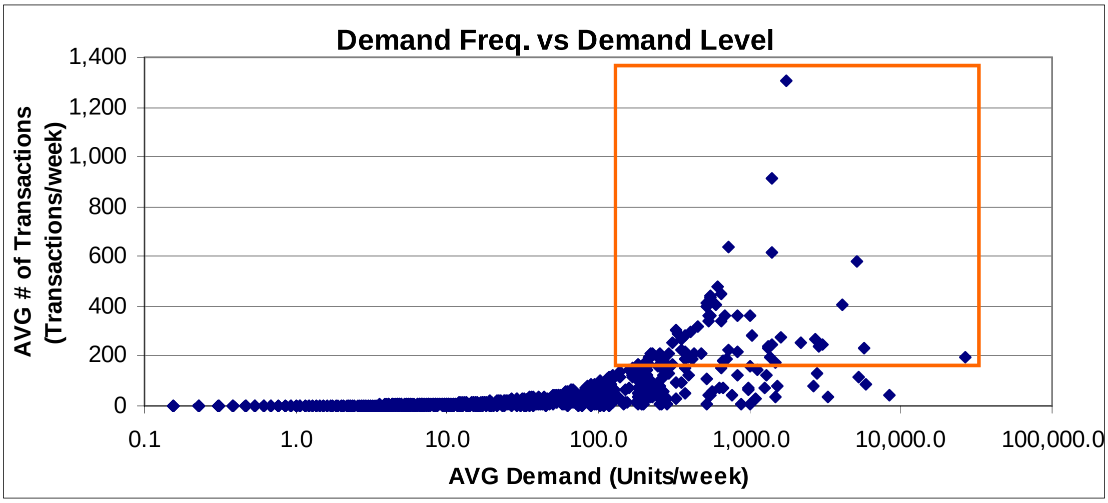
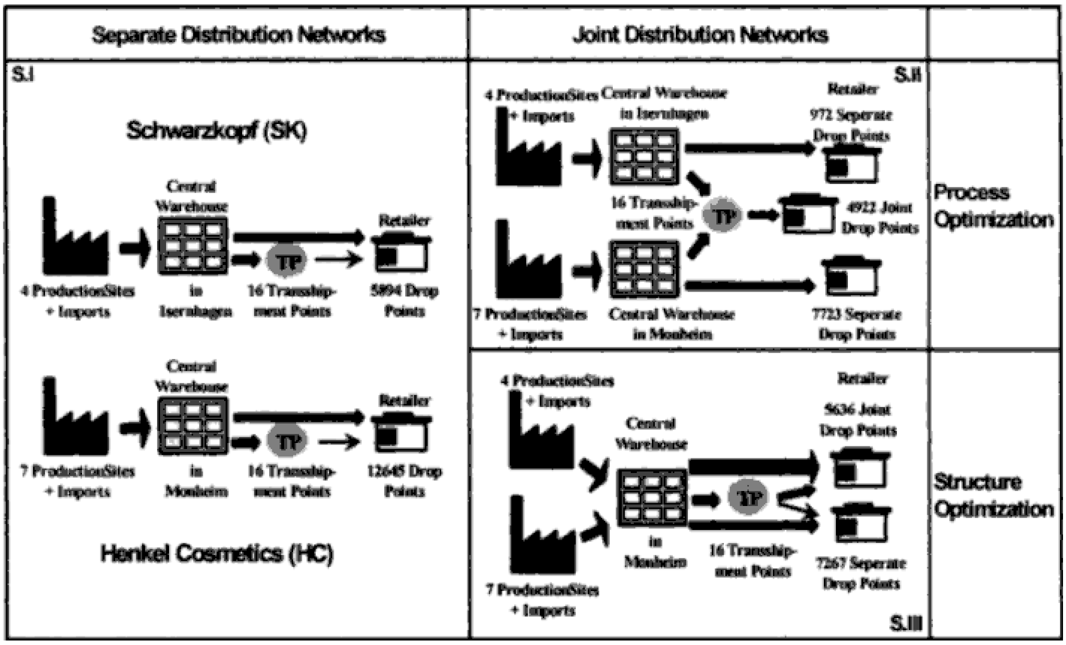


Figure 2: Demand Frequency vs Demand Level

The improvement of supply chains in the fast-moving consumer goods industry could originate from the concept of horizontal cooperation, as opposed to vertical cooperation, such as a Just-In-Time strategy used between suppliers and manufacturers in the automotive industry (Seuring et al.2002). The concept of horizontal cooperation leads to the collaboration of partners on the same level of value chains but from different sectors, or even collaboration among competitors. By implementing both process optimization and structure optimization, the horizontal cooperation can be realized as a joint distribution network, as opposed to a separate distribution network of different production sites and different drop points.

The “transshipment point” (TP) is a good example of a strategy used to reduce the complexity of networks and gain mutual cost savings. The illustration of the joint distribution network is shown in figure 3. In the hospital industry, hospitals could share the distribution networks and warehouses. For example, except for necessary safety stock in several wards (described in section 3.5.1), hospitals could try to use joint network and joint inventories to reduce supply chain costs. However, the concept of joint distribution networks does not imply that several hospitals should merge and use only one supplier or distributor. Instead, the concept of TP allows hospitals to maintain their old suppliers/distributors for the shipment to the TP. The distribution from TP to each hospital could then be open for bids or use other alternatives. Further discussion will be presented in chapter 4.



Source: Seuring et al.2002

Figure 3: Joint Distribution Networks (Seuring et al.2002)

4.5.5 Demand Variability

Demand variability described here is defined by the coefficient of variation for demand frequency. In the hospital industry, demand frequency better demonstrates the demand pattern of medication and medical/surgical items. Therefore, demand frequency is used to capture the variability of the demand. The coefficient of variation is defined as the standard deviation of the number of transactions divided by the average number of transactions. Figure 4 indicates that the items with high demand-variability have low demand frequency. The trend is made clear by the linear cluster that is displayed with only a few outliers. In practical use, these outliers are worthy of further research and a more in depth understanding could be useful to improve the supply chain policy, but these outliers are not significant for segmentation purposes. The plotted data do not show significant peculiarities and therefore, for our purposes, the variability may not be a good variable to consider for segmentation.

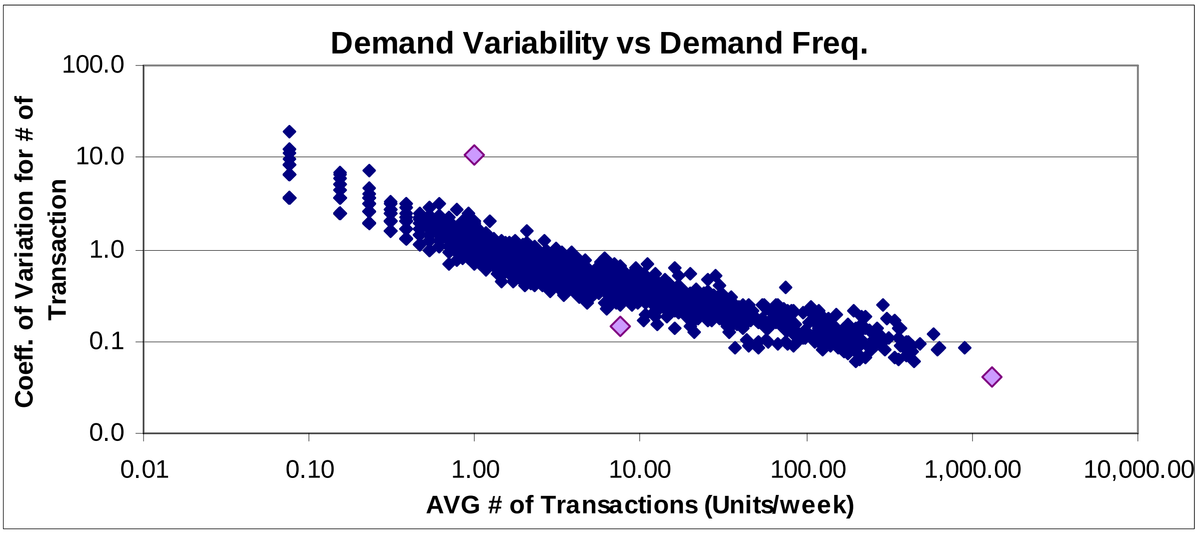


Figure 4: Demand Frequency vs Demand Variability of Transactions

4.5.6 Demand Dispersion

Demand dispersion is interpreted as the number of locations where demand occurs; the larger the number of locations, the higher the demand dispersion. In a hospital, some of the common medication or medical/surgical items are widely used in many wards of the hospital, while some other items are only intensively used in a few specific wards. Whether the demand is fragmented or not can also affect the decision-making process in the supply chain network.

There are 107 automated point-of-use stations (APU) in NEH. Most of them are subject to one specific ward or one unit of a ward. The number of stations where demand occurred can be analogized to the number of locations where the true demand occurred in the ward. When the number of stations increased, the implication was that the demand became more dispersed and fragmented across the hospital.

Figure 5 displays the demand dispersion versus the frequency of use for each item. The item which has only been used at one station is shown in the X-axis equivalent to one; the average demand frequencies range from 0.08 unit per week to 17 units per week. The average demand frequency of each number of stations used is shown as the red dotted line. When the number of stations (demand dispersion) increases, the average demand frequency increases as well. For these high-demand-dispersion items with high demand, the supply chain network could be analogous to *the supply chain network of convenience stores*.

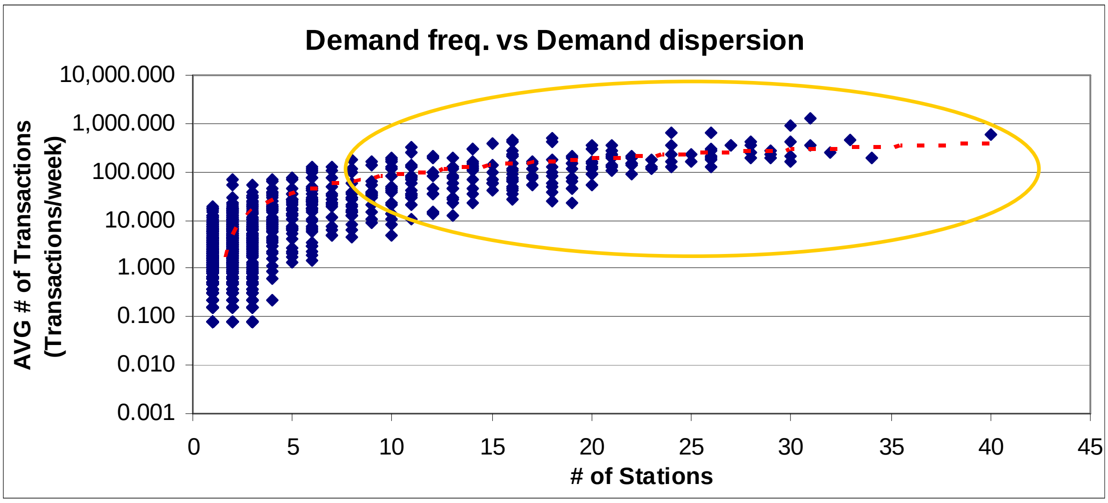


Figure 5: Demand Frequency vs Demand Dispersion

A key feature of convenience stores is information sharing that allows the supply chain to achieve efficiency gains in various forms like lower inventory, higher service levels, lower logistics cost, and better customer satisfaction with fresh products. Types of information shared by supply chain partners are point-of-use sales data (POS), sell-through data, inventory levels, demand forecasts, order status, performance measures, and production schedule.

Seven Eleven Japan has created a solid information system that enables the company to have timely and comprehensive signals indicating the market demands, and an intelligent process to turn such data into useful information for product information as well as new product creation. The company also developed an extremely agile logistics system that supports the replenishments of products to the stores (Harrison et al. 2003).

In contrast, the hospital industry requires information technology (IT) infrastructure to enable the transformation of physical fragmented inventory into virtual centralized inventory (Danas et al. 2006). If there is a real-time central database used to store the demand information and inventory level at each of the APU stations, once a certain APU station stock-outs, the nurses could use the system to determine the closest station with available inventory while waiting for the next replenishment. This “borrowing” behavior currently exists in practice. Nevertheless, with the assistance of an IT system, the true demand could be recorded and feedback could be given for future demand forecasting as well as maintaining an accurate count to ensure that the inventory policy can be followed.

4.5.7 Handling Characteristics

When items flow through the pipeline system, different treatments of items are described as *Handling Characteristics*. In the hospital supply chain system, medication and medical/surgical supplies may be temperature-sensitive, humidity-sensitive, sterilization-sensitive, radiance-sensitive, or security-sensitive. While some of the items should be refrigerated along the entire distribution process until the patient receives it, most of the items are protected by their own packages. The refrigerated items and radiance-protected items are already specially treated and isolated from the common supply chain. Since these items only account for very small proportions, the *Handling Characteristics* will not be considered in the macro-perspective.

4.5.8 Physical Size and Weight

In the medical supply chain, *Physical Size* and *Physical Weight* are determined by the physical properties of the item and how it was packed. For medication, the products differ in their physical properties, such as solid and liquid, and package. Additionaly, there are different forms such as tablet, capsule, vial, infusion, patch, and ointment. The quantity and volume (for liquid) may vary from one package to the other. Different hospitals may demand different quantity per package for the same kind of item. For example, the pediatric hospitals may demand lower-quantity packages. However, most distributors transport the items with totes and U-boats. The physical size and weight are less sensitive for transportation process. Hence the *Physical Size and Weight* will not be considered as a deterministic segmentation variable for the current practice.

4.5.9 Shelf life

Many drugs are sensitive to the expiry date. Based on our interviews with three hospitals, the loss of expired drugs is estimated to account for 5% to 10% of total drugs in terms of dollar value. The expiration of drugs mainly results from low inventory turnover. One of the most important reasons medications expire is safety stock for certain extremely slow-moving items. The hospitals have to keep these items in order to respond to any emergency. For this kind of situation, expiration is inevitable.

Most medical/surgical supplies have a fairly long shelf life. This insensitivity to expiry date is the reason that the medical staff does not need to care too much about the shelf life. Coupled with the “must-fill” demand for reserved medication, shelf life (expiry date) is not a significant segmentation variable for the pharmaceutical and medical/surgical supply chains.

4.5.10 Applicable Segmentation Variables in the Hospital

Previous sections have discussed the applicability of nine segmentation variables for the pharmaceutical and medical/surgical supply chains in hospitals. Except for *criticality*, which is customer- (patient) oriented segmentation, other variables are drivers of product-oriented segmentation. Five out of nine variables were found to be more applicable and corresponding supply chain recommendations were discussed. A summary of applicable variables is given in table 9.

Due to the difference in the basic characteristics and business model of hospitals, not all five variables could be applied to every hospital. Moreover, instead of exploiting all variables to segment the hospital supply chains, the balance between the degree of segmentation and complexity of supply chains is more critical. The benefit from segmentation could be significant, but the consequent pragmatic change would increase significantly as well. It is important to choose appropriate segmentation variables among these five and implement the corresponding improvements in the decision-making process of supply chain design.

Once the pharmaceutical and medical surgical supply chains have been physically separated, it is then possible to segment and aggregate each of the supply chains individually. This process is also a good opportunity for hospitals to re-evaluate and determine if there are possible synergies that could be achieved if any of the segmented supply chains are combined. The benefits could include 1) the cost savings of a joint distribution network; 2) the savings from staff time and redundant human resource; 3) the consolidation of storage space; and 4) the economic scale and bargaining power to distributor. The combined supply chain could adopt the same segmentation approach as well.

Variables	Observations	Strategy/Recommendation
Criticality	Varies among hospitals	Ward-oriented minimum safety-stock, (e.g. ICU, ER or, OR)
Unit price	High unit price, low demand	Customer-responsive supply chain (agile supply chain) e.g. pack-to-order and centralized inventory with frequent distribution,
Demand level	High demand, low unit price	Lean supply chain, Fragmented inventory
Demand frequency	High frequency, high demand	Horizontal cooperation – shared distribution networks and warehouses
Demand dispersion	High dispersion, high demand	Virtual centralized inventory

Table 9: Summary of Segmentation and Supply Chain Strategies for Hospital

4.6 Data Analysis: Integrated Segmentation for Medical and Surgical Items in NEH

Integrated segmentation based on several variables to segment the target supply chain is key to maximizing cost-savings and improve efficiency with a reasonably balanced effort. With 2,483 SKUs and 107 APUs, NEH's medical and surgical supply chains are chosen to illustrate the integrated approach.

Criticality is the first variable used to segment. From the customer's perspective, it is essential to keep fundamental safety stock in certain wards or units for emergency use. Via the interviews with the staff at NEH, it is recommended that the Emergency Rooms (ER), Operating Rooms (OR), and Surgical Intensive Care Units (SICU) own their own safety stock. Not only because stock out costs can be extremely high in the hospital, but also because keeping safety stock in these three units will not change the medical staffs' perception and will not cause them to resist implementation of the pooled inventory system. Therefore, more important than any other supply chain strategy, the authors recommend as a first priority, keeping safety stock locally in stations in an ER, OR, or SICU.

Unit Price is the second item description used for segmentation, but the first variable used to segment the product because the unit price links directly to the value of inventory, namely the capital cost. Table 10 shows the relationship between unit price and value of inventory among the 2483 SKUs.

Unit Price of Item	% of INV units among all	% of INV value among all	% of number of SKU among all
Greaten than $1,000	0.18%	54.82%	12.28%
Greaten than $900	**0.23%**	**59.47%**	**14.62%**
Greaten than $800	0.23%	59.81%	14.90%
Greaten than $700	0.23%	60.18%	15.22%
Greaten than $600	0.25%	61.48%	16.23%
Greaten than $500	0.26%	62.03%	16.63%
Greaten than $400	0.28%	63.12%	17.04%
Greaten than $300	0.35%	65.87%	18.65%
Greaten than $200	0.64%	73.50%	27.67%
Greaten than $100	**0.99%**	**79.13%**	**31.98%**

Table 10: Unit Price Distribution vs Inventory Value

Items with unit prices greater than $900 account for 59.47% of the total inventory value because there is a large gap in inventory value with a small incremental number of SKUs. For this academic research, “unit price greater than $900” has been chosen as the threshold. These items have been grouped for developing targeted supply chain strategy. However, the interviews with hospital medical staff indicated that the fixed cost of processing physical supply chain increases in a step-wise function. For example, handling 14.62% of SKUs may require two materials management professionals for picking and distributing, but these two individuals may actually be able to handle over 30% of the SKUs in inventory. Items whose unit prices are greater than $100 account for 31.98% of the SKUs and 79.13% of inventory value. Therefore, from a practical perspective, we recommended that the unit prices of items greater than $100 should be grouped together and treated with one specific supply chain strategy. Figure 6 and 7 indicate that the high cost segment of the inventory has relatively low demand and relatively low demand variability. Therefore, it is recommended that this segment of the inventory adopts the centralized inventory with frequent delivery in order to reduce safety stock cost and pipeline inventory cost.

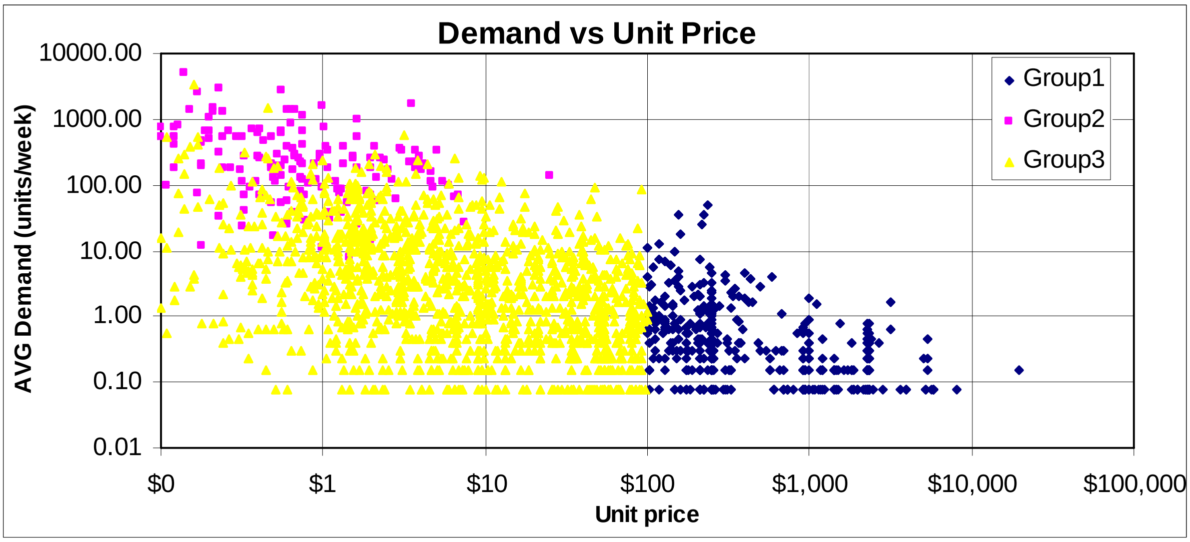


Figure 6: Grouped Items Displayed by Unit Price against Demand

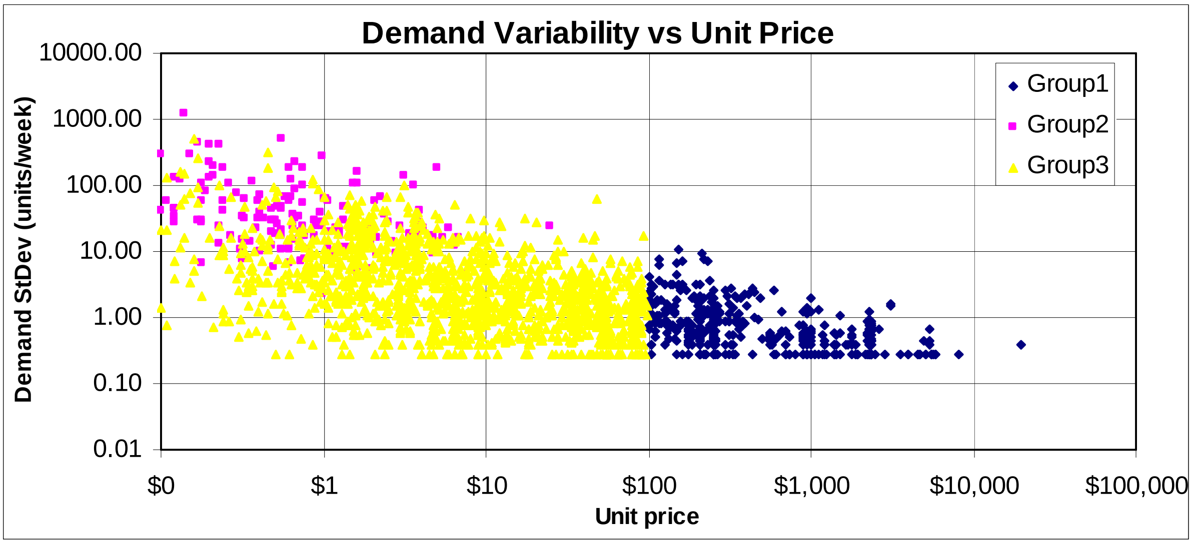


Figure 7: Grouped Items Displayed by Unit Price against Demand Variability

Demand dispersion can be linked to the complexity of the distribution network. In one hospital, the more dispersed the demand is, the higher the material management cost. The additional costs include the salaries of the materials management staff, dock receiving costs, picking costs, and transportation costs within the hospital. Table 11 shows the distribution between *demand dispersion* and units of inventory among the 2483 SKUs

# of Station	% of INV units among all	% of INV value among all	% of number of SKU among all
Greaten than or equal to1	100.00%	100.00%	100.00%
Greaten than or equal to2	85.01%	41.64%	44.18%
Greaten than or equal to3	74.78%	23.59%	27.47%
Greaten than or equal to4	71.49%	6.50%	14.94%
Greaten than or equal to5	68.33%	4.70%	12.81%
Greaten than or equal to6	67.17%	4.09%	11.32%
Greaten than or equal to7	64.58%	3.68%	9.71%
Greaten than or equal to8	63.34%	3.63%	9.02%
Greaten than or equal to9	62.28%	3.45%	8.18%
Greaten than or equal to10	**60.23%**	3.14%	7.57%
Greaten than or equal to11	58.02%	2.96%	6.85%
Greaten than or equal to12	54.88%	2.89%	6.20%
Greaten than or equal to15	49.84%	2.03%	4.75%
Greaten than or equal to20	32.96%	1.38%	2.42%

Table 11: Demand Dispersion Distribution vs Inventory Unit

Items demanded at more than nine stations account for 60.23% of the total inventory units and thus a demand dispersion of nine has been chosen as the threshold for grouping these items as another independent group. Items that fall into this category are segmented into Group 2, and will be handled with their own unique supply chain strategy. Figure 8 indicates that items in Group 2 have a relatively low unit price, which is exclusive from group 1. Meanwhile, figure 9 and 10 show that Group 2 has a relatively medium to high degree of demand and also a relatively medium to high degree of demand variability. Since Group 2 items are all low unit price, high demand and high demand variability, these items should maintain a fragmented inventory policy and they should be located as close as possible to the demand location with sufficient safety stock at this location as well.

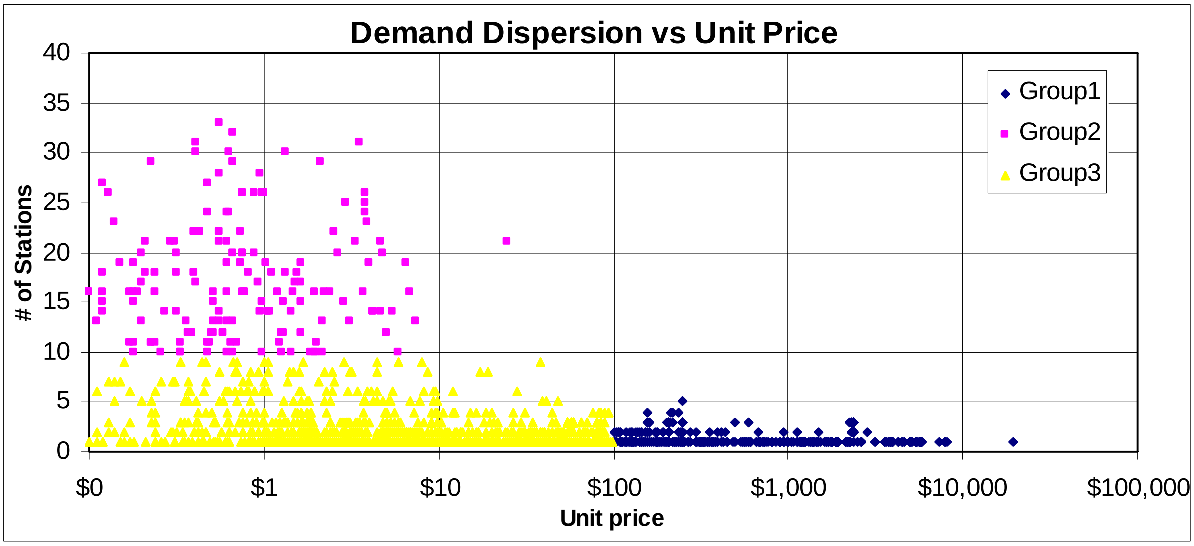


Figure 8: Grouped Items Displayed by Demand Dispersion against Unit Price

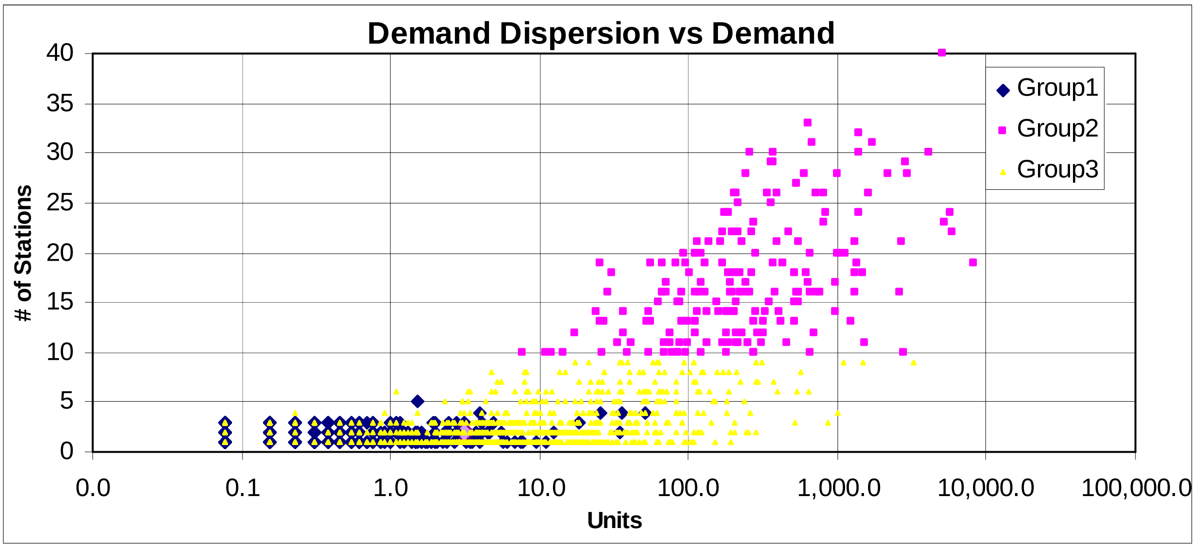


Figure 9: Grouped Items Displayed by Demand Dispersion against Demand

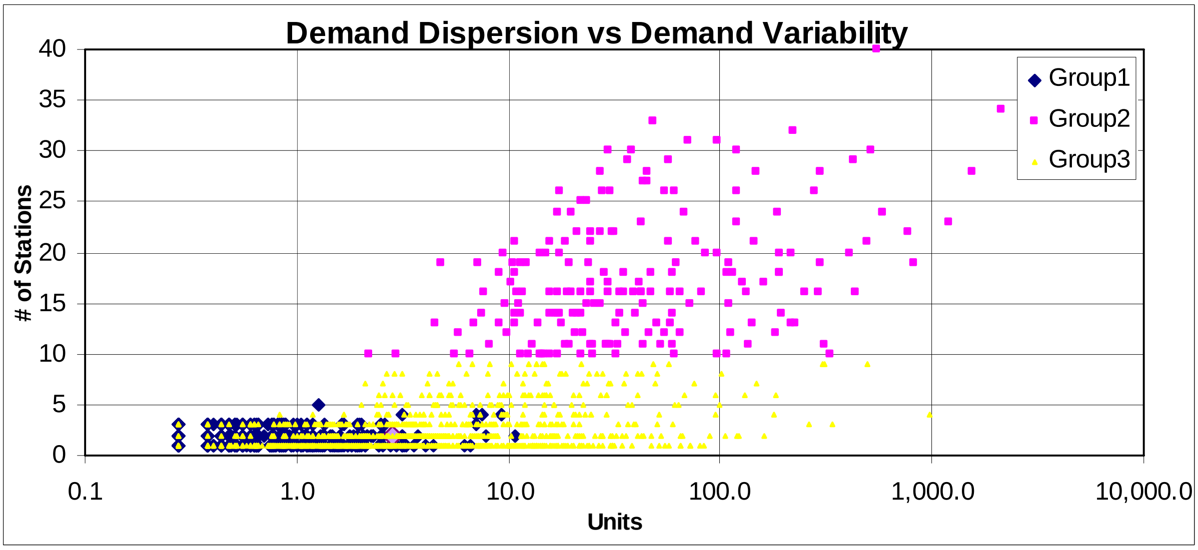


Figure 10: Grouped Items Displayed by Unit Price against Demand Variability

The rest of the items will be segmented into Group 3 and should be treated as a common group with one general supply chain policy. This group should maintain the current policy that is in operation at the hospital. Although this segment will maintain present supply chain practices, the segmentation process should be revisited every two to three years, and minor adjustments should be made. The proportions of each group are shown at table 12.

Group	Percentage of total inventory units	Percentage of total inventory value
1	0.99%	**79.13%**
2	**60.23%**	3.14%
3	38.78%	17.73%
Sum	100.00%	100.00%

Table 12: Proportions of Segmented Groups

The segmented item groups and corresponding policies are shown in table 13. Each group has its own characteristics and shows a clearly heterogeneous trend. The relative weight of each group is significant and each corresponding recommendation or policy is proposed. It is important to understand that segmentation is the preparation step that is necessary prior to optimizing the supply chain for efficiency. When the supply chain is well segmented, some benefits will emerge and induce certain levels of cost reduction. Yet, the true value will come from further supply chain improvement techniques. Further details will be discussed in the next chapter.

Group	Criteria	Observations	Importance	Policy
1	Unit Price: >=$100 per unit	Dispersion: low (Number of Stations <=5) Demand: low Demand variability : low	**79.13% of inventory value** 0.99% of inventory units	Centralized Inventory with frequent delivery
2	Number of Stations: >10	Unit price: low (<$7 per unit) Demand: medium to high Demand variability: medium to high	3.14% of inventory value **60.23% of inventory units**	Fragmented inventory
3	Rest items	NA	17.73% of inventory value 38.78% of inventory units	General supply chain policy
4	Stations locate at OR, ER, SICU	NA	Special importance for patients	Individual safety stock

Table 13: Recommended Segmentation and Corresponding Policy for NEH

5 The Next Generation Hospital Supply Chain

Inefficiencies in the inventory storage and distribution procedures within hospitals lead to excess inventory and as a result, materials management costs within hospitals tend to be much higher than they would be if efficient processes were in place. In this section, we will discuss the specifics of several different supply chains at three hospitals, and areas that these supply chains can improve upon.

5.1 Current Hospital Supply Chains

Given the scope of this research, all of the supply chains that were investigated for this thesis originate at a warehouse that supplies products to multiple hospitals in their region. These warehouses receive orders from the hospitals on a daily basis, and the orders are picked, packed and shipped to the hospitals within one day. The last order that will be filled by the warehouses is received by 9:00pm the night before the product is delivered. The short turn around time between the hospital ordering a product and receiving the product enables lean manufacturing inventory techniques to be implemented. However, orders are generally received just once a day, so there is a limit to how much of the hospital's inventory can be removed from the hospital's inventory storage locations.

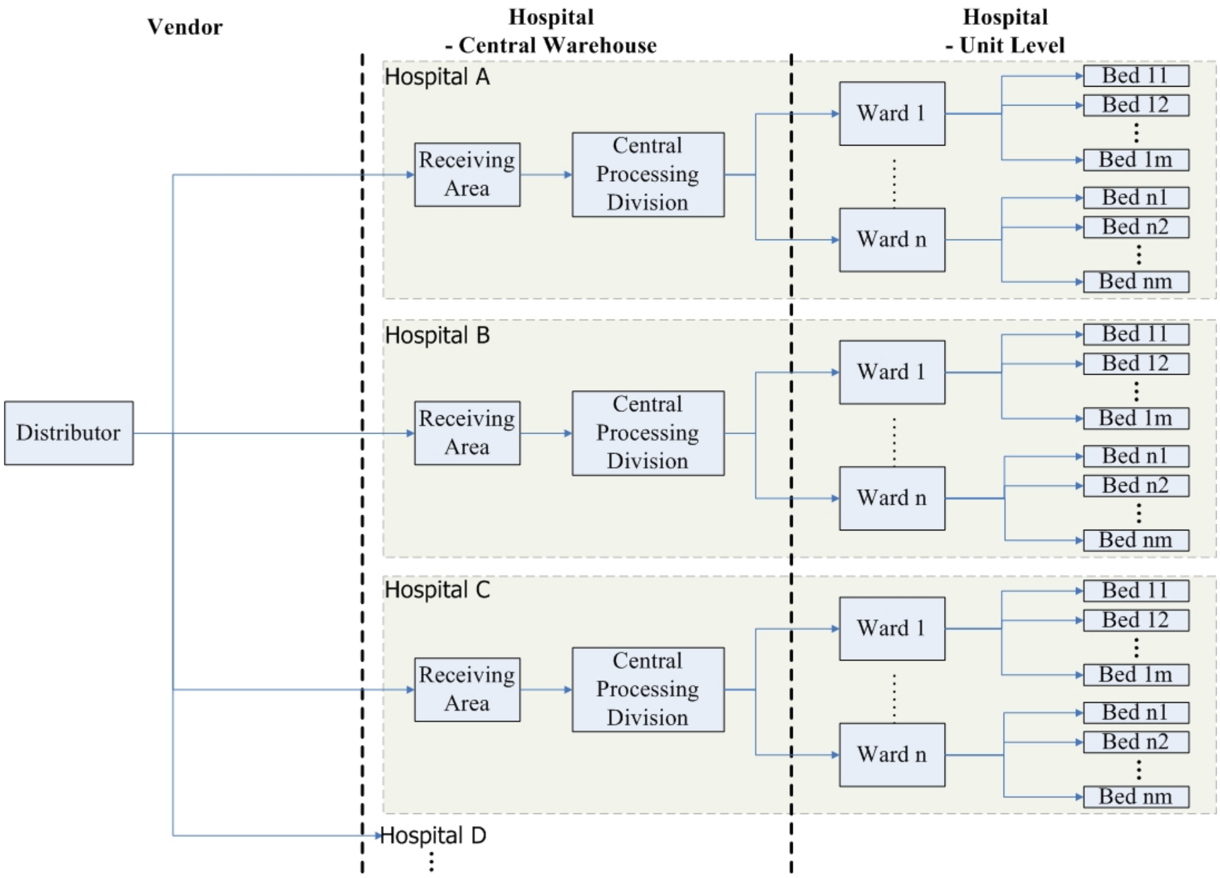


Figure 11: Current supply chain layout from Distribution Center to Hospital Bed

MWU receives one shipment of drugs each day. The most frequently used pharmaceuticals are picked by an automated machine within the warehouse, while the items that are not used as frequently are manually picked throughout the warehouse. All of the items on the pick list are merged into the least number of totes as possible. Once the pick list has been completely picked, the totes are then bar coded and loaded onto trucks. All totes for each hospital are loaded together in the reverse order of deliveries that will take place. In other words, the last delivery is loaded first.

Figure 12: Plastic Shipping Tote for Shipping Pharmaceuticals and Medical Supplies from Warehouse to Hospitals

Many of the totes that are filled with pharmaceuticals for delivery to the hospitals contain at least one controlled substance. In order to ensure that these controlled substances arrive at the proper final destination, the totes are delivered directly to the pharmacy within the hospital. Once the totes have arrived at the pharmacy, at MWU, a Pharmacy Inventory Controller checks to make sure the order is accurate. One of the most common problems that occur is when a single item is delivered, but a complete box has been ordered, or a box is delivered when a single item has been ordered. When this occurs, adjustments must be made to the inventory and the Inventory Controller must contact the supplier to resolve the problem.

One way the suppliers could reduce the frequency of this type of error would be to implement standard barcodes for all products. Standardized barcodes, otherwise known as universal product codes in the grocery industry have been commercially used since April of 1974. The lack of standardized barcodes is a significant challenge to overcome for both the pharmaceutical and medical product segments of hospital supply chains.

Without standardized barcodes, it is very difficult to efficiently manage the sourcing of products from medications to latex gloves. A materials management specialist at MWR indicated that it is very common for their inventory system to have several separate records of one item, but they do not know that there is redundancy because the items are entered into the system by product description and a number that has been given to the item by the hospital. If items are received, and the materials management professionals are now aware that the specific item they are receiving is already in the system, then they will create a new item number and description for the item. Not only does this type of redundancy make it very difficult for the materials management specialists in the hospital to keep an efficient and organized electronic database, it also creates a large amount of excess inventory within the hospital. Items that should be consolidated and stored in one space may be stored in several different places within the hospital's storage locations.

The absence of standardized barcodes also leads to the inability of one hospital to compare the amount they are paying for an item to the amount another hospital is paying for the same item. This lack of visibility gives the suppliers a significant advantage over the hospitals when it comes to pricing the items they supply. In the opinion of a materials manager at MWR, there is no one hospital that has the ability to put enough pressure on suppliers to force them to create a standardized bar-coding system. The suppliers do not have any incentive to give up the advantage of providing limited visibility to their customers. In the opinion of the materials manager at MWR, the only way that this change will take place is if the GPOs pressure the suppliers to implement standardized bar-codes. Implementing this type of standardization is an improvement that would immediately result in substantial cost savings within the healthcare industry.

Once the pharmacy inventory controller has ensured that the order is correct, the items from the order are brought to a central storage area. At this point there is a difference between the way MWU and MWR handle the medications. At MWU, there are two separate central storage areas for the medications. One of the central storage areas is used to stock inpatient medication stocking locations throughout the hospital, which are APU systems (Figure 13). The other central storage area is used to stock outpatient inventory locations in the inpatient pharmacy. At MWR there is only one central location that holds all of the pharmaceutical inventory. Drugs are distributed throughout the hospital from the central storage location.

Figure 13: Automated Point of Use System

Medical and surgical orders are handled in a similar manner, but the security requirements for these products are not as strict as the security requirements for the pharmaceutical items. The relaxed security requirements allow general materials management professionals to receive the orders. Orders at NER are received once a day at approximately 5:00am. The orders are checked in the same way that the medications are received. Once any problems have been identified and resolved, the items are transferred throughout the hospital. NER has an arrangement with a distributor that requires rolling carts called U-boats to be delivered. Each individual U-boat is loaded with inventory that is delivered directly to the unit that ordered the items.

This procedure eliminates several steps in the supply chain process, which in turn reduces the amount of inventory that is held in central storage. Although the inventory that must be held in central storage is reduced by delivering inventory directly to the units, it is necessary for NER to maintain inventory in central storage. Therefore, some of the received shipments are brought to central storage to replenish inventory that has been taken to stocking locations within the individual wards.

MWU, MWR and NER all maintain inventory in central storage locations. Each of the hospitals manage the inventory in slightly different ways, but the process for all of the hospitals is labor intensive and requires full time employees to maintain accurate and appropriate levels of inventory. Each of the stocking locations maintain minimum and par levels, but the process of managing the inventory in the system for a specific location is done manually. A materials management employee visually inspects each of the locations to ensure adequate supply, and if there is not enough inventory, an order is placed with the supplier. Par levels and reorder points are set as a result of experience and knowledge related to the individual products. The lack of structure in the system presents inefficiencies. Some inventory locations contain excess inventory, and some locations contain insufficient inventory.

All three of the hospitals that were studied for this thesis used a combination of APU systems and manual inventory management procedures within their wards. A vast majority of medications and some of the medical supplies are stored in APU systems that require employees to log in to the equipment prior to access inventory. Nurses make use of the APU systems more than any other hospital employees. Nurses either use their identification numbers or finger prints to log onto the system. Next, they type in the patient's identification number, and the drug that the patient requires. The system then checks to ensure that the specific drug has been prescribed for the patient. Once verification occurs, the nurse indicates how many items have been taken from the drawer, and then closes the drawer. The procedure for taking medical supplies from the APU systems is nearly identical to the procedure for taking medications from the APU systems. The two exceptions are when controlled substances are taken from the APU systems, and when the nurse indicates that medical supplies have been taken from the APU systems. When controlled substances are taken from the APU system, the transaction must be verified with by another employee of the hospital. This procedure is intended to prevent controlled substances from being used for purposes they are not intended to be used for. The other difference between the two systems is that the nurses must push a button for each item that they take when they take medical supplies from the APU system.

One of the major drawbacks of these two systems is the need for hospital employees to accurately indicate the number of items that have been added or withdrawn from inventory. Conditions within the hospital can vary from relaxed to chaotic, and when the employees become extremely busy, it is not difficult to imagine that inventory management errors are made. Inventory management is not a nurse’s primary responsibility, and if managing inventory inhibits the quality of service that a patient experiences, then inventory management will suffer. In order to ensure that transaction errors are fixed and inventory is accurate, every one of the hospitals have employees that check each of the stock locations on at least a daily basis in order to ensure that the counts are correct for all products. Inventory adjustments are often made by these materials management employees in order to ensure that stock out conditions do not occur, and also to ensure that orders are not placed unnecessarily.

Handheld electronic devices are used by the materials management employees at MWR to transmit the inventory levels to the inventory management system. If the adjustment drops the inventory level below the reorder point, then an order is automatically placed in the system. Once the order is placed, the process starts over from the point of picking the items that have been ordered.

5.2 The Revolver

In order to determine the best possible supply chain that could be implemented in the hospital setting, supply chains from other industries have been investigated. In this section, we will propose a supply chain model using best practices that are currently being employed in industries external to the healthcare industry. This supply chain model will be a significant improvement compared to the current supply chain practices in the healthcare industry.

5.2.1 Dell: central warehouse

Dell gained a competitive advantage in the computer manufacturing industry due to the use of an extremely efficient supply chain. Although it is not completely intuitive how Dell's supply chain techniques can be transferred into the healthcare industry, there are several practices that would greatly benefit supply chains in hospitals.

In order to have just in time manufacturing plants, Dell has implemented something they call a revolver. A revolver is an offsite warehouse that supplies the manufacturing facility with computer components. The location of these revolvers are very close to the manufacturing facility, so that the lead times between determining an item is needed and having the item on hand is as short as possible. Approximately every two hours a truck leaves the revolver and heads to Dell to drop off a delivery of recently ordered components.

Another characteristic of the revolvers is that the inventory is owned and maintained by the suppliers of the components. In order to do business with Dell, vendors have agreed to lease space in the warehouse. The vendors use this space to stock and manage their components in the same way that vendor managed inventory is done by PepsiCo. Vendors recoup their rental cost of supplying products in the revolver through sales of the products that they stock in the revolver.

Dell selects the vendors that are allowed to maintain a presence in the revolvers, and they also set inventory levels that they expect each of the vendors to meet or exceed. This is a slight change to classic vendor managed inventory, but it allows Dell to have more control over the process of sourcing components and service levels of those components. Dell keeps track of how well each vendor performs against the expectations that Dell has for them. If a specific vendor or specific vendor and part combination is not meeting expectations, Dell has the option of sourcing the specific component from an alternate vendor, or in extreme cases, the underperforming vendor may be eliminated from the revolver altogether. Dell maintains the presence of at least two vendors in the revolvers for each of the components that they require to make the computers they manufacture. This practice gives vendors an incentive to meet Dell's expectations, which results in very high service levels.

5.2.2 Application of Revolver in Hospitals

Once the correct product mix has been determined using the techniques described in Chapter 4. Our model suggests that these items be stored in an offsite warehouse known as a revolver (Figure 14). As many of the different SKUs from each hospital as possible will be stored in the revolver, critical items must be stored within the hospital wards so that the healthcare professionals have immediate access to these items. As figure 14 indicates, multiple distributors would have the opportunity to stock items at the revolver. A prerequisite to the implementation of this system would be standardized barcodes throughout the healthcare industry. Without standardized barcodes, management of the inventory from multiple distributors going to multiple hospitals would not be possible.

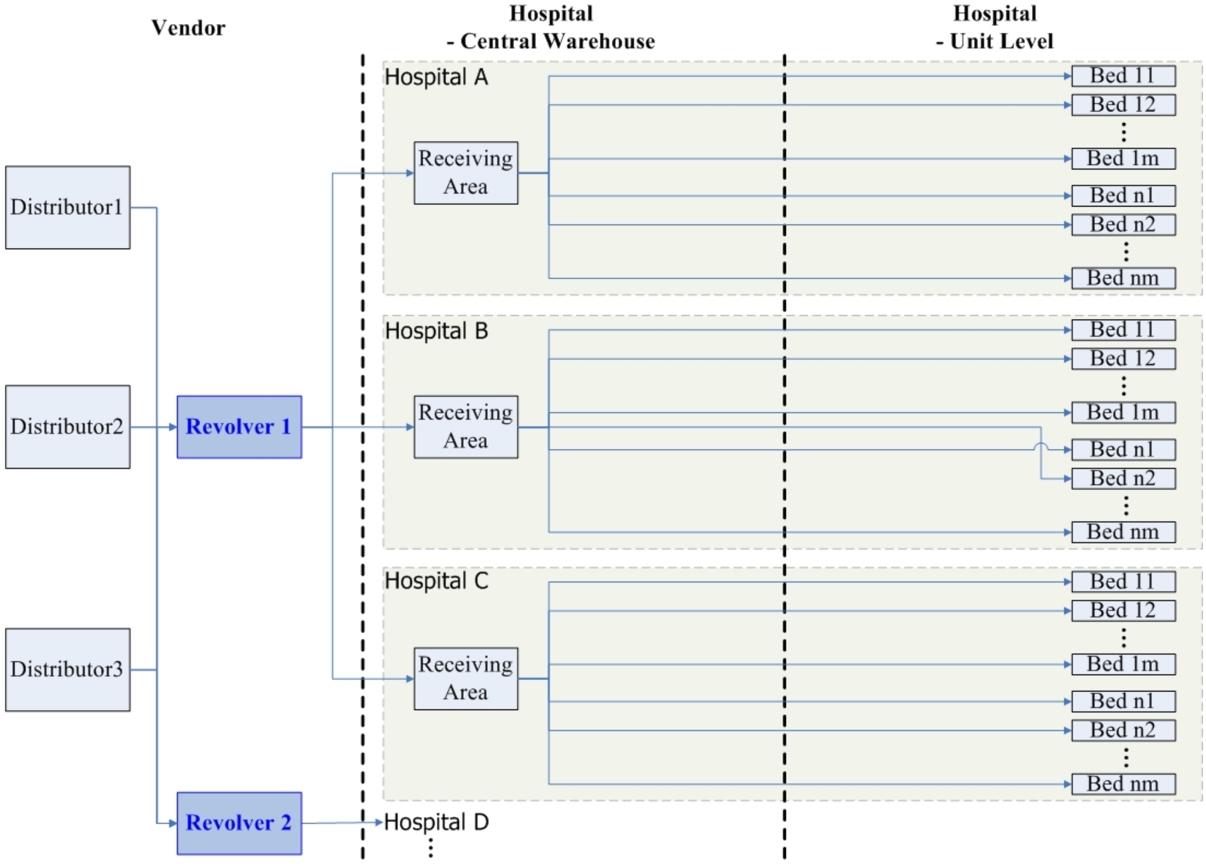


Figure 14: Revolver supply chain layout from Distribution Centers to Hospital Beds

Centralizing inventory in one offsite warehouse has many advantages due to the effect of risk pooling. Instead of storing inventory in many stocking locations throughout the hospital, each individual location having safety stock, there would be just one stocking location for each item. This advantage is even greater if multiple hospitals merge their inventory within one revolver.

Frequent deliveries hold the key to the success of this model. Each delivery would contain totes, and in each individual tote would be items destined for a specific patient within the hospital. Using these customized totes would enable the hospital to eliminate one supply chain echelon within the hospital. Currently, hospitals receive inventory and store many of the received items in a central storage facility within the hospital. Implementation of the revolver would allow items used by the hospital to be transported from the offsite warehouse directly to the patient.

In order for this type of practice to work in the healthcare industry, the location of the revolver would need to be selected very carefully. Suppliers would be incentivized to rent space in a healthcare revolver if the revolver serviced at least one very large hospital, or several smaller hospitals. It is common practice for suppliers to charge Dell a 3% premium for goods that are stored in the revolver. This cost goes toward paying for the leasing fees that Dell charges. The same type of surcharge should be expected in the healthcare industry. This charge also indicates that vendors will initially not be interested in stocking revolvers that do not have a large volume of product being sent to the hospitals on a daily basis.

Another advantage of supplying several hospitals with one revolver is the ability to risk pool. Most hospitals have one area that they designate as central supply. If any of the products in this central supply area run out, then it can be many hours, or even a full day before the item will be restocked. In order to prevent this type of situation from occurring, hospitals tend to have much more stock on hand than is necessary. It is far easier to predict the combined demand of several hospitals, than it is to predict demand for each of the hospitals separately.

This will allow the overall inventory in the channel to be reduced. Instead of holding a great deal of stock very close to the end user, the revolver will hold much less stock in a centralized location that is available to several hospitals.

It is extremely important that hospital staff never run out of inventory, so deliveries will need to be made as frequently and quickly as necessary to make sure stock outs do not occur. Furthermore, the items will be packaged in totes similar to the totes that are currently used by hospitals to deliver inventory directly to the wards.

5.2.3 Revolver to Bed (R2B)

The major difference in the proposed model is that these totes will be filled with product specific to a bed. Nurses and doctors will use electronic handheld devices to place orders in the system. The orders will indicate the items that are needed and the bed that the items are for. Criticality will also need to be taken into account, because there are some patients that would not see a decrease in service even if items are not delivered for several hours. On the other hand, there will be patients that need to have orders filled within hours.

Surgeons often take advantage of something called a preference list when they are getting ready for surgery. Preference lists indicate what a doctor prefers to use during surgery. These lists in combination with pre made kits specific to a surgery are the basis of the kits that will be created at the revolvers and sent to the hospitals. Doctors and nurses will have the option to build preference lists that can be edited for any type of disease or medical problem that patients are admitted for in a hospital. These preference lists will be stored electronically, and when a diagnosis has been made for a news patient, the order can be placed to the revolver through a handheld electronic device.

This method will not eliminate the need for hospitals to have stock on hand, because critical items will always need to be available within seconds. In most hospitals, the number of items that are considered critical is approximately 20% of the total items in the hospital. All of these critical items will be stocked within the hospital, but will also be stocked in the revolvers. This will reduce the number of critical items that will need to be on hand at the hospital, and it will move nearly 80% of the stock out of the hospital.

If medications are to be stocked in a revolver, then special precautions will need to be put in place. Hospitals generally staff pharmacists to check prescriptions prior to filling them. This process is crucial to the safety of the patients. In order to preserve this safety factor, pharmacists will need to continue to check the prescriptions prior to filling them. In order for the pharmacists to check the prescriptions, the doctors and nurses will have to send the prescriptions electronically to pharmacists that will not need to be on site. The pharmacists will be able to work at any location that has access to the electronic transmissions. Due to issues that may arise when filling prescriptions, such as confusion about specific pills, the best place for the pharmacists to physically work is in the revolver.

5.2.4 Adapting Amazon Personalized Kits Practice

In order to quickly pick, pack and ship large numbers of items in a short time period, strategies employed Amazon warehouses can be used as a model. Amazon allows customers to log on to their site and order as few or as many items as they desire. Once the order has been placed, a credit check is automatically completed and if the customer's credit is deemed acceptable, the items are sent to the customer by mail. This system is analogous to the doctor or nurse using a handheld device in order to put together an order and send the order to the revolver.

Once the order has been received by the revolver, substituting for the credit check would be a check of any prescriptions that are included in the order. If there are any prescriptions included in the order, then a pharmacist will need to make sure that the items indicated will not present any problem for the patient that will be receiving the prescription. Once this check is completed, the order can move on to the next stage in the process, namely picking the order.

Order picking commonly comprises up to 55% of the total cost of operating a warehouse. Therefore it is important to optimize this aspect of the order fulfillment process. Amazon's warehouses primarily use people to perform the picking function of the process. But, when there is a very large volume of orders coming into their warehouses; the most efficient way to pick and consolidate orders is to use put systems or order distribution systems. This type of strategy breaks the order picking process up into two separate functions. First, a set of employees within the warehouse travel around the warehouse, pick items that will eventually complete many different orders and place the items in bins that the pickers travel around the warehouses with.

An algorithm that takes into account the location of each of the items is used to determine the fastest routes from one item to the next. This algorithm determines the items that will be picked by each individual and the path that the individuals will take in order to pick all of their items. On average, travel time comprises 50% of a picker's total time picking orders, which indicates that optimizing the travel time of the picker dramatically reduces picking costs, and decreases the number of employees needed in order to pick orders (Tompkins et al. 2003).

In the warehouse revolvers, pickers will be separated into critical and non-critical pickers. A greater number of pickers per item will be used for critical items. This increased ratio of pickers to items will result in faster order fulfillment. Once a picker has completed picking items from the pick list, these items will be brought to revolver personnel who will separate the picked items. The personnel that transfer the items are known as order pickers, because they transfer the items from the bins that have several orders in them to totes that are specific to one order of the end customer. Once the individual order has been completely picked and packed, the package is then placed on a conveyor belt system that sorts the packages. Packages are sorted according to their final destinations and shipping preference.

The picking, packing and shipping procedures in the revolvers in the healthcare industry would need to be run differently, but there are many similarities between orders that are placed by customers online and doctors or nurses within a hospital. The first similarity is that orders specific to a patient would need to be filled by picking items from stock locations throughout the warehouse. Optimizing the route that the pickers take would be critical to saving costs related to the picking process. The most important difference between the process used by Amazon and the process that would need to be used by the healthcare revolvers is the idea of critical versus non-critical orders.

There would need to be two separate supply chains running in parallel to make this type of a system viable. One way to separate the two different supply chains is with different color totes, and also with different pickers and packers. The first supply chain would cater to patients that need supplies and medications in a very short period of time. This type of a patient may include any patient in the critical care units within the hospitals, and any patient that unexpectedly needs some type of medication or medical supply that is not stocked within the hospital. This supply chain will need to be given priority over the second supply chain that caters to patient with less urgent needs. These patients may include individuals that are located in post operative recovery rooms, or even patients that have scheduled surgeries. If patients have scheduled a surgery, then there would be plenty of time to pick and pack a tote with the items that would be needed for the surgery.

Picking the medications would be managed differently than picking medical supplies. Major medication distributors currently use machines that automatically pick items that are required by hospitals. This type of a system would be employed in the revolvers, but there would need to be one major change in the system. Currently, items that are picked for hospitals are in whole bottle or whole box quantities. The revolver would require that medications are packaged as single doses. In order for the automated system to work, revolvers would need to require drug manufacturers to package all of their medications differently and also include bar codes for each of the individual doses.

The most efficient way to consolidate patient specific orders that are sent to the hospitals in individual totes would be to pick the medications with the automated system first, and then split the items up that have been picked for multiple orders. Optimally designed picking and packing procedures will enable the pickers to pick over 500 items an hour. This method would enable the totes that are shipped to each individual bed to include both the medications and the medical products.

5.2.5 IT/Automation

One of the major challenges of incorporating revolvers is the complex information technology system that would need to be designed and maintained. The IT system would allow doctors and nurses to place bed-specific orders. These orders would be transmitted to the warehouse, and then pickers within the warehouse would pick and pack the orders according to their priority. Orders that have been designated as critical by the doctors or nurses would be picked immediately and sent to the hospital in the next delivery. The most important aspects of the information technology system would be ease of use, stability of the system and flexibility.

Specifically, the IT system will work in the following manner. Doctors and nurses will be able to set specific preference lists according to different diseases or symptoms that are typical to patients. These lists will be editable, and they will be stored in a central database. The lists will include pharmaceuticals and medical supplies that the doctor or nurse prefers to use when treating a specific set of conditions. These lists must be editable since it is common to prescribe different set of items to the same symptoms. An example of this is related to the medications that are used to treat specific diseases. There is generally a large difference between what a doctor or nurse prescribes a 5 year old and a 35 year old exhibiting the same set of symptoms.

The ideal IT system will link a patient specific database to the database holding the doctor and nurse specific preference lists. Each doctor and nurse will have a handheld personal digital assistants (PDA) with which the orders will be placed for the patient. The PDA will hold the preference list of the individual doctor or nurse, which will be edited to match the specific patient's needs. Once the order has been completed, it will be wirelessly sent to the ordering system. The ordering system will cross reference the list of items in the order with the database that has patient specific information. The intent of this cross reference will be to determine if there are any possible negative drug interactions as well as any allergies that the patent may have to a prescription. The PDA will also have the option to send the order as a critical order, which will be handled within the warehouse as a top priority and will be transported to the hospital in the shortest amount of time possible.

If the system determines that there are conflicts resulting from the order, an alarm will be sent back to the nurse or doctor. Once the order has been accepted by the system, it will be sent to the revolver to be approved by the pharmacist. The pharmacist will ensure that the system has accurately screened the orders for any conflicts, and that the prescribed dose is appropriate for the specified patient. The order will then be passed on within the computer system.

As was mentioned in the previous section, the critical and non-critical orders will be handled with separate personnel within the warehouse. Aggregating several orders together, using detailed inventory location information and warehouse layout, the IT system will calculate the route that each picker will use in order to maximize their picking efficiency. Once the consolidated orders have been separated into the individual totes for delivery to the hospital, they will be tracked by either bar-coding or RFID tags. The totes will be linked in the system to the specific patient within the hospital. Once the totes arrive at the patient's bedside, the bar-code or RFID chip will be read and the order will be changed from open to complete within the IT system.

5.3 Evaluation of the Personalized Kit Supply Chain

We analyzed the data were collected from APU systems located in wards at NEH in order to determine the viability of the proposed supply chain model. The same data have also been used to determine the difference in inventory management costs between the current situation and the proposed personalized kit solution to meet the hospital supply chain needs. The comparison will also investigate any differences in transportation costs and personnel costs associated with the different supply chains.

5.3.1 Model Basics

In order to develop a proof of concept for the personalized kit supply chain, two models were created. The decentralized inventory storage model (Case 1) uses the data described in the previous section to determine the costs associated with a supply chain carrying the optimal amount of inventory and operating under the current procedures. The only change from the current inventory management practices for these products would be an optimization of the safety stock that the hospital has on hand. The pooled inventory model (Case 2) uses the same data to demonstrate the costs that would be associated with operating the personalized kit supply chain. The two cases have been compared with the current situation to determine the benefit of optimizing or redesigning the supply chain (Table 14).

	Decentralized Inventory Storage (Station-SKU level)	Pooled Inventory Storage (Item-SKU level)
Actual Inventory (Empirical)	Current case CSL: 80.42%	Target case
Model-based Inventory	Case I CSL: 80.42%	Case II CSL: 80.42%

Table 14: Breakdown of SKU Type and Inventory Data

To determine the average value of the inventory in the current situation, the average weekly quantity of each station-SKU was calculated across 13 weeks. The sum of the average weekly station-SKU units was then multiplied by each individual station-SKU's unit cost. In order to calculate the customer service level (CSL) for the current situation, the total number of stock-out events throughout the 13 week period was divided by the total number of transactions across all of the APU systems. The inventory levels and CSL determined by these calculations was then compared with the modeled costs of implementing Case I and Case II with the same CSL.

The demand levels indicated in Table 15 show that 94.35% of the medical items in the APU systems are slow moving items. Another industry that has a similar intermittent demand pattern is the spare parts industry. In order to develop an accurate technique, demand must be modeled using a method that can accurately predict intermittent demand. Traditional models developed to predict demand for moderate or high demand products will not accurately predict demand for slow moving products. In order to determine the inventory levels necessary for Case I, demand was modeled using Croston's method (Croston 1972). Croston's method was selected because it has been shown that this method is superior to other traditional methods when demand can be shown to be intermittent (DeScioli 2006).

Demand Level	Description	Total	Percentage
Slow Moving	Less than 10 per	7093	94.35%
Moderate	10 - 100 per day	395	5.25%
High	Greater than 100 per day	30	0.40%

Table 15: NEH Station-SKU Classification by Daily Demand

Two different distributions were used in order to model the number of picks per week and the average demand per pick. The Poisson distribution was used to simulate the number of transactions per week (N) by using the average number of demand transactions (λ). For case I, the average number of weekly demand transactions on the station-SKU level was used, and for case II the average weekly demand transactions on the item-SKU level was used. The normal distribution was used in order to simulate the average volume per transaction (μ) and the standard deviation of the volume per transaction (σ) across the 13 week time period.

$$N = PoissonInv(CSL, (R + L) * \lambda)$$

$$k = NormInv(SL)$$

$$Inventory\ units = N * \mu/2 + k * sqrt(N) * \sigma$$

$$R = review\ period = 2\ days$$

$$L = lead\ time = 0.5\ day$$

The models for both Case I and Case II were created assuming the same review period of two days. This was selected because it is very unlikely that under either scenario the review period would be longer than two days. In fact, for Case II, the review period would be close to zero because the IT system would automatically update the inventory whenever an item is picked in the warehouse. Inventory would be checked every day in Case I, but two days has been selected as a worst case scenario. In all three scenarios, the lead time from the distributor to the warehouse or units is less than 12 hours, so L is equal to 0.5 days in Case I and Case II.

The decentralized inventory storage model, Case I, is a situation in which all of the existing APU systems are in use, but the inventory within each system is maintained at optimal levels. The data that were input into the model for this scenario were obtained in the following way. First, the number of transactions, demand per transaction and stock out events for every station-SKU was determined. Once these numbers were determined, an average across all 13 weeks was obtained for the number of transactions, the average quantity per transaction and the standard deviation of the demand quantity per week. Once all of these values were calculated, they were used to calculate the inventory value and the inventory units in stock for Case I.

The pooled inventory model, Case II, is a situation in which the inventory is maintained in a centralized warehouse, with limited inventory at the ward level. The data that were input into the model for this scenario were obtained in the following way: First, items that are stocked in multiple APU systems were aggregated. For example, if one item was found in five separate

APU systems, the inventory statistics for all five of these station-SKU's were aggregated. Statistics such as Number of Transactions and Number of Stock-Out Events were summed up and average quantity per transaction was determined using all transactions involving this item across all five APU systems. Once these aggregated numbers were obtained, the average quantity per transaction, the average number of transactions and the standard deviation of the demand per week were input in to the model.

5.3.2 Revolver Evaluation

The three different materials management strategies, namely current situation, Case I, and Case II, are compared in Table 16. The results indicates that currently the inventory at NEH is not being managed optimally. Controlling for service level, the inventory could be reduced by nearly $2 million for this 13 week period. An even greater savings could be achieved if Case II is implemented and reduces inventory to $342,494 over the 13 week period, which is a 67% improvement over Case I. This is equivalent to holding just 32.32% of the stock required for Case I. The number of items that would need to be held in inventory would also be dramatically reduced. Nearly 200,000 items could be eliminated from the current inventory if Case I was implemented and this number could be further reduced by nearly 70,000 items if Case II were implemented. Case II only requires 43.98% of the units of inventory required for Case I.

Most of this decrease in inventory can be attributed to the effect of pooling inventory, but another reason that the current scenario is so costly is because the order up to levels are 14.22% higher than the necessary order up to levels for the achieved CSL.

	Current	**Ideal Safety Stock**		
	Station-SKU (Current)	Station-SKU (Case I)	Pooled Item-SKU (Case II)	Ratios
# of SKU	7,518	7,518	2,483	
Sum of INV Value	$2,967,425	$1,059,538	$342,494	32.32%
Sum of INV Units	341,251	121,344	53,373	43.98%

Table 16: Financial Comparison of Inventory for Three Scenarios

5.3.2.1 Centralized Inventory Analysis

Sensitivity analysis was done in order to determine the number of inventory units, and the associated value of the inventory that would be necessary to achieve service levels from 80.42% through 99.5%. Currently, the data from NEH indicate that the service levels at the station-SKU level are only 80.42%. This value was obtained by summing up all of the times an employee of NEH attempted to obtain an item from an APU system, but the item was not in the system. This does not necessarily indicate that the item did not exist in the hospital, because the employee may have been able to walk to another APU system or even to central inventory in order to obtain the item. This CSL number is calculated keeping in mind that the hospital employee attempting to obtain the item is assumed to be the customer. One out of every five times an employee of NEH attempts to obtain a product from the APU system, the item is not there. This lack of product leads to frustration and added cost due to the time it takes the employee to find the desired item.

Transactions across Both Case I and Case II indicate that the incremental cost to achieve higher service levels increases as the CSL increases. The reason for this increase is due to the way necessary safety stock for each specific CSL is calculated. Assuming a normal distribution for each transaction, inventory levels must be increased by 4.76% in order to increase service levels from 80% to 81%, but to increase customer service levels from 98% to 99%, inventory levels must be increased by 13.66%. Figure 15 illustrates why the value of the on hand inventory increases rapidly as the CSL approaches 100%. The service factor is multiplied by the standard deviation of the demand for the item in order to determine a component of the safety stock for the item.

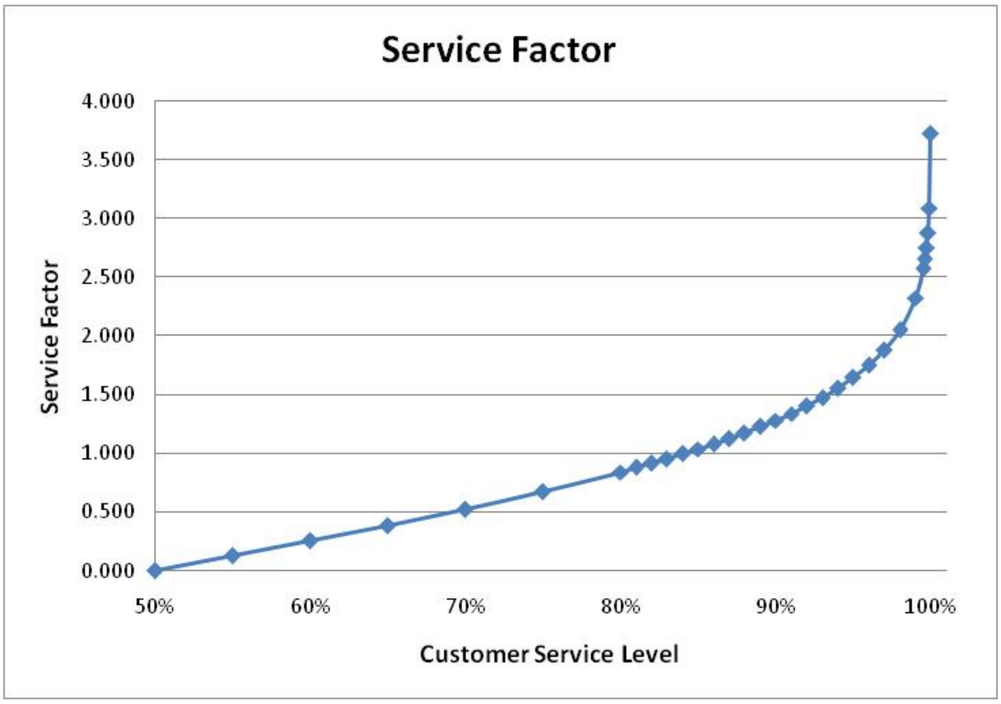


Figure 15: Increase in Service Factor Relative to Increased Service Level

Table 17 indicates that under the current scenario, NEH would need to increase their inventory by $6,872 in order to increase the CSL by 1.68%. In order to increase the service level from 99% to 99.5%, a much greater investment must be made. The hospital would need to increase the units of inventory by 280,236 units, which translates into $113,041, in order to achieve this increase of 0.5%. This model also assumes that the inventory is managed optimally using Croston's method to predict demand. If the inventory is not managed at an optimal level, it may not be possible to reach the indicated service levels by increasing the amount of inventory that is held in each of the APU systems. Table 17 can be used by hospital administration as a guideline for making decisions related to the investment the hospital is willing to make in order to increase service levels.

CSL	Inventory Units	Increment	Inventory Values	Increment	Cumulative Increment
80.42%	121,344		$1,059,538		
82.00%	125,450	4,106	$1,066,410	$6,872	$6,872
85.00%	133,882	8,432	$1,081,468	$15,057	$21,929
88.00%	144,638	10,756	$1,102,314	$20,846	$42,775
90.00%	153,218	8,580	$1,115,299	$12,985	$55,760
92.00%	163,671	10,454	$1,141,428	$26,129	$81,889
95.00%	183,361	19,690	$1,182,945	$41,517	$123,406
96.00%	193,272	9,910	$1,197,922	$14,977	$138,383
97.00%	206,283	13,011	$1,232,213	$34,290	$172,673
98.00%	224,608	18,325	$1,278,529	$46,317	$218,990
99.00%	251,763	27,155	$1,358,310	$79,780	$298,770
99.50%	280,236	28,473	$1,471,351	$113,041	$411,811

Table 17: Customer Service Level Sensitivity Analysis for Decentralized Model (Case I)

The same analysis was performed for the pooled inventory model (Table 18). In order to increase from the current service levels of 80.42% to 82%, the amount of inventory held in the revolver would need to increase by 844 units, which is equivalent to $3,671 of inventory. In order to increase CSL from 99% to 99.5%, the amount of inventory held in the revolver would need to increase by 4,721 units, which is only 615 units more than the requirement to increase service levels from 80.42% to 82% in the decentralized inventory model.

CSL	Inventory Units	Increment	Inventory Values	Increment	Cumulative Increment
80.42%	53,373		$342,494		
82.00%	54,216	844	$346,165	$3,671	$6,872
85.00%	55,873	1,656	$354,679	$8,514	$15,386
88.00%	57,872	1,999	$364,255	$9,576	$24,962
90.00%	59,303	1,431	$371,765	$7,510	$32,472
92.00%	61,048	1,745	$385,259	$13,494	$45,966
95.00%	64,733	3,685	$405,274	$20,014	$65,980
96.00%	66,261	1,528	$414,359	$9,086	$75,066
97.00%	68,429	2,167	$431,244	$16,885	$91,951
98.00%	71,166	2,737	$453,867	$22,623	$114,574
99.00%	75,941	4,775	$499,746	$45,879	$160,453
99.50%	80,662	4,721	$560,168	$60,422	$220,875

Table 18: Customer Service Level Sensitivity Analysis for Pooled Model (Case II)

The advantage of the pooled inventory model is not only that the total number of units and value of the inventory necessary for specific CSLs is less than the necessary number of units and inventory value for the same CSL in the case of the decentralized inventory model. The pooled inventory model has the additional advantage that lower incremental investments are necessary in order to achieve increased service levels (Figure 16 and 17).

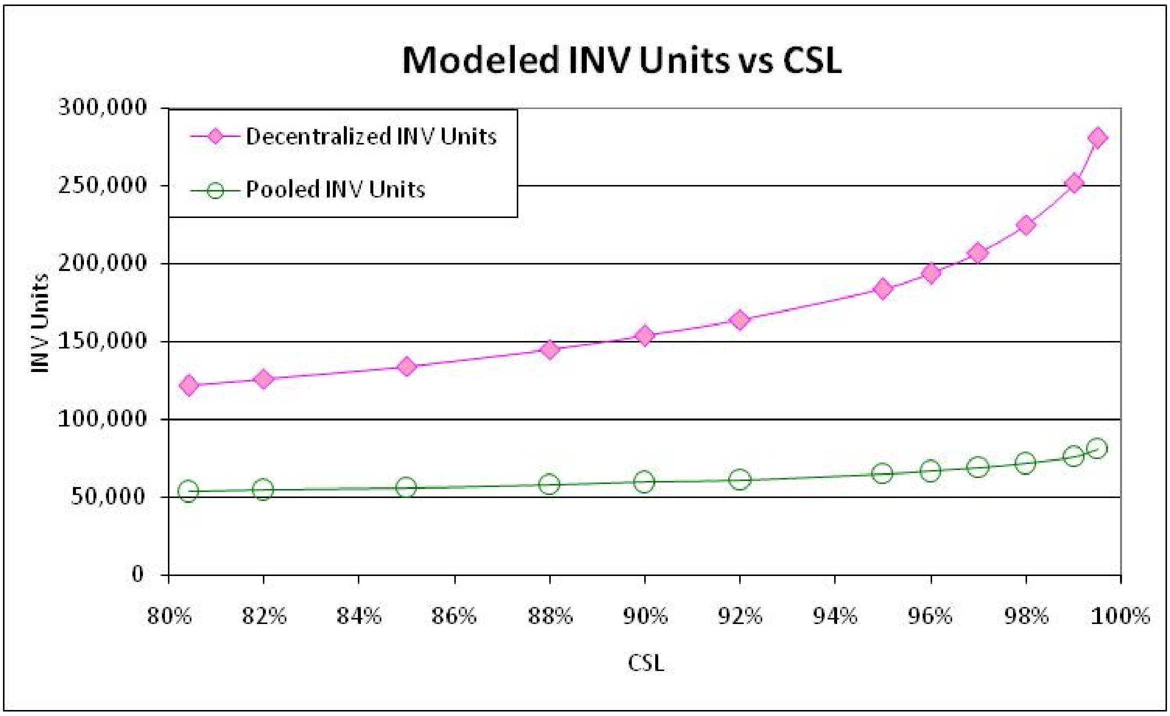


Figure 16: Comparison of Inventory Units Necessary for Specific Customer Service Levels

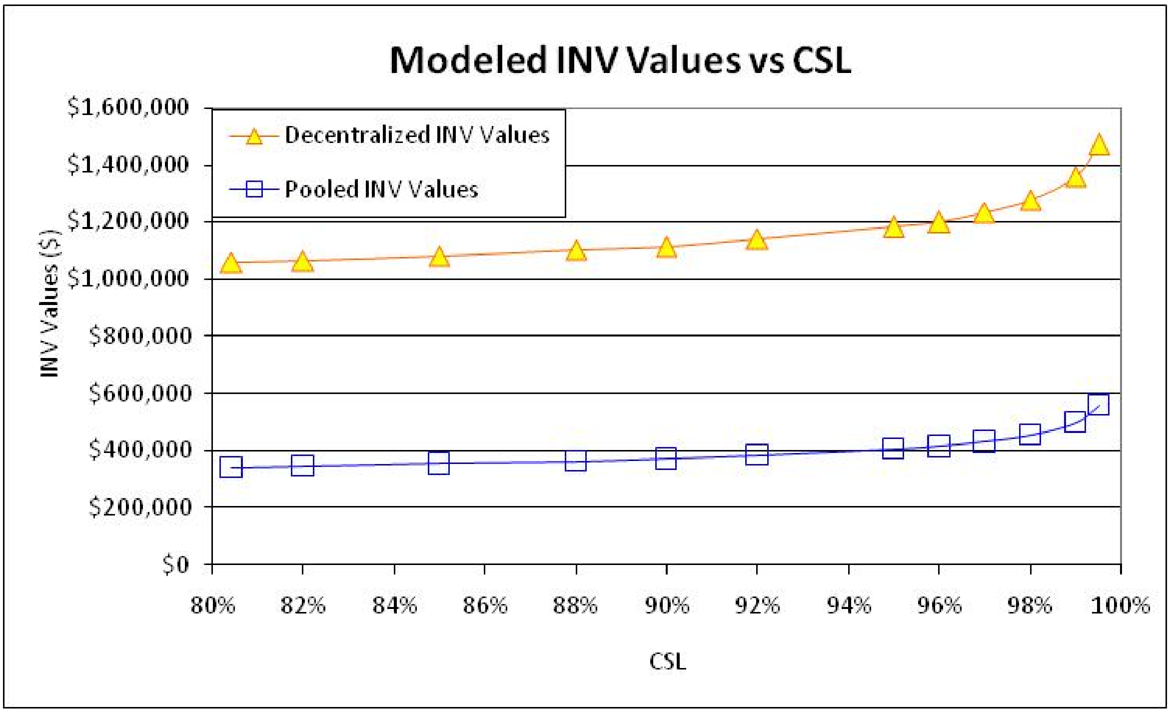


Figure 17: Comparison of Inventory Values Necessary for Specific Customer Service Levels

5.3.2.2 Value of Hospital Real Estate

MWU and NEH were both adding new floor space at the time that this thesis was prepared. The national average cost to add one square foot to a hospital was $216 per square foot in 2006 (www.reedfirstsource.com). The offsite revolver would enable hospitals to reclaim the central storage areas within the hospital. These rooms could be converted to rooms with other uses, and the cost of building additions on the hospital would be avoided. Table 19 indicates that reclaiming a moderate sized central storage area of 1,200 square feet would enable the hospital to avoid investing $259,200 in order to add this amount of space on to the hospital.

Size of Central Storage Within Hospital (ft^2)	Resulting Savings from Reclaimed Floor Space
100	$21,600
200	$43,200
300	$64,800
400	$86,400
500	$108,000
600	$129,600
700	$151,200
800	$172,800
900	$194,400
1,000	$216,000
1,100	$237,600
1,200	$259,200
1,300	$280,800
1,400	$302,400
1,500	$324,000
1,600	$345,600
1,700	$367,200
1,800	$388,800
1,900	$410,400
2,000	$432,000

Table 19: Potential Savings Resulting from the Reclamation of Central Storage Floor Space

Not only will there be savings as a result of additional available space in the hospital, there is also the possibility of generating revenue with the new space. *A conservative estimate of the revenue per bed in an average hospital is $50,000 per year. If enough space is reclaimed from central inventory to add 20 additional beds, this would result in $1,000,000 in additional annual revenue*.

5.3.2.3 Saving of Nurse's and Pharmacist's Time

One of the primary benefits of implementing a pooled inventory model with customized kits delivered to the patient's bedside is the amount of time that the nurses would likely save. At MWU, MWR and NEH the nurses had varying degrees of responsibility related to materials management. For example, at MWR a nurse is in charge of distributing medications from the pharmacy to the APU systems that are located in wards throughout the hospital. At NEH nurses are responsible for ordering items that are stored within their wards.

Table 20 indicates that even a modest amount of time saved by nurses in a hospital employing 500 full time nurses would translate into a large amount of cost savings per year. In 2006, the average salary of a nurse was $28.21 per hour. Theoretically, using this salary assumption, a hospital would save $366,730 per year if each of the nurses saved just six minutes per day as a result of the pooled inventory system. The relationship is linear between cost savings and the number of hours saved per day by the nurses, so if just 20 minutes are saved a day on average, the total cost savings per year would be over one million dollars.

Time Saved per nurse per day (hr/day)	Time Saved per nurse per year (hr/year)	Total Nursing Time Saved per year* (hr/year)	Total Cost Savings per Hospital** ($/year)
0.10	26	13,000	$366,730
0.33	86	42,900	$1,210,209
0.50	130	65,000	$1,833,650
0.67	174	87,100	$2,457,091
1.00	260	130,000	$3,667,300
1.50	390	195,000	$5,500,950
2.00	520	260,000	$7,334,600
2.50	650	325,000	$9,168,250
3.00	780	390,000	$11,001,900
3.50	910	455,000	$12,835,550
4.00	1,040	520,000	$14,669,200
4.50	1,170	585,000	$16,502,850
5.00	1,300	650,000	$18,336,500
5.50	1,430	715,000	$20,170,150
6.00	1,560	780,000	$22,003,800

*Assumes a total staff of 500 nurses

**Assumes an average hourly salary of $28.21/Hour

Table 20: Annual Cost Savings as A Result Of Daily Savings of Nurse's Time

An interview with a nursing manager at MWU, however, revealed that processes that save time within the hospital setting do not generally result in a reduction in the number of nurses employed by the hospital. If time is saved in one area of the nurse's responsibilities, then the nurses generally fill their time performing other tasks. Therefore, table 20 would not directly represent cost savings that the hospitals would see on their books. Table 20 would rather translate into a related increase in the service levels that the patients perceive. Greater dollar values in table 20 would indicate higher customer service levels. If nurses spend less time managing the inventory located within their wards, they will be available to meet the needs of the patients they are responsible for. There is currently a nursing shortage, so from a hospital's perspective it would be desirable if they could maximize the output of each of their nurses and in effect reduce the number of additional nurses they need to hire each year.

5.3.2.4 Transportation Costs

From the perspective of the hospital, receiving deliveries from the revolver every few minutes would be desirable, but there are costs associated with delivering the products to the hospital that prohibit this delivery frequency (Table 21). It would be the responsibility of the materials management professionals within the hospital to manage the delivery frequency from the revolver. When deciding on the delivery frequency, variables such as fuel costs, the cost of purchasing a truck, truck driver salaries and maximum allowable time between deliveries must be considered.

In order to take advantage of economies of scale, the revolver would need to be located in close proximity to one large hospital or several average sized hospitals. It has been assumed the revolver would not be more than 6 miles from the hospital. In order for a large number of beds to be concentrated in a small area, the hospitals would need to be located in an urban area. Keeping this in mind, the average speed of the delivery truck between the revolver and the hospital has been set at 20 miles per hour.

Parameter Description	Value	Units
Assumed Average Truck Speed	20	Mph
Average Distance from Hospital to Revolver	6	Miles
Number of Hospitals Served By Revolver	3	Hospitals
Average Peak-Hour Transportation Time per Trip	20	Minutes
	0.333	Hours
Average Off-Peak Transportation Time per Trip	1	Hour
Peak Hours per Day	16	Hours
Average Number of Trips	56	Trips/Day
Total Peak-hour Truck-miles	576	Miles
Total Off-peak-hour Truck-miles	96	Miles
Total Truck Mileage	2016	Miles
Truck Mpg*	5.5	Miles/Gal
Cost of Diesel Fuel**	$2.94	$/Gallon
Truck Driver Salary***	$15.33	$/Hour

* Assuming 15L engine http://www.peterbilt.com/pdf/AeroReturns.pdf

** source is (http://tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp) (AVERAGE of 2007/3/26~2008/3/17)

*** Based on data from http://www.bls.gov/oco/ocos246.htm

Table 21: Values Used to Model Transportation Costs to And From Revolver

Using the assumptions indicated in table 21, the number of trucks running at one time has been calculated. The calculation assumes that three different hospitals are being served by the revolver. All three transportation networks to the hospitals would be independent from one another. Each hospital would own their own trucks, so Figure 18 indicates that for replenishment times of between 20 and 35 minutes, each hospital would need to have two trucks. In order to reduce the delivery time to 15 minutes, an additional truck would be necessary.

The rapid increase in the number of trucks necessary to reduce replenishment frequency times from 20 to 5 minutes is due to the percent change in the delivery frequency. The number of deliveries per hour for a delivery frequency of every 5 minutes is 400% greater than the number of deliveries per hour for a delivery frequency of every 20 minutes. This 400% increase in trucks directly translates into a 400% increase in the number of trucks that are needed.

Figure 18 indicates that 6 trucks would be sufficient for replenishment frequencies of between 20 and 35 minutes. There is a range of times because the 6 trucks would be underutilized if the replenishment frequency is every 35 minutes, but 3 trucks would not be enough to replenish the hospitals every 35 minutes. At 20 minutes, the 6 trucks would be nearly fully utilized.

Figure 18: Number of Trucks Necessary to Deliver To three Hospitals from Revolver for Varying Replenishment Frequencies

If each hospital has three trucks, it would be possible to replenish the patient specific kits once every 15 minutes, but because the items that will be ordered from the revolver are not the items that need to be available within several minutes of the time they are requested, the optimal choice for each hospital would be to own two delivery trucks that transport personalized kits to and from the revolver all day. Figure 19 also supports the conclusion that two delivery trucks with delivery frequencies of 20 minutes would be optimal.

Figure 19 indicates that the fuel cost for each hospital with replenishment frequencies of 20 minutes would be less than $400 per day.

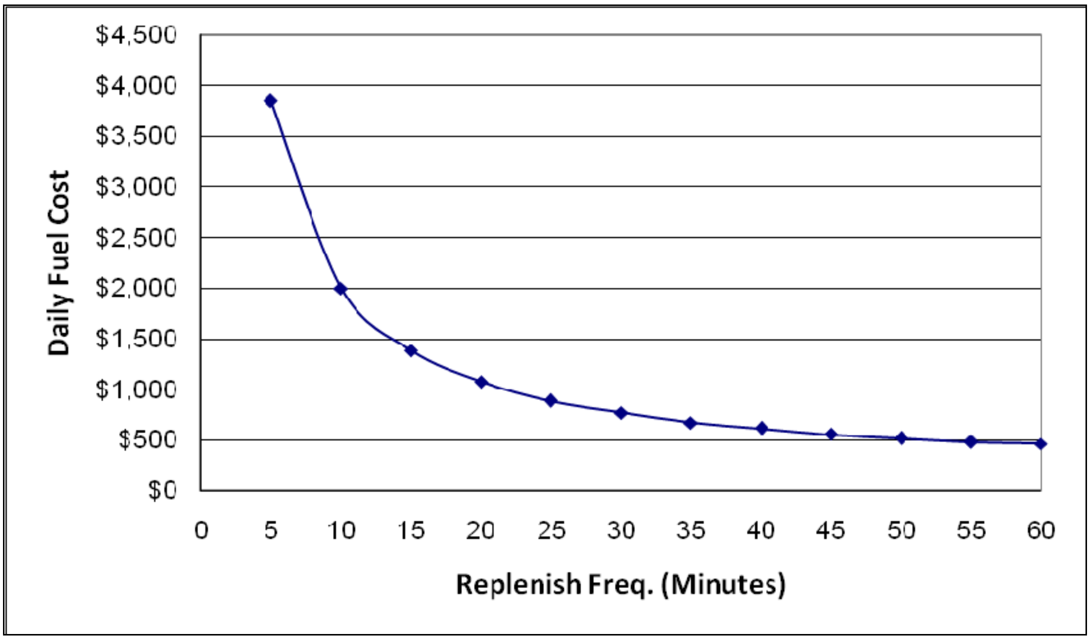


Figure 19: Daily Fuel Cost to Deliver to Three Hospitals from Revolver for Varying Replenishment Frequencies

If the delivery frequency was decreased to 15 minutes, the amount each hospital would pay for fuel on a daily basis would be nearly $500. The total weekly cost for this transportation system would be the cost of the fuel, which would be $2,800 per week, plus the cost of the driver. Another cost of the transportation system would be the salaries of the truck drivers. This operation would be functioning 24 hours per day, seven days per week. Two drivers would be driving trucks during peak hours, which account for 16 hours in one day, and one driver would be driving for the other 8 hours of the day. The average salary of truck drivers in May of 2006 was $15.33 an hour. Multiplying this hourly wage by the total number of hours the truck drivers must work in a week results in a weekly cost of approximately $4,300. Benefits generally increase the cost to a company of hiring an employee by 50%. Therefore, the total weekly cost of the drivers would be $6,450. There would also be some additional costs related to insurance, truck maintenance and truck purchases that would add to these costs, but relative to fuel costs and the cost of hiring truck drivers, the other costs are small. The total cost to transport the personalized kits to the hospitals would be slightly more than $10,750 per week.

5.3.2.5 Cumulative Benefits

There are significant costs associated with making a change of this magnitude in the healthcare industry. These costs have not been calculated, because they would vary widely from one hospital to another, and they are also very difficult to quantify. Many of the costs would be related to policy changes, investment in infrastructure, investment in training and the costs associated with the initial loss of productivity that generally occurs at the beginning of any large scale implementation.

We will argue that in order to rule out this type of a materials management system, the costs that have not been calculated would have to be extremely large. Table 22 indicates the cumulative annual cost savings directly related to the implementation of the personalized kit supply chain if it were implemented at NEH using the following assumptions:

- The inventory reduction has been calculated using a customer service level of 99% in both the current case and the personalized kit supply chain.
- Space savings has been calculated assuming that 1,000 square feet can be reclaimed from central storage.
- Revenue from additional beds has been calculated assuming that 5 new beds can be added to the hospital.
- Savings related to a reduction in nurse's time spent dealing with materials management has been calculated using the number of nurses at NEH, which is 1,175, and assuming that 20 minutes a day can be saved and that each nurse works 240 days each year.
- Transportation costs have been calculated exactly the way they were calculated in section 5.3.2.4.

Category	**Savings/(Loss)**	**Duration of savings**
Inventory Value Savings	$858,564	One-time
Space Savings	$216,000	One-time
Revenue from Additional Beds	$250,000	Continuous
Nurse's Time Savings	$2,651,740	Continuous
Transportation	($559,000)	Continuous
Total Annual Savings	**$3,417,304**	

Table 22 Annual Cost Savings at NEH upon Implementation of Personalized Kit Supply Chain

There are many tangible difficulties associated with implementing a pooled inventory system, but possibly the most challenging aspect of this type of implementation would be the intangible difficulties associated with managing the personnel both within and outside of the hospital during implementation. The next section contains a discussion of what would likely be the most important aspect of implementing a pooled inventory and customized kit system within the hospital environment.

6 Change Management in Healthcare

Changing processes and procedures in a hospital environment presents many challenges. The challenges that can inhibit a successfully implemented and integrated supply chain fit into three categories. The first category is environmental, which represents the environment in which hospitals operate. This category consists of product distributors and group purchasing organizations. The second category is the organizational level of the supply chain. This aspect of the supply chain includes management within hospitals. The third category is operational, which includes the materials managers, supply chain managers and healthcare professionals within the hospitals. Each of these categories will be discussed in relation to observations that were made during visits to MWU, MWR and NEH. Suggestions will be made in order to achieve a successful supply chain redesign and also to provide guidelines to improve supply chain practices within these three hospitals and the healthcare industry as a whole. A case study will be presented in order to illustrate an attempt at implementing the proposed guidelines as they relate to an information technology system within a hospital setting.

6.1 The Healthcare Environment's Impact on the Supply Chain

The primary responsibility of the GPO is to leverage economies of scale, and relationships with manufacturers to obtain the best possible prices for hospital purchases through the GPO.

However, this does not always happen because incentives are not always aligned between the GPOs and the hospital. Another dynamic that can lead to inefficiencies in this part of the supply chain is the common belief of hospital executives that once they have selected a GPO, they can expect cost savings throughout the foreseeable future without actively managing the relationship with the GPO.

When a hospital selects a GPO, it is important for the hospital understand GPO's strategy. The GPO's strategy should be very clear, and it should be well aligned with the strategy of the hospital supply chain. There should be an obvious connection between the GPOs' strategy and cost reduction within the healthcare supply chain. Although this may seem intuitive, there are many instances in which the incentives of the personnel within the GPOs are not well aligned with reducing supply chain costs.

In the 1970s, GPOs began collecting fees from the manufacturers that they purchased items from. It was at this point that the motivation for choosing manufacturers shifted from obtaining the best possible financial deal for the hospital, to a situation that enabled the GPOs to profit from selecting manufacturers that were willing to pay higher fees. In some cases GPOs were given higher fees for specific products, which gave the GPOs incentive to attempt to push these products into the hospitals. This type of an arrangement does not provide a situation in which the hospital carries the items that are best suited for the hospital, but they will instead carry items that are the most profitable for the GPOs to source. Presently, if a product has a viable substitute and is manufactured by more than one manufacturer, GPOs are required by law to make both of these items available to the hospital. This policy is a step toward aligning incentives, but now GPOs tend to carry many different items from a major manufacturer and the substitutable item is sourced from a small unknown manufacturer. This effectively promotes the large manufacturer because the usage rate of items manufactured by a well known manufacturer will be higher than the lesser known substitute.

All three hospitals we visited indicated that they had problems with at least one aspect of the GPOs practices. The most common problem that was expressed by the hospital personnel was a lack of bar code standardization of the products within the healthcare industry, and more specifically, sourced through the GPOs. This is an industry wide problem that manifests itself in the form of widely varying prices from hospital to hospital for items that are exactly the same. A senior supply chain professional at MWR indicated that she believed a great deal of cost savings could be achieved simply by implementing something that has been used in the retail business for decades. Standardized bar codes would enable hospitals to simplify some of their systems, and would also ensure that identical objects would not unnecessarily be stored in two different stocking locations. It was the supply chain professional's belief that the GPOs are the key to achieving this type of standardization. Since individual hospitals do not have the power to force this type of standardization.

It is important for the management of any hospital to make sure strategies are aligned with the GPO that they select, not only at the beginning of the relationship, but continually throughout the relationship. In the case of implementing an offsite pooled inventory system, it would be critical to form a close relationship with the GPOs. Automation would be an important part of the pooled inventory system, and a basic first step toward becoming more automated would be standardized barcodes. GPOs could help the hospital create standardized barcodes, and the GPOs could also help materials management professionals within the hospital ensure that the items within the IT system are currently available and also if items should be added to the system.

6.2 Organizational Impact on Healthcare Supply Chains

Currently in some hospitals the most senior supply chain personnel are purchasing managers or other employees at a similar level. This structure leads to the problem of a lack of senior leadership sponsoring projects that are undertaken by the supply chain professionals. Even relatively small projects may meet some resistance without senior leadership approval, and it is very unlikely that major projects will be undertaken without executive management approving and spearheading the project. In order for any significant change in hospital supply chain management to be successful, the project must have buy in from executive level management. In the case of implementing the pooled inventory model, the change to the current structure of hospital supply chains is so great that the project would surely fail without executive leadership support. Similar to the ensuring that the GPO's incentives and goals are aligned with the hospital's goals and incentives, it is necessary that the hospital's goals are very clear. Clarity of the hospital's goals will ensure that there is no confusion throughout the supply chain as to what is expected at each step in the chain.

Goals should be presented prior to the start of any project that will significantly impact the supply chain. Another step to take prior to implementing significant change is ensuring that the correct people have been hired and trained for the tasks that they will be performing during and after the transition. Until recently, supply chain management has been viewed as an afterthought within the hospital setting, and as a result, many of the individuals performing supply chain tasks have not been trained or educated in the field of supply chain management. Many individuals managing the supply chains within hospitals have come from another position within the hospital and have transitioned into their current role because of an in depth knowledge of the inner workings of the hospital environment. This deep understanding is important to managing an efficient supply chain, but it is also very important that the supply chain professionals are aware of the available technologies and best practices within the field of supply chain management. It is the responsibility of senior management to ensure that the correct personnel are hired or trained to effectively perform their supply chain tasks.

Another important aspect that must be considered prior to implementing any major change in the supply chain is the technology. The individuals that work in the information technology department must be involved in the project from the beginning, and they must be engaged throughout the process. The pooled inventory strategy is highly dependent upon the functionality and capability of the IT systems that are selected for the project. IT professionals should be capable of informing the project manager as to the costs that will be incurred, and they should also be able to propose a range of dates in which the project implementation will likely be completed. Constantly evolving technologies can make the IT implementation aspect of any project challenging, but this challenge can be overcome if the correct implementation strategy is selected for the project.

There should be enough organizational flexibility to deal with missteps or slight changes in direction. Using the spiral model for project management, which focuses on gradual improvement and periodically revisiting each step in the process, would likely produce significantly better results than a plan that does not account for the possibility of errors and delays at different points in the process. The spiral model will enable management to have visibility into the project and although all target deadlines may not be met; there is a significantly higher chance that tasks will be completed close to the original target dates because each aspect of the project is regularly revisited and bottlenecks are removed much faster than they would be if other project management strategies are employed.

6.3 Operational Impact on Healthcare Supply Chains

There are several aspects of internal supply chain operations that must be managed properly in order to effectively implement change in hospitals. As with the environmental and organizational strategic alignment that must be in place, there must be a clear and well aligned strategy at the operational level of the hospital. The strategy must involve the entire organization in its scope, and all employees of the hospital that are impacted by the supply chain must be aware of and comply with the operational strategic goals. In order to determine if the strategy is understood and being effectively implemented the last operational aspect that must be considered is the collection and use of data. The collected data should be used in order to determine if specific benchmarks are being reached, and also to make supply chain related decisions.

At the operational level, the strategy must take into account the needs of the doctors, nurses and patients. This strategy must be consistent with the organizational strategy, but should be more specific to supply chain operations. One part of the communicated strategy must convey the message to the supply chain professionals that the cost of items is not the only aspect of a product that should be investigated when determining which products to purchase. Many buyers have an incentive to reduce the price that is paid for a specific product. Cost reduction is an important goal, but it is more important that the clinicians and doctors are able to obtain products that they believe add value and increase the service level of the patients they are treating. Once the operations part of the hospital supply chain has determined specific best practices that are aligned with the needs of the hospital, doctors, clinicians and patients, these best practices must become a part of the internal culture of the hospital.

In order to change the culture, there must be an extremely collaborative environment. All parties that will be affected by the significant change in supply chain practices must be involved in deciding the best course of action to take when implementing the change. There are two main reasons that all individuals must be involved during the planning stages of major change. The first reason is that involvement will enable each group to shape the project that is being implemented. Excluding any of the affected groups may lead the project team to overlook aspects of the project that are specific to that group. Another important reason to include all affected individuals and groups is that having a voice will ultimately increase the probability that each of the involved groups will accept the changes taking place.

The final operational aspect of change management that must be carefully considered and managed is the information technology aspect. All three of the hospitals that were visited for this research had varying levels of IT capabilities, and even with respect to different areas within the hospitals. Supply chain practices as basic as ordering products just by the use of "gut feel" were employed at one of the hospitals, and all three hospitals had some medications that were automatically ordered when the APU system determined that the inventory level had dropped below the reorder point. Two things that are common to all of the hospitals are that there are not enough data being collected in order to make decisions solely based on data, and the second thing is that the data that is being collected is not being analyzed carefully enough to extract all of the information that could be obtained from the data.

One challenge that was faced when attempting to use medication data that had been collected at MWU from their APU systems was that the data could not be transmitted in electronic form. Reports are consistently generated and distributed in paper format. In order to gain the maximum advantage from an APU system, the data should be easily transferable from the internal computer of the system to external systems and spreadsheets. Once the data are external to the system, it could be analyzed and manipulated in order to create forecasts, determine optimum safety stock levels and demand data. Using extracted and cleaned data, the APU systems can make important inventory management decisions reliably.

6.4 A Case Study: Children's Hospital of Pittsburgh

Ideas presented in sections 6.1 through 6.3 are illustrated through the case study below. The case is especially relevant because the successful implementation of the system in the case relied heavily upon an information technology system that had not been in use at the hospital in the past. This was a computerized physician order entry (CPOE) system implemented with the purpose of reducing the number of adverse drug events (ADEs) that occurred within the hospital. The system implementation took place at the Children's Hospital of Pittsburgh (CHP) between October 2001 and September 2003 (Figure 4).

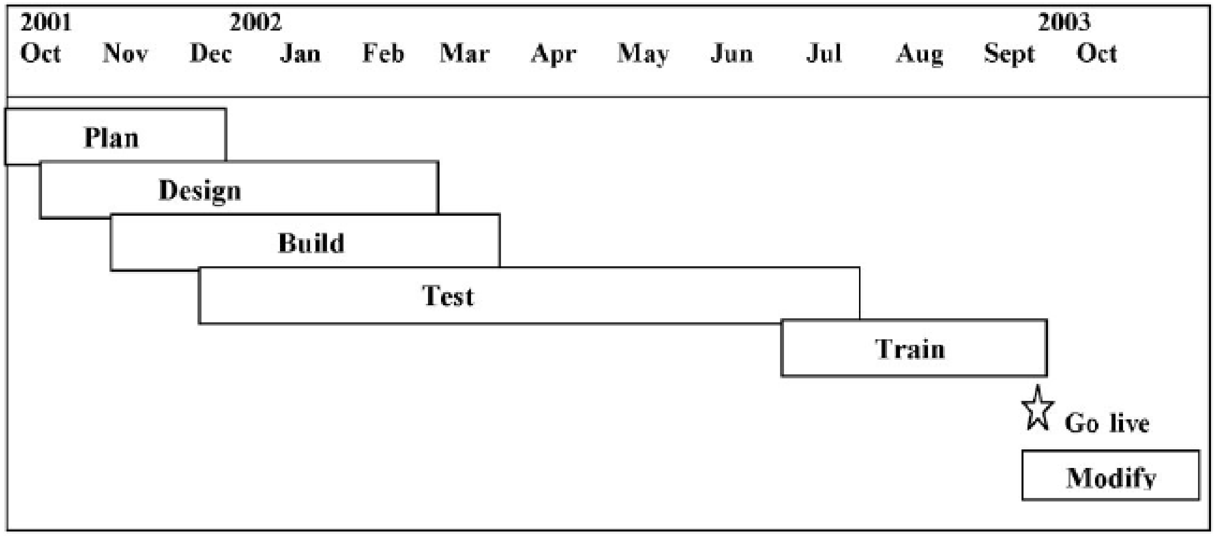


Figure 20: CPOE Development and Implementation Timeline (Upperman 2005)

Implementation of this system was planned for and executed very carefully due to the unique atmosphere that exists in hospitals and the criticality of the system that was being implemented. The primary focus of the system was to reduce the number of ADEs, but the system would also promote standardization within the hospital. The system enabled physicians to enter drug orders directly into computers instead of writing the orders on paper.

Once the order was submitted into the system, the physician could see if the system found any conflicts between the order and the patient that would ultimately receive the order. Many doctors understood the benefit of such a system, but there was some apprehension about the automation aspect of the system. Some doctors became concerned that the process would be "deintellectualized".

In order to counteract these concerns, physicians were involved in the planning stage of the implementation process, which is the very first step. "Change is daunting for many physicians, nurses, and health administrators, which is why a clear understanding of CPOE and its benefits, possible drawbacks, and obstacles is necessary. An institution must overcome these barriers for a successful transition. Organizational change is a cyclical process that requires perpetual evaluation." One year before the project went online at CHP, a physicians' advisory committee was formed. The purpose of this committee was to allow the physicians to provide input in the design stage of the process, and also to ensure that the physicians were continually updated with regard to the progress that was being made. The committee remained in place and active even after the implementation was completed successfully.

Once the CPOE system was selected and development was underway, the first integrated meeting between the company providing the CPOE system and stakeholders at the hospital took place. The purpose of this meeting was to ensure that senior management was involved and to brainstorm potential issues that may arise. Attendees were encouraged to express their concerns related to the product, and share negative experiences from past implementations that may repeat themselves if they are not corrected prior to the date that the CPOE system goes online. It was noted that these meetings were not only beneficial in determining what risks the new system brought about, but also to create buy in from senior management.

Seven months prior to the planned date that the CPOE system would go live, a group was formed to determine readiness of the individuals that would be impacted by the system. Surveys were put together and distributed among the employees, and when any areas were found to be lagging behind, these areas received special attention. This process continued throughout the seven months to ensure that all of the employees would be ready once the system went online.

Just prior to the CPOE system going live, a committee was formed in order to advertise the new system. This committee put together four weekly meetings that were attended by all of the employees of the hospital. The meetings briefed the employees on how to use the system and the system's capabilities, and attempted to calm any fears the employees may have had about implementation of a new system. The committee also distributed emails, newsletters and put up posters in order to convey the message that the new system was going online. The intent of the communications was also to ensure that employees understood the benefits of the new system.

Another key to the success of the project was the creation of a group of employees that became "super users". The group was formed prior to the implementation of the CPOE system.

The group was composed of employees from different departments throughout the hospital, and these individuals were trained to be experts at operating and understanding the system. This group of people was integral to the success of the project because they understood the advantages of the system and they were able to convey this message throughout the hospital. They were also able to help other employees operate the software systems, which in turn avoided a large amount of confusion that would have likely occurred without this group of "super users".

Lessons learned from this case would be important to remember in the event that the pooled inventory system is implemented. Support from senior level management would be critical in order to have the project even considered. Once the project has passed this benchmark, it would be important to form committees to investigate the viability of this type of a system within the hospital in question. The committees should include supply chain personnel, doctors, clinicians and senior management. If the committees decide that the project would be beneficial to the hospital, then the committees should remain intact and the process of selecting a vendor should take place.

The vendor for the project should have goals that are well aligned with the hospital, and there should be frequent transfer of information between any vendors selected for the project and the hospital staff. Communication between groups within the hospital must remain open, and all interested parties must be a part of the discussions that take place throughout the process.

Senior management must also remain engaged throughout the process. This would not be a project that could be signed off on by senior management and then forgotten. Goals should frequently be revisited and very clear criteria should be set in order to benchmark progress. Once the implementation has been completed, the processes put in place should be continuously improved, and progress should be periodically reviewed. Managing the change using these ideologies will maximize the likelihood that the project will result in a successful implementation.

7 Conclusion

This research concludes that implementation of an offsite warehouse in which inventory is pooled would result in a great deal of savings for hospital supply chains. The savings would be achieved as a result of a dramatic reduction in inventory holding costs, and also a dramatic reduction in on hand inventory. On hand inventory would be reduced because there would be one stocking location instead of the multiple locations that presently exist for items that are used throughout the hospitals. This decreased inventory cost would be even greater if several hospitals pooled their inventory in the same offsite warehouse.

Additional savings would be realized from a reduction in necessary storage space. Many hospitals presently have an extensive centralized warehouse within the hospital. This echelon of inventory would be eliminated if the offsite warehouse is implemented, and this savings of space may delay the need for hospital expansion. Alternatively, it could also be used to add additional beds within the hospital, which would potentially add to the revenue generated at the hospital.

The offsite warehouse would also reduce the time that nurses and pharmacists spend managing inventory. Inventory would instead be managed by individuals whose primary responsibility is to ensure accurate and appropriate inventory levels. The time nurses save would likely translate into an increased service level rather than a reduction in the number of nurses at the hospitals. There is presently a nursing shortage in the United States and the offsite pooled inventory would help alleviate strain on hospitals due to this shortage.

We have argued in this thesis that each hospital must be viewed as a unique entity, and therefore the supply chains within these hospitals must be designed specifically for that hospital. There is no one-size-fits-all solution to the supply chain inefficiencies that currently exist in hospitals. Segmentation of the product mix that exists within each hospital must be undertaken in an objective manner. Each hospital will need to determine which product characteristics are important to their supply chain, and also the weighted importance for each of these characteristics. This segmentation should dictate which items are suitable to be stored offsite and which items must be stocked within the wards. It is crucial that all critical items are stocked within the hospital wards they may be needed in.

Another important aspect of hospitals that must be understood prior to implementation of the pooled inventory system is the strong resistance to change that generally exists within the hospital environment. In order to successfully implement such a dramatic change, executive management must be involved in the decision making process from the planning stages and must maintain support throughout the entire process. Internally and externally, incentives must be aligned in such a way that everyone working on the project is headed in the same direction. In order to reduce the severity of the resistance to change, it will also be very important to educate all of the users of the system. Doctors and nurses must be educated very early on, and they must also be involved in the planning and implementation stages of the project.

7.1 Future research

There is a significant amount of research that must be undertaken to fully explore the rich area of healthcare supply chain management. Key areas of research are discussed below.

This research determined that significant cost savings could be achieved if hospitals adopt a pooled inventory policy with customized kits delivered to patients in 20 minute intervals. However, this research primarily focused on the benefits of such a system and did not address some of the costs that may be associated with implementing such a system.

Undoubtedly, IT systems would be an integral part of the proposed solution, because such a system would provide the necessary communication of information between the warehouse and the hospital. IT systems can be very expensive, and many times costs increase dramatically once a project has begun. It would be prudent to determine exactly what kind of IT system would be capable of handling the degree of automation and complexity presented by this solution, and how much such a system would cost. If there are no systems available, then an estimate of the cost of developing such a system should be made.

This research briefly discusses a model to reduce warehousing costs, but it is likely that the hospitals would need to financially support the offsite warehouses either directly or indirectly through the vendors. Warehousing costs would need to be determined for this type of pooled inventory warehouse.

Another area for future research is related to the regulations surrounding medications and controlled substances. There are many strict regulations that govern the way medications can be handled. Further research would be needed to determine if controlled substances could be handled at an offsite warehouse and what precautions must be taken to ensure that the supply chain is not compromised.

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Appendix 1: Example of Spreadsheet from APU Station

Start Transaction Time	End Transaction Time	ItemID	Item Name	FacilityStation	Cost
11/15/2007	11/22/2007	26618	(08133)210338	01.S_CL_SR_1	65.96
11/15/2007	11/22/2007	37279	(G00493) 009275	01.S_CL_B	34.50
11/15/2007	11/22/2007	66598	000617	01.S_N_ENDO_3	3.75
11/15/2007	11/22/2007	13409	000671	01.S_OR_GYN	52.00
11/15/2007	11/22/2007	59904	0014M	01.S_OR_CAR_1	5.67

Number of Picks	Volume Per Pick	Reorder Point	Order Up To Point	Average Inventory
0.38	1.00	4	5	5.05
0.23	1.33	3	5	9.62
5.15	2.63	25	50	42.97
0.69	1.00	10	15	12.27
2.77	2.32	18	36	22.78

Days Without Inventory	Stockout Events
0	0
0	0
0	0
0	0
1	1