Differentiating the Hospital Supply Chain For Enhanced Performance

by

Derek T. DeScioli

B.S Industrial Engineering (2001)
Rutgers University, New Brunswick, NJ

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Signature of Author ....
Engineering Systems Division
May 06, 2005

Certified by ....
Dr. Jonathan L.S. Byrnes
Senior Lecturer
Thesis Supervisor

Accepted by ....
Yossi Sheffi
Professor of Civil and Environmental Engineering
Professor of Engineering Systems
Director, MIT Center for Transportation and Logistics

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Abstract

This thesis determines how to design the supply chain policies in a hospital for the wide array of products that exist there. This research was done through interviewing staff and analyzing data of two hospitals implementing automated point of use systems. This thesis argues that a hospital needs to implement more than one supply chain policy in order to achieve its objective of maximizing patient care while avoiding prohibitive costs. The research further proposes that a hospital should develop its supply chain for a specific product based on that product's unit cost, demand, variability, physical size, and criticality. The research analyzes demand data from two hospitals and demonstrates that hospital demand can be modeled using a variation of Croston's method for intermittent demand. This fact was used to generate an appropriate s, Q inventory policy that can be adjusted to fit any product and supply chain policy implemented within the hospital. Under simulation, the proposed inventory policy outperformed existing policies by over 50%. This research further argues current aggregate and "one-size-fits-all" strategies are inappropriate in a hospital and discusses the importance for hospitals to add physical size and criticality attributes to their product master files as these will enable further supply chain enhancements.

Thesis Supervisor: Dr. Jonathan L.S. Byrnes
Title: Senior Lecturer

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Most importantly, I would like to thank the company (referred to as DTD, Inc) and its staff that sponsored and helped organize this research. It is these visionary companies that lead all industry innovation.

Dedication

This thesis is dedicated to my beloved new wife, Xiaoli, who has been a complete angel and true partner throughout this entire process. She has truly shown me that love has no boundaries and surpasses both space and time.

Biographical Note

Derek T. DeScioli is a 2005 candidate for the MLOG degree. Derek is currently the COO of a start-up company, Agiltechnologies, Inc, and is a VP of the Supply Chain Club at MIT. Prior to attending MIT, he worked as the Operations and Logistics Manager for an industrial electronics manufacturer in Shenzhen, China. Derek received his undergraduate degree in Industrial Engineering at Rutgers University, where he graduated with Highest Honors.

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1 Introduction

In any business, a supply chain needs to be designed with respect to the strategy and the nature of the company's business. Across hospitals, the strategy is consistent. To put it simply, a hospital's strategy is to maximize patient care. The hospital supply chain enables this strategy by:

- Ensuring product availability
- Minimizing storage space → Maximizing patient care space
- Reduce material handling time and costs for all medical staff (nurses, pharmacists, doctors)
- Minimizing non-liquid assets (inventory)

Hospital supply chains are complex. The hospital product line consists of high cost and low cost items as well as perishable and durable goods that are consumed in large and small volumes. In addition, there are highly critical and non critical items. Hospital supply chains have to be constructed such that they can handle products with all combinations of these various traits (i.e. highly critical, low volume, high cost, perishable goods).

A hospital's size, geographic location, diversification, and various specializations all affect the nature of its business, and, hence, the requirements of its supply chain. Likewise, each ward within a hospital is unique. The number of products and demand of those products, for example, varies greatly from an Emergency Room to a Cardiac Cath Lab to an Intensive Care Unit. Therefore, the optimal supply chain in one ward of a particular hospital is not necessarily the best solution for any other ward in that hospital or any other hospital. Nor should the supply chain policy for a particular product within a ward be identical to that of other products in the same ward.

For that reason, this study focuses on differentiating the supply chain policies within a hospital. That is, the supply chain policy developed for a particular product should reflect the nature of that product, and differing products should have different policies. This study proposes that a hospital should develop its supply chain for a specific product based on that product's unit cost, demand, variability, physical size, and criticality. Thus, a hospital requires more than one supply chain policy in order to meet its strategy of maximizing patient care without incurring prohibitive costs.

The typical extended supply chain for a hospital can be seen in the figure below.

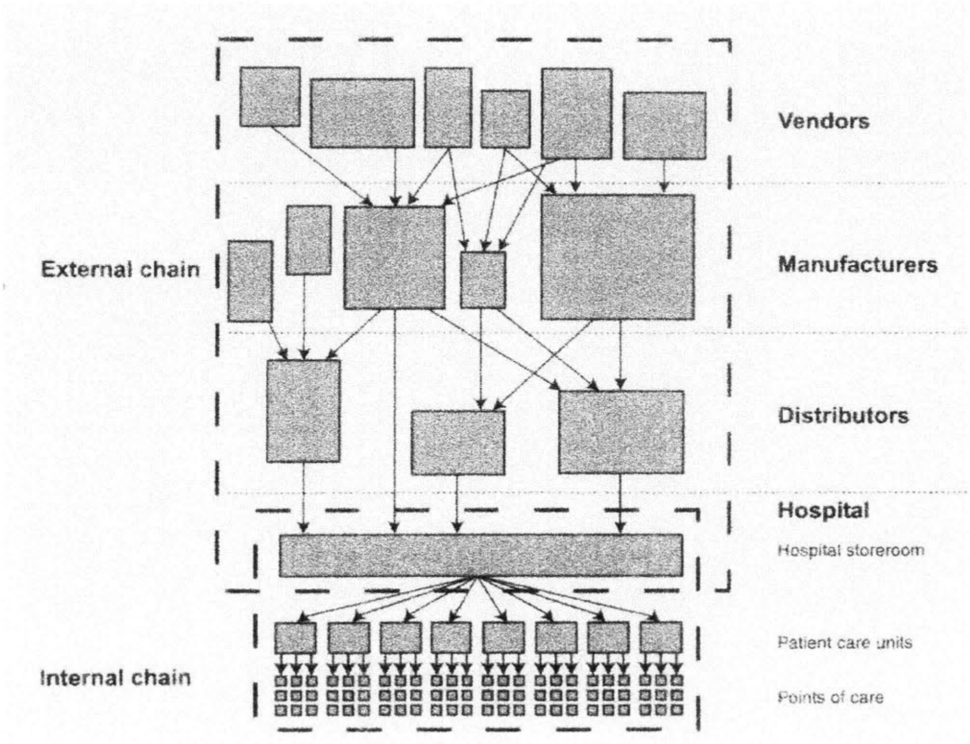


Figure 1: Typical Hospital Supply Chain. Source (Rivard Royer et al, 2002)

This study focuses on the process and flow from the distributor's (or manufacturer's) shipping dock to the points of care, but will not address the supply chain design elements at the distributor or manufacturer.

1.1 Thesis Background

To complete this research, the author worked closely with one of the leading U.S distributors for medical supplies and pharmaceuticals, DTD, Inc (disguised name). DTD, Inc offers a wide array of services, supporting all of the various supply chain paradigms that will be discussed in chapter 3. The objective of the study was to analyze a new product and service offering that DTD, Inc was offering to its clients. This service was a stockless, vendor managed inventory system coupled with automated point of use systems (These terms are defined in Chapter 3). At the time of this research, DTD, Inc was implementing this new offering in 14 different hospitals. In particular, the author studied two of these hospitals, Mid West Hospital (MWH) and West Coast Hospital (WCH), that were in the process of converting to the new supply chain strategy. The study included interviews of various hospital staff at each location as well as DTD, Inc employees that were working to implement the new supply chains within the hospitals. In addition, each hospital provided the data that will be used in this study to determine the proper inventory policy.

1.1.1 MWH

Mid West Hospital (MWH) started its partnership with DTD, Inc in April 2003. In this partnership, DTD, Inc instituted a VMI stockless solution coupled with Automated Point of Use (APU) systems (These terms are defined in Chapter 3). At the time of this research, DTD, Inc.

had only assumed material management functions for the medical supplies, within MWH and had not implemented any systems for the pharmaceutical products.

Some general statistics on MWH can be seen in Table 1. MWH is a university hospital and specialized treatments include solid organ transplantation, cardiac care, burn care, wound care, geriatrics, bone marrow transplantation, radiation therapy and oncology.

MWH Summary Statistics	
Number of Beds	700
Inpatient Admissions (2003)	22,000
Emergency Visits (2003)	45,000
Outpatients (2003)	300,000
Number of Employees	5,250

Table 1: MWH Summary Statistics

1.1.2 WCH

West Coast Hospital (WCH) started using Automated Point of Use (APU) systems for its pharmaceutical supplies over 10 years ago. In the last two years, it partnered with DTD, Inc to implement a stockless solution with APU systems for its medical supplies. Unlike MWH, at the time of this research, DTD, Inc did not have material management responsibilities within the hospital.

Some general statistics on WCH can be seen in Table 2. WCH is a not-for-profit community hospital and specialized treatments include Cardiac Care, Cancer Care, High Risk OB & Newborn Care, Dialysis, and Orthopedics.

WCH Summary Statistics	
Number of Beds	411
Inpatient Admissions (2003)	20,000
Emergency Visits (2003)	36,000
Outpatients (2003)	400,000
Number of Employees	2,000

Table 2: WCH Summary Statistics

2 The Hospital Industry

Since the 1970s, the U.S hospital industry has been characterized as having ever increasing costs and reduced cash flow. In 2002, the Center of Medicare and Medicaid Services (CMS) reported that health care expenditures totaled to $1.4 Trillion, or about 14% of the national GDP, as compared to 7% in 1970. In addition, CMS reported that hospitals accounted for 31% of the nation's healthcare expenditures in 2002. As of 1998, the U.S department of labor began to monitor the hospital price index. From 1998 to 2002, the hospital price index increased by 30 points, as compared to the general consumer index, which only increased by 15 points (see Figure 2.1).

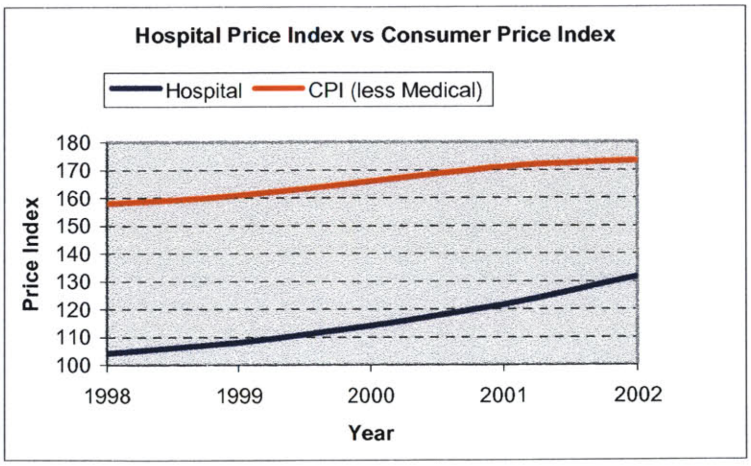


Figure 2: Hospital Price Index vs Consumer Price Index (Source CMS/OACT and U.S Department of Labor)

Healthcare expenses have consistently outpaced inflation and the higher costs have an impact on the entire nation's economy. According to the CMS, in 2002, government agencies (Medicare, Medicaid, etc) compensated for 47% of those expenses and private health insurance companies paid about 35% of the total. In 2004, Standard and Poor's reported that U.S employers expected their heath care costs to rise 12% (Conneley 2004).

Meanwhile, hospital cash flow has been quite low. For example, for-profit hospital profit margins average 3% to 5% (CMS 2003). This reduction in cash flow limits the hospital's ability to invest in more personnel and advance equipment that further enhance patient care. Hence, the industry has focused on innovative strategies to reduce costs in several areas of its process and operations not just for the benefit of the hospitals, but also the general public good, as Medicare, Medicaid, and other government agencies pay approximately 47% of the country's healthcare expenses (CMS 2003). One of the areas of focus has been increasing supply chain efficiency.

2.1 Supply Chain Costs

It is estimated that inventory management accounts for anywhere between 17% and 35% of a hospital's total revenue (Nathan and Trinkus 1996). Inventory management is defined as the cost of supplies and labor required to manage inventories, material, and information flows. Figure 4 depicts the proportions of the major expenses for publicly traded hospitals in the U.S. Therefore, a small reduction in inventory management expenses can have an enormous impact on the hospital's bottom-line. For example, a hospital running at 5% profitability, with 30% inventory management costs could improve profitability by 60% with a 10% reduction in its inventory costs. Hospitals can then reinvest these savings into equipment and personnel that further enhance patient care.

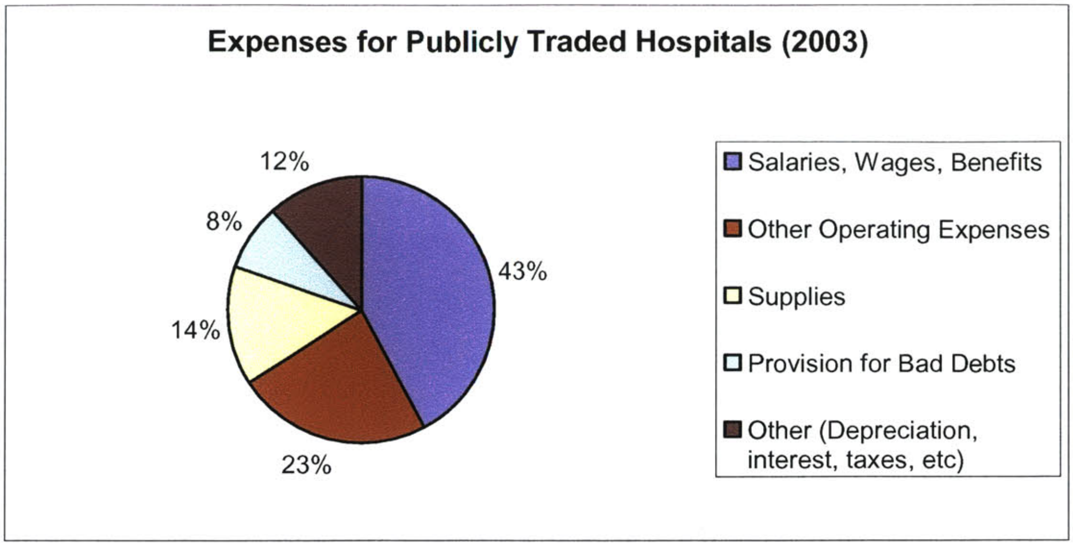


Figure 3: Expense Breakdown for Publicly Traded Hospitals (Source: CMS 2003)

3 Hospital Supply Chain Evolution

In the 1980s, hospitals began implementing innovative supply chain strategies in order to reduce costs and, more importantly, improve service levels. The standard supply chain was replaced with new paradigms, dubbed as stockless inventory, vendor managed inventory, consignment, and automated point of use systems. For clarification, this chapter will define the nature of the standard supply chain and the four emerging paradigms.

3.1 Standard Supply Chain

In a standard hospital supply chain, all material operations are controlled by the hospital. Material personnel include purchasers, material handlers, and stockroom personnel. Other personnel, mainly nurses, technicians, and pharmacists, also spend a significant amount of time with material operations. Purchasers and material handlers are typically assigned to one or more wards within a hospital.

Material from the hospital's various suppliers is delivered in bulk to the hospital's loading dock and transported to a main store room. Material handlers then transport material from the main store room to various secondary store rooms in wards throughout the hospital as the inventory in those wards diminishes. Typically, hospitals do not track perpetual inventory, but rather use visual cues to decide when to place an order for more material. Various hospital employees can pull inventory as they see fit with no record or accountability.

The standard hospital supply chain is characterized as having inflated inventories (6 – 8 weeks) and a high occurrence of stockouts (90-95% fill rate) (Rivard-Royer, 2002). In general, medical staff has no incentive or time to be concerned with efficient material operations as they are much more concerned with taking care of patients. In addition, the lack of any inventory system makes it virtually impossible for the personnel to know which inventory is in excess and which is short as they have no visibility into the inventories that are scattered all over the campus.

3.2 Stockless Inventory

In order to help hospitals reduce inventory and increase fill rates, healthcare distributors began to offer stockless inventory programs to their various customers. Under a stockless program, the distributor delivers product in pieces rather than bulk. The hospital is still responsible for placing the orders. Orders are transmitted from individual wards, and the material is delivered directly to the ward, bypassing the store room. Some redundant functions are removed from the supply chain as shipments are counted only once (at the distributor) as compare to the old system where each shipment was counted twice (at the distributor and at the hospital receiving dock). In essence, as compared with the standard supply chain, distributors have assumed the duties of holding inventory and replenishing individual locations. The implementation of a stockless system requires a "continuous flow of information between the point of use and the distributor" (Rivard-Royer, H., Landry, S., Beaulieu, M. 2002).

The benefit to the distributors under the stockless program is that they capture a larger share of the hospital's total purchases and typically charge a markup between 3-7% on all the products they deliver to the hospital (Wagner 1990). In addition, under this program, the distributors have more visibility into the actual usage of the hospital; thereby reducing the bull whip effect that is prevalent in many extended supply chains. The bull whip effect explains that demand variations tend to increase as one moves up the supply chain.

The benefit to the hospitals under the stockless program is that it reduces inventories, labor costs, and stockouts. Wilson, Cunningham, and Westbrook (1992) documented three hospitals that reduced inventories anywhere between 40 and 80%. Rivard-Royer et al (2002) reported that hospitals reduced full time equivalents (FTE's) by 45%. Several studies reported between 15 – 25 FTE reductions, totaling to an annual cost savings between $400,000 and $1,000,000 (Kerr, 1991; North, 1994; Wilson et al. 1992). Nathan and Trinkaus noted two hospitals with item fill rates over 99%, compared with a conventional average of 92% (Rivard-Royer 2002).

The removal of a main store room can also be beneficial. In some cases, hospitals rented their stockroom space, and stockless programs allowed them to close those areas and remove those expenses. In other cases, hospitals were able to convert their store rooms into patient care units, enabling higher revenues for the hospital.

Reduced expenses free up cash such that the hospital can invest in medical equipment and other assets. In addition, as its number of suppliers is reduced, the hospital's associated administration expenses reduce.

3.3 Vendor Managed Inventory

While stockless inventory systems have clear benefits for hospitals with virtually no inventory control, the system still does little to reduce costs and optimize operations within the entire supply chain channel. It removes fiscal accountability from hospital employees placing orders on the distributors. With no cost penalty, hospitals can, for example, order one piece of a particular part every day (i.e. a comb) rather than consolidate to weekly shipments of five pieces. In short, there is no incentive for the ordering group to be efficient. To no surprise, over time, many distributors increased their charges for their stockless accounts to offset these inefficiencies inherent in the system (Marino, 1998).

As a result, distributors offer a service of vendor managed inventory (VMI). Under VMI, the distributor hires employees to work in the hospital and assume all material operation duties, including material handling, warehousing, and purchasing. The distributor not only purchases material from its own facilities, but also from manufacturers and their competitors, as directed by the medical staff. In his article "Profit from Customer Operating Partnerships," Dr. Jonathan Byrnes (January 2003) noted that VMI stockless systems are mutually beneficial to both channel partners as they reduce costs by "removing redundant functions and inventory within the channel" and "alter the picking, materials management, and information processing systems". As these distributors have a high incentive to focus on the supply chain efficiency, they implement inventory systems within the hospital operations and focus on optimizing order sizes and inventories. In addition, VMI has a major impact on the control "unofficial inventories" (Sjoerdsma 1991). Unofficial inventories are those inventories that are unaccounted for in the hospital accounting and inventory records. For example, before implementing APU systems, WCH recorded an inventory expense when inventory was issued to the ward rather than when the inventory was actually used. It is estimated that conventional hospitals may have 6 times more unofficial inventory than reported.

3.4 Consignment

Under consignment, the vendor (i.e. distributor or manufacturer) owns the inventory until it is actually issued to the end user, termed the point of care. Consignment policies exist within each of the above supply chain strategies. The only real benefit of a consignment policy is that the hospital's inventory assets decrease and the hospital can invest the cash in medical equipment and other assets.

3.5 Automated Point of Use Systems

An advancement in hospital supply chains in recent years has been the implementation of Automated Point of Use (APU) systems (see Figure 4). The device on the left is for medical supplies, while the device on the right is for pharmaceuticals. These devices are placed in the various wards throughout the hospital and only allow authorized users to pull inventory. Pull transactions are inputted directly on a computer or monitor or by pressing a "take" button located on the appropriate bin. These systems keep perpetual inventory records and automatically place orders based on the established reorder and order-up-to points. APU systems apply accountability to those using the inventory; and therefore, reduced shrinkage and increase cost capture. Cost capture is defined as the act of charging patients for the actual materials that were administered to them. Although these items can be quite effective in controlling inventory, they are also quite costly and slow down inventory deployment, as medical staff is required to login before they can take any supplies. Therefore, it may not be cost effective to place low cost, non critical items into these devices, as they are currently designed. This assertion will be analyzed further in this study.

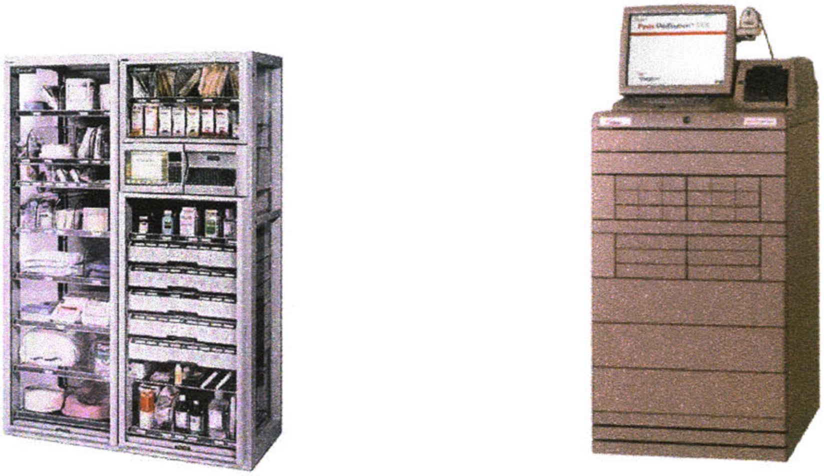


Figure 4: Automated Point of Use Systems -- OmniSupplier® and Pyxis Medstation®

Another benefit of APU systems is that they allow for visibility into the entire hospital's inventory. Hence, for common parts, a shortage in one ward can be mitigated with excess inventory from another ward until the next replenishment arrives. This is a very significant advantage. Duclos (1993) performed a study that demonstrated that point-of-use safety stock was much less effective than central store safety stock in preventing stock-outs during shock demand situations. In her model, Duclos defined shock demand as a 300% increase in typical demand for 24 hours. As emergency demand is a characteristic of many hospitals business model, the study's conclusions are cause for concern and question the stockless model. However, in this study, Duclos's model assumed no visibility of inventory from ward to ward. The added visibility from APU systems void Duclos's findings and increase the resiliency of the hospital supply chain under emergency demand situations.

3.6 The Next Step in Supply Chain Evolution:

With the advent of Automated Point of Use systems, the hospital industry has enabled itself to become much more sophisticated in the implementation and measurement of its supply chain policies. First of all, data collected by APU systems can be used to automatically generate statistical appropriate inventory policies rather than the rules of thumb that were used in the past. As mentioned earlier, there is a wide array of products within a hospital; and therefore, there is an inherent flaw to treat them alike and measure supply chain performance at an aggregate level. For example, all interviewees agreed that the service level for a critical component, such as a stent, should be higher than that of a non critical item, such as a gauze pad or glove. However, neither the hospitals surveyed in this study nor the ones surveyed in literature accounted for this in the supply chain policy design or performance measurements.

Hospital part master files should be updated to go beyond the standard part number, description, unit of measure and unit price information to include attributes such as physical size, and criticality. These added attributes, particularly criticality, will enable the hospital to further meet its strategy of maximizing patient care.

4 Methodology

This research was divided into two parts -- interviews of members within the hospital supply chain and data analysis of hospital demand and inventory policies. Staff members interviewed ranged from nursing staff to DTD Inc Sales Directors to the hospital CEO, CFO, and CIO. A detailed list of all interviewees in each hospital can be seen in Appendix A. The purpose of these interviews was to achieve a clear understanding of the key success factors for a hospital supply chain and shortcomings of existing supply chain policies.

Data analysis was used to develop and evaluate an appropriate inventory policy model that would consistently meet targeted service levels while minimizing material management costs. The majority of the data analysis was done with information provided by MWH. MWH provided 3 months of transactional data for its medical supplies including remove and refill transactions, a current inventory report including inventory levels and SKU cost information, and specific par level information for a select number of wards. MWH also provided general financial information that was used to estimate order costs.

WCH provided 6 months of daily demand data for its medical supplies. However, it did not provide transactional data, pricing information, or an inventory report for these products. WCH also provided 3 months of transactional data for its pharmaceutical products along with current par level information. However, it, again, was unable to provide unit cost information for these products. Hence, data provided by WCH could not be used in developing and evaluating an inventory policy, but its demand patterns could be compared to the data provided by MWH in order to determine if the methods developed for MWH could also be applied to WCH and other hospitals.

4.1 MWH Data

The data provided by MWH was examined at the Station-SKU level. In other words, each SKU (Stock Keeping Unit) in a given station was treated as a separate entity. MWH provided data for 83 stations comprising 30 different wards. Table 3 characterizes the number of Station-SKU's and SKU's present in MWH.

MWH Data Points	
Data Points	**Qty**
Station-SKU's with Inventory	15,061
Station SKU's with Transactions	11,270
Station-SKU's with Demand	9,837
SKU's with Inventory	4,439
SKU's with Transactions	3,026
SKU's with Demand	2,726

Table 3: MWH Data Points

As can be seen in Table 3, a significant number of SKU's (~1700 or 38%) and Station-SKU's (~5200 or 35%) held in the hospital did not have any recorded demand over the three month period used in this analysis. No analysis could be completed on these items; and hence they were not used in developing and evaluating inventory policies. It is unknown whether these were parts with no movement, parts being phased out of the hospital, or parts recently introduced to the hospital. However, DTD, Inc and MWH should review this inventory carefully as it has little to no usage. The 9,837 Station-SKU's modeled in this study represent approximately $1.9 million of a total of $3.6 in medical supplies inventory. The 3 months of transactional data provided for these Station-SKU's consisted of over 222,000 remove transactions and 76,000 refill transactions.

5 Developing an Inventory Policy

This chapter discusses current inventory policies within MWH and WCH, and then proposes two alternative inventory policies that are based on statistical analysis rather than rules of thumb. The major advantage of these proposed policies is that they can be customized to a particular product's characteristics, whereas the current inventory policies are much less flexible.

The inventory policies developed in this chapter account for three of the five product characteristics that should be used to determine the appropriate inventory policy – unit cost, demand, and variability. The data provided by the hospitals included this information; and therefore, specific models could be developed and analyzed using this information. For the other two characteristics, physical size and criticality, there was no data available for specific products. Therefore, their inclusion into supply chain policy decisions will be discussed at a more theoretical level in Chapter 7.

5.1 Current Inventory Policies

Most hospitals, including MWH and WCH, institute an s, S inventory policy, where s is the reorder point, and S is the order-up-to point. This means that if the current inventory is less than or equal to s at the time of an inventory review, then an order is placed to bring the inventory up to a level of S. Within the healthcare industry, these are dubbed as par levels. The inventory is reviewed periodically; and the length of the review periods is not constant. Both WCH and

MWH review their inventory levels on Sunday, Monday, Wednesday, and Thursday evenings with deliveries arriving the next morning. Hence, the inventory review period varies between 1 day and 3 days for both hospitals, and the lead time is approximately a half day.

In MWH, the par levels for medical supplies are arbitrarily chosen by the supply technicians employed by DTD, Inc. Procedurally, the supply technicians are directed to collaborate with nurses when setting these levels, ensuring the customer agrees to the changes. Most likely, the operator adjusts the minimum point higher on any particular SKU that happens to stockout. As there is no particular incentive to lower any minimum points, it is likely that the inventory has been gradually increasing, though no data was provided to analyze this.

In WCH, the original par levels for medical supplies were established in a similar fashion to that of MWH. However, during the time of this research, they were changing the system, such that the par level would be a multiple of the maximum daily usage in the last 6 months. WCH proposed to set "4 times maximum" as the order-up-to point and a "3 times maximum" reorder point.

5.2 Demand Modeling

In order to develop an appropriate inventory policy for a product, one must first characterize the demand of that product as the volume and variability determine the appropriate stocking levels. This section analyzes the hospital demand patterns from the data provided by MWH and develops a mathematical model to accurately describe and simulate those patterns.

For hospitals implementing stockless supply chain policies, the demand needs to be analyzed and modeled on a daily basis. Table 4 shows the general nature of the daily demand for medical supplies in MWH across all the Station-SKU's.

MWH - MPS Station-SKU Classification by Demand			
Demand Level	**Description**	**Total**	**Percentage**
Slow Moving	Less than 10 per day	9465	96.20%
Moderate	10 - 100 per day	337	3.43%
High	Greater than 100 per day	37	0.38%

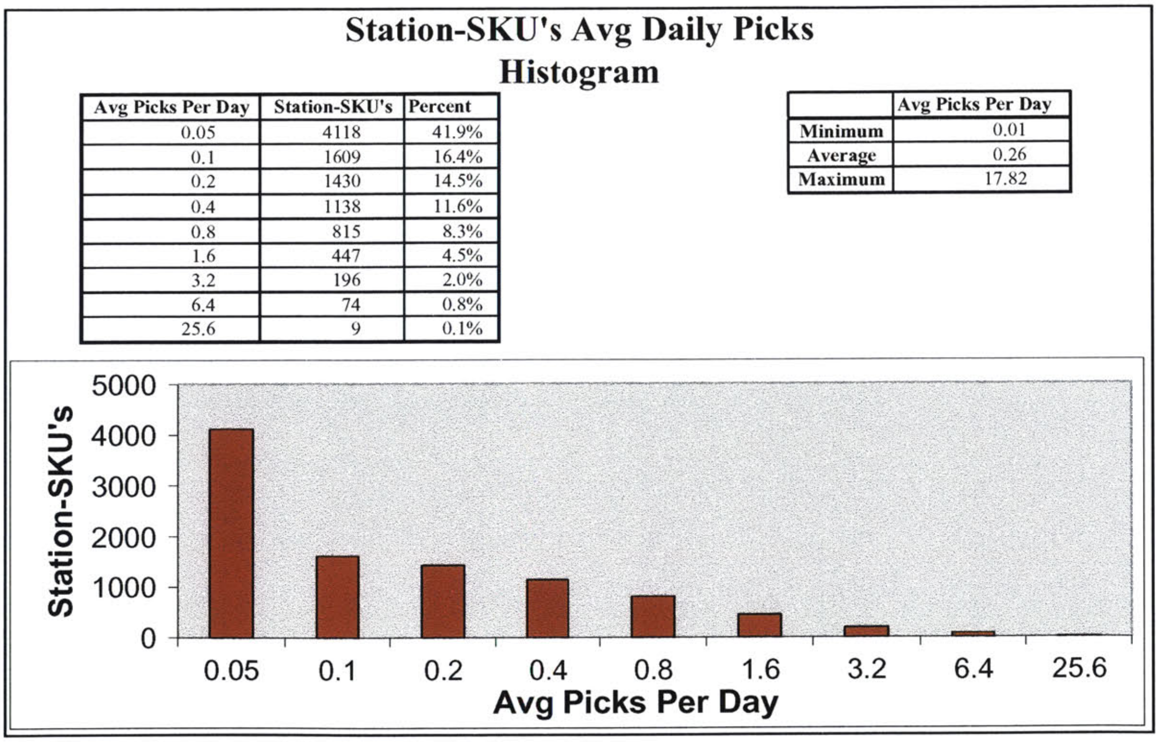
Table 4: MWH Station-SKU Classification by Daily Demand

Over 96.2% of the Station-SKU's can be classified as slow moving. Hence, traditional demand models, such as moving average and exponential smoothing, are not effective in modeling hospital demand. One MWH manager noted that the hospital industry should be focusing towards spare parts industries for developing its inventory policies. Hence, this research investigated successful techniques used in spare parts to develop a proper modeling technique for the hospital.

5.2.1 Model for Intermittent Demand

Further analysis of the daily demand for MWH's Station-SKU's demonstrated that they can best be described as intermittent demand. Intermittent demand is described as an inventory pattern where there are many periods with no demand and a few periods with either small or large demand. Croston (1972) developed a method for modeling systems with intermittent demand and demonstrated its superiority over traditional forecasting methods. Croston's method segregates demand into two elements – demand size and demand frequency. A variation of that method was used in this research to model hospital demand. This section will demonstrate that the demand within the hospital is, in fact, intermittent and will develop the mathematical model for describing that intermittency.

In accordance with Croston's method, the demand for each Station-SKU was analyzed in two segments, the pick event itself, and the quantity of each pick. Figure 5 illustrates a histogram of the average number of picks for all Station-SKU's. The average daily number of picks was 0.26, and over 93% of the Station-SKU's had an average daily pick of less than 1. Over 60% of the products were picked less than once per week. This clearly demonstrates the appropriateness of Croston's method.



Station-SKU's Avg Daily Picks Histogram

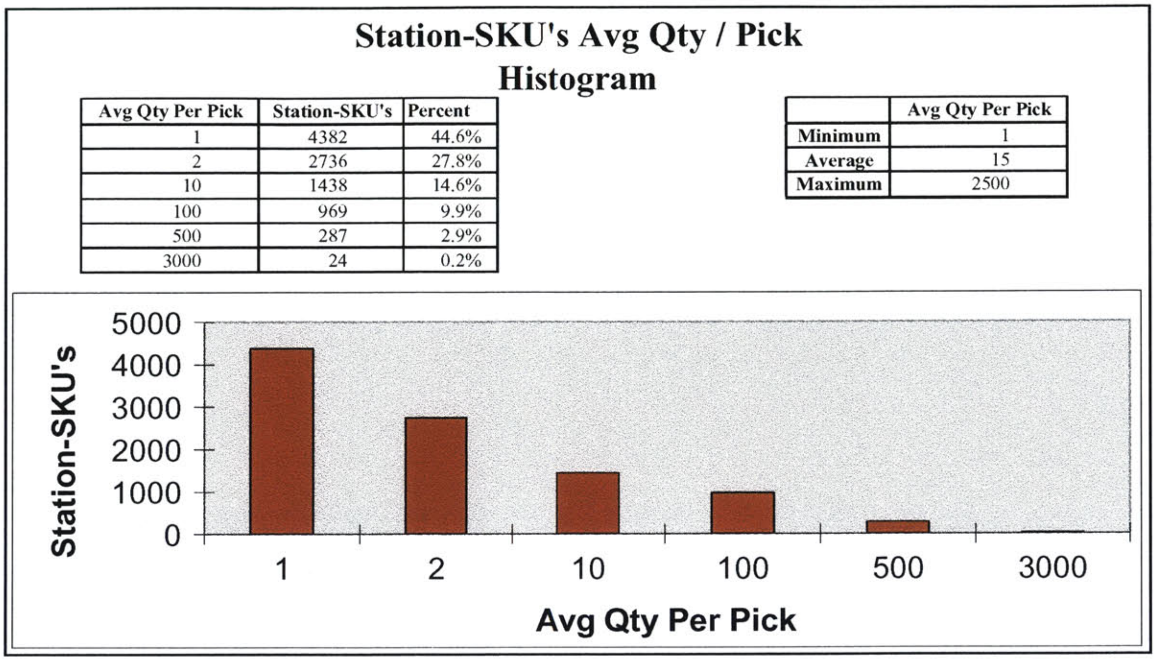
Avg Picks Per Day	Station-SKU's	Percent
0.05	4118	41.9%
0.1	1609	16.4%
0.2	1430	14.5%
0.4	1138	11.6%
0.8	815	8.3%
1.6	447	4.5%
3.2	196	2.0%
6.4	74	0.8%
25.6	9	0.1%

	Avg Picks Per Day
Minimum	0.01
Average	0.26
Maximum	17.82

Figure 5: MWH Station-SKU's Average Daily Pick Histogram

Figure 6 illustrates a histogram of the average quantity per pick for all Station-SKU's. The average quantity per pick was 15 pieces. However, this average is skewed as 87% of the Station-SKU's had an average less than 10 pieces.

Both Figure 5 and Figure 6 further demonstrate the sporadic and intermittent nature of the demand. Most Station-SKU's had more days with no movement than days with demand; and for 25% of the Station-SKU's, average demand was in batches rather than single pieces. In addition, most Station-SKU's had varying quantities per pick.



Avg Qty Per Pick	Station-SKU's	Percent
1	4382	44.6%
2	2736	27.8%
10	1438	14.6%
100	969	9.9%
500	287	2.9%
3000	24	0.2%

	Avg Qty Per Pick
Minimum	1
Average	15
Maximum	2500

Figure 6: MWH Station-SKU's Average Quantity per Pick Histogram

The daily demand (D) is modeled as a compound distribution of two variables – the number of demands (N) and the size of each demand (x). The number of picks for a particular Station-SKU is assumed to be Poisson distributed with a daily average of λ. The Poisson distribution is a discrete distribution. A graphical representation of the Poisson distribution for different values of λ can be seen in Figure 7. The size of each demand is assumed to be normally distributed with a mean of μ and a standard deviation of σ. A graphical representation of the normal distribution can be seen in Figure 10.

Hence,

$$
\begin{aligned}
&D = x_1 + x_2 ... + x_N \\
&N \sim Po(\lambda) \\
&x \sim Norm(\mu, \sigma)
\end{aligned}
$$

For a given number of demands (N), the daily demand can be expressed as follows:

$$D \sim Norm(N\mu, \sqrt{N}\sigma)$$

As Poisson is a discrete distribution, the expected daily demand (E[D]) can be calculated with the following summation:

$$
\begin{aligned}
&E[D] = \sum_{n=0}^{\infty} (P(N = n) * n\mu) \\
&OR \\
&E[D] = \sum_{n=0}^{\infty} (\frac{\lambda^n}{n!} e^{-\lambda} * n\mu)
\end{aligned}
$$

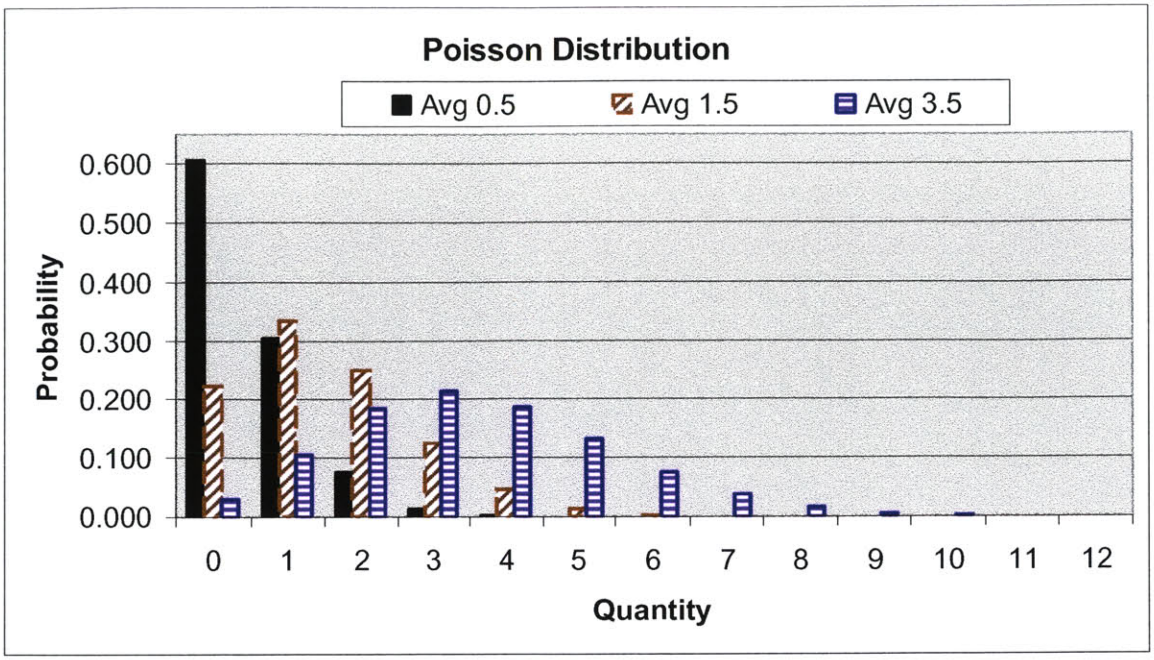


Figure 7: Poisson Distribution for various λ's

5.2.2 Daily Demand Variations

Another observation was that some wards demonstrated cyclicality with respect to weekdays and weekends, while other wards had an equal amount of demand on all days. Wards were classified into three sections – Regular Demand (R), where the demand level was constant for all days of the week, cyclical (C), where the total weekend demand was less than 16.7% of the total demand and highly cyclical (CC), where the weekend demand was less than 1% of the total demand. Of the thirty wards, six were highly cyclical, five were cyclical, and nineteen were regular. The classification for each station and ward can be seen in Appendix C.

It is important to adjust for this cyclicality in developing the demand model. Otherwise, the model will understate the potential demand occurrences for any given day. When developing the model, the average pick per day was calculated assuming a 5 day work week for highly cyclical wards, a 6 day work week for cyclical wards, and a 7 day work week for regular wards.

5.2.3 Model Validation

The model and simulation were derived using MS Excel and the Simtools Add-in. To simulate the demand in MWH, the number of picks on a particular day for a particular part was randomly generated using an inverse poisson function (Poisinv(Rand(), λ)). The quantity for each pick was randomly generated using the inverse normal function (Norminv(Rand(), μ, σ)). Any negative quantities generated by the inverse normal function were rounded to zero. The average pick per day, λ, was adjusted for wards demonstrating cyclicality (See 5.3.1). Likewise, cyclicality was accounted for in the final demand generation. Highly seasonal wards were modeled with zero demand on the weekends and seasonal wards were modeled with 50% the randomly generated demand on the weekends.

The model itself generated 30 days of demand for each simulation run. The demand model was simulated 50 times (~50 months) for all wards (9,837 Station-SKU's) and the aggregated data was compared to the actual 3 months of transactional data that was provided by MWH. The results can be seen in Table 5.

Demand Characteristics (30days)					
	Actual Data	**Simulation**	**Percentage**	**Std Deviation**	**CV**
Total Pcs	724,461	733,216	1.2%	15,585	0.021
Total Value	$858,134	$847,700	1.2%	$31,097	0.037
Sum of Daily Zero Demand	251,887	251,738	0.1%	152	0.001
Daily Max Demand (Pcs)	34,662	32,274	6.9%	779	0.024
Daily Min Demand (Pcs)	18,168	17,325	4.6%	577	0.033

Table 5: Demand Model Validation

To validate the model, five measurements were analyzed. First, the total demand, measured in pieces, was compared. The actual data averaged 724,461 pieces over a 30 day period, and the modeled demand had an average of 733,216 pieces with a coefficient of variation (CV) of 0.021, which was within 1.2% of the actual data. Secondly, the total demand, measure in dollars, was compared. The actual data averaged $858,134 while the simulated demand had an average of $847,700 with a CV of 0.037, which, again, was within 1.2% of the actual data.

The next measurement looked at the total number of days with zero demand for all Station-SKUs to ensure that the model accurately reflected the intermittent and sporadic nature of the demand in the hospital. The actual data had 251,887 total Station-SKU days with zero demand, and the modeled demand had 251,738 Station-SKU days with zero demand with a CV of 0.001, which was within 0.01% of the actual data.

The final two measurements analyzed the maximum and minimum demand, measured in pieces, for a given day to ensure that the random demand generated in the model accounted for the aggregate variation in daily demand, and that the actual data did not contain any particular days that had a disproportionately high or low level of demand. The simulated maximum daily demand was 6.7% less than the actual maximum daily demand, but was within 3 standard deviations of the simulated demand. This suggests that the demand across Station-SKU's is not completely random, and there may be particular days with higher demands, though it was not considered significant enough to adjust the model.

Given the high accuracy of the first three measurements and the acceptable accuracy of the next two the model was confirmed to accurately display the nature of the hospital demand at the Station-SKU level.

5.3 Ordering Cost

The ordering cost is the fixed cost associated with placing an order for a single line item regardless of the quantity of that item. From the hospital's perspective, the ordering cost includes the cost to place the order, the cost to receive the order and refill the appropriate location, and the administration cost to pay for the order.

In cases where vendor managed inventory (VMI) is implemented, the distributor would also want to include the cost associated with both the hospital and the distribution warehouse.

Based on cost information provided by MWH, the order cost in this analysis was estimated to be $5 per line item. The details of this estimation have been kept confidential.

5.4 Carrying Cost

Neither MWH nor WCH provided carrying costs. In this analysis, the annual carrying cost for inventory was assumed to be 20% of the unit cost for all products. Chapter 7 will later discuss the fact that some products should have higher carrying costs than others.

5.5 Stockouts

Stockouts are the number one concern within the hospital supply chain. DTD, Inc is contractually obligated to maintain a 98% service level within both MWH and WCH. Here service level (SL) is a fill rate defined as:

$$SL = 1 - \frac{NumberofStockouts}{NumberofPulls}$$

A stockout is recorded every time the inventory for an SKU in a particular station is zero. Although this is not technically a stockout as it is unknown whether or not there was actually demand for the product during the no stock period, it is the only measurement that it is available; and therefore, the same measurement is used in this analysis.

5.5.1 Calculating Implied Stockout Cost

Neither MWH nor WCH developed a cost associated with a stockout, but rather, targeted a particular aggregated service level. The cost of a stockout is implied by the targeted service level and required safety stock to achieve such a service level such that:

$$SS * C_c = N_{SO} * C_{SO},$$

SS is safety stock, C_c is carry cost, N_{SO} is number of stockouts and C_{SO} is cost of a stockout. Therefore, the cost of a stockout was estimated using the actual current practice in MWH. Assuming a target of 99% service level (which is the current level obtained by DTD, Inc in MWH), a stockout has an implied cost of $77.75 (See Appendix D for detailed calculation). This analysis assumed the majority of inventory with no demand was slow moving inventory, and hence, used $3.6 million as the average inventory rather than the $1.9 million that was actually included in the generated demand model. This cost will be used throughout this analysis in evaluating the effectiveness of the existing and proposed supply chains.

This implied stockout cost is lower than might be expected and demonstrates the downfall of establishing service levels and measuring supply chain effectiveness at the aggregate level. This will be developed further in Chapter 7.

5.6 Proposed Inventory Policies

An inventory policy should take into consideration all the costs associated with managing the inventory. This includes purchasing costs, inventory carrying costs, ordering costs, and stockout costs. The purchasing costs are outside of the scope of this research and considered constant for all inventory policies. Hence, this research focuses on developing an inventory policy to optimize the total material management costs associated with inventory carrying costs, ordering costs, and stockout costs.

For any given product, the total cost, TC, can be expressed by the formula listed below:

$$TC = I_{avg}C_c + AN_O + C_{SO}N_{SO}$$

I_{avg} is the average inventory, C_c is the carrying cost, A is ordering cost, N_O is the number of orders, C_{SO} is the stockout cost, and N_{SO} is the number of stock outs.

As such, two typical periodic review inventory policies were developed, and they are discussed in the two subsequent sections.

5.6.1 Base Stock (*S*) Inventory Policy

The first proposed inventory policy minimizes inventory while achieving a targeted service level. This policy is termed as a standard base stock, or *S* inventory policy, with periodic review. Under this policy, inventory is replenished up to the base stock point, *S*, every time the inventory is reviewed. Figure 8 illustrates this policy. The inventory level is reviewed every time period R, and after an order is placed, the inventory is refilled after a lead time L. Inventory is ordered up to point *S* each review period.

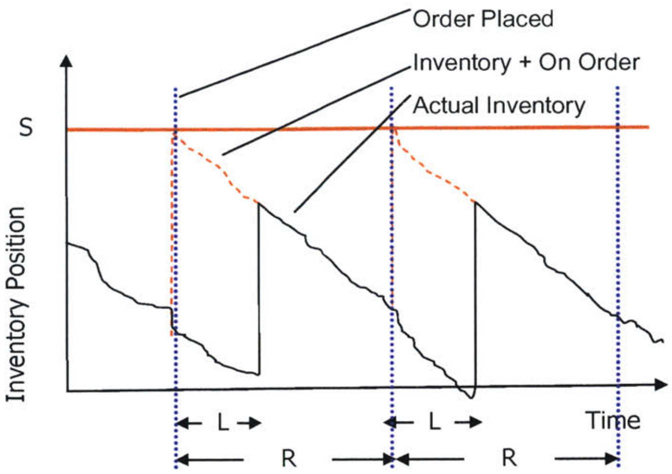


Figure 8: *S* Inventory Policy Illustration

To achieve a targeted service level (SL), the safety stock must be set such that the probability that the demand over the lead time is larger than the safety stock is less than or equal to 1-SL. Mathematically, this is calculated using an inverse cumulative function, such that the sum of the individual points is greater than or equal to the targeted service level. Figure 9 illustrates a service level of 95% for a demand that is poisson distributed with an average lead time demand of 1.5. The service level is met at a quantity of 4.

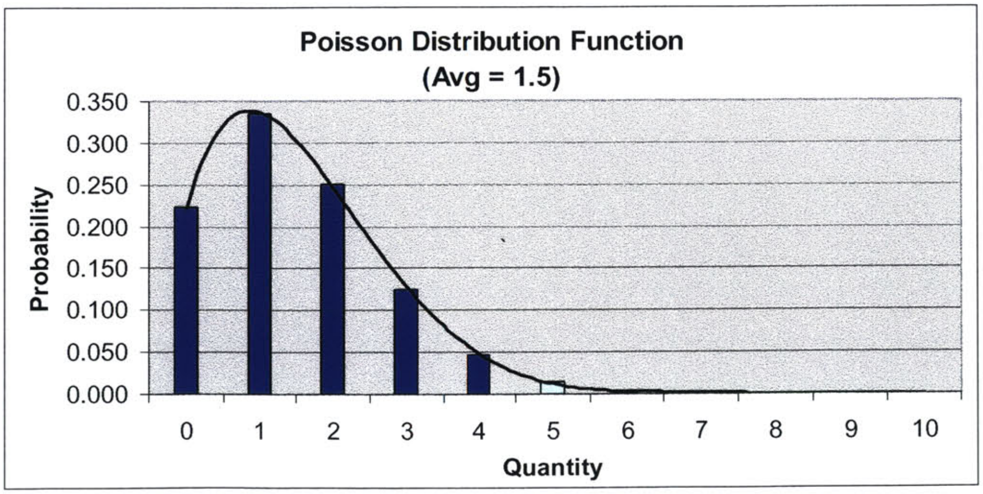


Figure 9: Service Level Illustration with Poisson Distribution

The order point, *S*, was calculated using the following formulas.

$$N = PoissonInv(SL, (R + L)\lambda)$$
$$k = Norms\,Inv(SL)$$
$$S = N\mu + k\sqrt{N}\sigma$$

N is the number of picks on a particular day, SL is the service level (set to 99%), λ is the average number of picks per adjusted day, k is the service level constant, μ is the average quantity per pick, and σ is the standard deviation of the quantity per pick. In developing the stocking level for this policy, the review period, R, was assumed to be 3 days, which is the longest case for both MWH and WCH. The lead time, L, was 0.5 days. However, it is important to note that the proper level for S can be calculated for any product's review period and lead time using the same equation.

Note that this equation for *S* implies that for larger values of N, there is relatively less variation in demand, as compared to the daily average. This is illustrated in Figure 10.

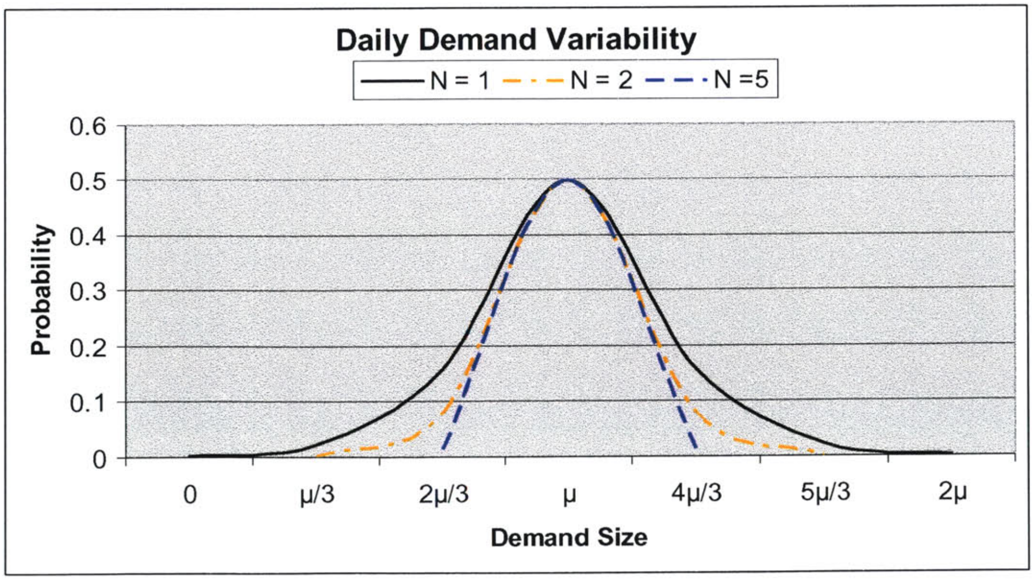


Figure 10: Demand Variability Reduction for Higher Pick Rates

This calculation of S would achieve targeted service levels in the strictest sense. In other words, this calculation is accurate when measuring demand *greater than* existing safety stocks. However, as mentioned before, the hospitals record a stockout every time the inventory in a particular location is equal to zero as there is no way to record demand once the inventory has reached zero. Given this, S must account for demand that is *greater than or equal to* existing safety stocks. This only becomes a significant issue in cases where λ and σ are very small.

Hence, to satisfy the applied measurement, the calculation for S was adjusted to the following:

$$S = Max(N\mu + k\sqrt{N}\sigma, 2\mu)$$

The S policy was used to clearly establish the minimum amount of inventory needed to meet the required service level for a particular product at assumed values of R and L. This policy is not an optimal policy as it does not consider ordering cost or carrying cost in its calculations, but it can be used in cases where ordering costs and carrying costs are negligible and in cases where hospitals need to determine their minimum capacity requirements.

5.6.2 *s, Q* Inventory Policy

The second proposed inventory policy is designed to achieve a targeted service level, while optimizing the order pattern. This is termed as an s, Q policy with period review, where s is the reorder point and $s + Q$ is the order-up-to point. The s, Q combines the base stock policy described in the previous section, but also considers order costs and carrying costs in determining the proper order quantity. Here, Q is the economic order quantity (EOQ) defined by the equation:

$$Q = \sqrt{\frac{2AD}{vC_C}}$$

A is ordering cost, D is the annual demand, v is the unit price, and C_c is the carrying cost. The EOQ defines the order quantity that minimizes the total costs associated with ordering costs and carrying costs. An illustration of the s, Q policy can be seen in Figure 11.

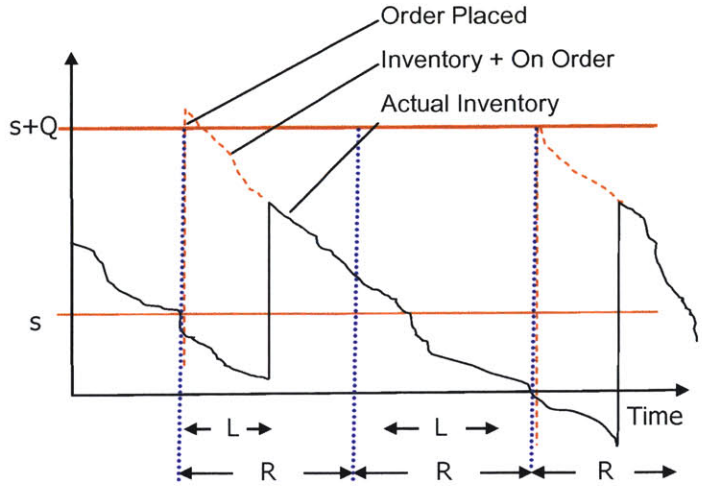


Figure 11: *s, Q* Inventory Policy Illustration

Similar to the base stock policy, the review period, R, was assumed to be 3 days, and the lead time, L, was 0.5 days. In addition, s is the same calculation as *S* in the base stock policy.

Q was calculated using the EOQ equation with the assumption that the order cost, A, was $5 and the Carrying Cost, C_c, was 20%. In this model, the calculation for Q did not take into consideration any capacity constraints as they were unknown. In reality, the order-up-to point would be equal to:

$$Min(s + Q_{EOQ}, Q_{Capacity})$$

The s, Q policy was used to clearly establish the optimal inventory policy, given no capacity constraints, and assumed ordering, carrying costs, and targeted service levels. As this policy considers all of the material management factors, it is very flexible and can be adjusted to fit any product within a hospital, which is essential to designing differentiated supply chain policies.

6 Inventory Policy Evaluation

Four inventory policies were simulated and compared. They included the existing policy in MWH, the "4 times max" policy as proposed by WCH, the base stock *S* policy, and the *s, Q* policy. All four policies were modeled for the wards where MWH provided its specific par level information. This included 7 of the 30 wards, represented 3,462 of the 9,837 Station-SKU's, and $1.2 million of the $1.9 million in inventory.

A model was developed in MS Exel to mimic the ordering rules of each of the four inventory policies. The model generated demand for 30 consecutive days and tracked inventory levels, ordering patterns, and stockouts. Each inventory policy was simulated 50 times within the 30 day model. For both the existing policy and "4 times max" policy, the initial inventory was set to the reorder point plus one, as to not over inflate the number of orders and yet ensure the reorder points were tested. For both the *S* policy and *s, Q* policy, the initial inventory was set to *S* and s, respectively.

This chapter will analyze the total costs (as defined in Chapter 5) and the stability of each inventory policy. This chapter will also review the shortages by ward to determine if any of the inventory policies are inherently biased towards any particular wards, as interviews of hospital staff suggested that current supply chain policies in some wards were much worse than others.

6.1 Simulation Results

The four inventory policies were compared based on their total cost as defined in section 5.7. As can be seen in Table 6, the *s, Q* inventory policy had the lowest total annual cost, $476,864. The next best policy was the "4 times max" inventory policy which was 52% more costly than the *s, Q* policy ($729,128). Both the existing inventory policy and the *S* inventory policy were more than twice as expensive as the *s, Q* policy - $993,424 and $1,077,152, respectively.

Average Annual Supply Chain Costs				
	Order Cost	Carrying Cost	Shortage Cost	Total Cost
Simulated Existing Policy	$449,220	$234,448	$309,756	$993,424
Simulated "4 times Max" Policy	$334,860	$393,335	$933	$729,128
Simulated S Policy	$766,440	$201,551	$109,161	$1,077,152
Simulated s, Q Policy	$166,920	$260,495	$49,449	$476,864

Table 6: Average Annual Supply Chain Cost Comparison

As mentioned previously, the goal of the *S* policy was not to provide the optimal cost, but rather define the minimum amount of inventory needed to achieve a targeted service level. Table 7 depicts a detailed comparison of the four inventory policies. As can be seen in the table, the *S* inventory surpassed its service level target of 99%, having a stock rate of only 0.474%, while the existing inventory policy in MWH had a stockout rate of 1.345% and 17% more inventory. Even the *s, Q* policy had less inventory than the existing policy, while achieving a stockout rate of 0.17%. The "4 times max" policy had the best stockout rate at only 0.002%, but achieved this service level with an inventory value 70% higher than that of the *s, Q* policy.

Measurement	Simulated Existing Policy		Simulated "4 times max" Policy		Simulated S Policy		Simulated s, Q Policy	
	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average	Std Dev
Number of Demands (30 days)	24678	N/A	24678	N/A	24678	N/A	24678	N/A
Number of Orders (30 Days)	7,487	69.99	5,581	45.67	**12774**	93.56	2679	24.06
Average Inventory ($)	$1,172,241	$17,382	**$1,966,673**	$3,624	**$1,007,756**	$1,401	$1,164,540	$5,513
Number of Stockouts (30 days)	332	25.52	1	1.10	117	13.91	42	15.92
Stockout Percentage	**1.345%**	N/A	**0.002%**	N/A	0.474%	N/A	0.170%	N/A

Table 7: Detailed Inventory Policy Comparison

These results are not surprising. Each policy, in fact, performed as it was inherently designed to perform. The "4 times max" policy is designed for the sole purpose of removing stockouts, with no concern for inventory and ordering costs. Thus, it minimizes stockouts while inflating the other two elements. Meanwhile, the *S* policy is designed for minimizing inventory while maintaining a service level. Hence, it did so, while inflating ordering costs. The *s, Q* policy is the only policy that considers all the cost elements of the system, hence, minimizes the entire material management costs within the system.

6.1.1 Inventory Policy Stability

As these inventory policies were developed and evaluated based on particular assumptions regarding order cost, carrying cost, and stockout cost, it is important to determine the stability of these policies if, in fact, there were any errors in the cost assumptions and developed models. The first analysis on stability reviewed the confidence interval of the calculated annual total costs based on the standard deviations of the simulations listed in Table 7. Figure 12 displays a 95% confidence interval for the calculated costs of each of the four inventory policies. A 95% confidence interval is defined as the average +/- 2 standard deviations for each measurement in the total cost equation (number of orders, average inventory, and number of stock outs).

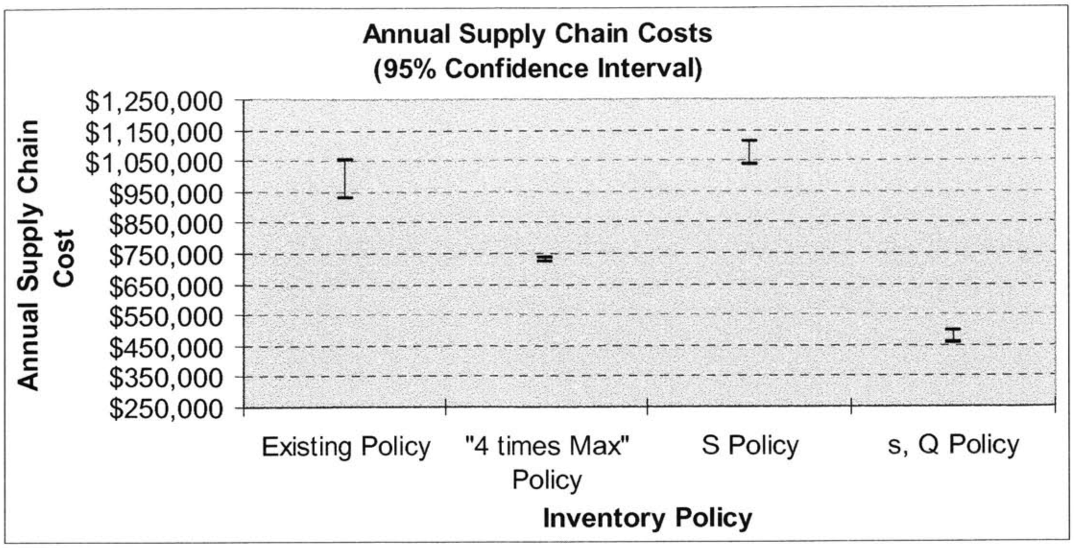


Figure 12: Annual Supply Chains Costs with Confidence Interval

As can be seen in Figure 12, both the *s, Q* policy and "4 times max" policy were quite stable, while the *S* policy is a little less stable and the existing inventory policy was the least stable.

The next analyses on inventory policy were sensitivity analyses on the order cost, carrying cost, and stockout cost. The order cost was reviewed for a range of $1 to $23 (Figure 13), the carrying cost was reviewed for a range of 10% to 40% (Figure 14), and the stockout cost was reviewed for a range of $25 to $250 (Figure 15).

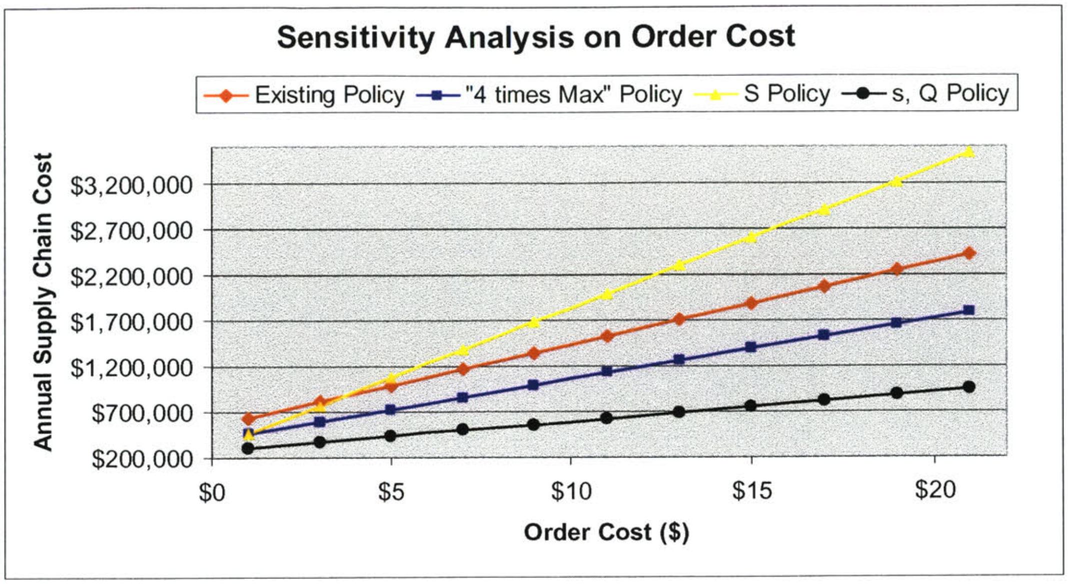


Figure 13: Sensitivity Analysis on Order Cost

As can be seen in Figure 13, the *s, Q* inventory policy is the best policy for the entire range of the order cost. Its relative advantage over the other inventory policies increases as the order cost increases.

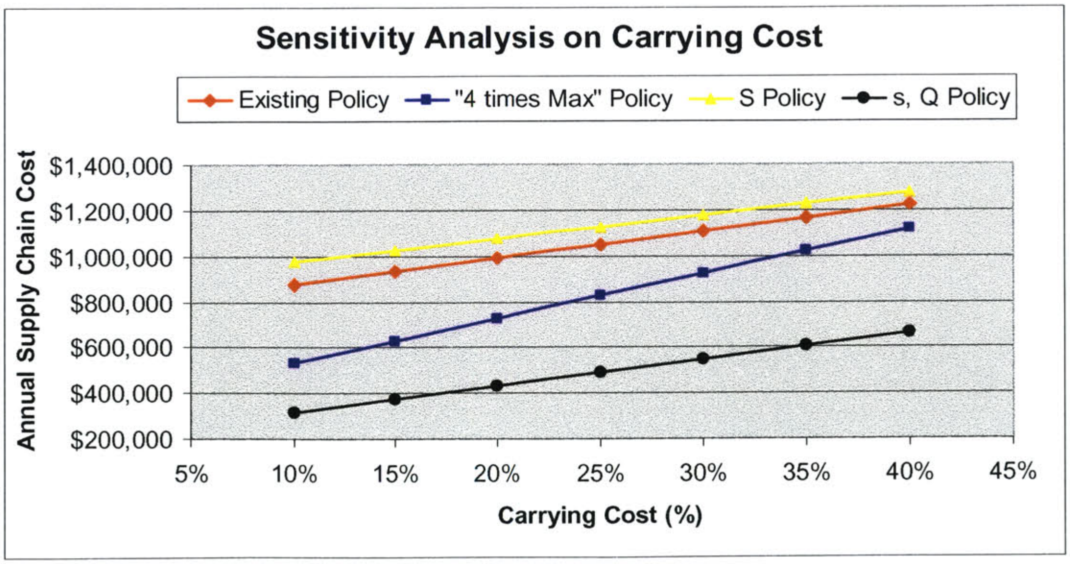


Figure 14: Sensitivity Analysis on Carrying Cost

Figure 14 also demonstrates that the *s, Q* policy is the best inventory policy over the range of carrying costs. The "4 times max" policy is the most sensitive to the carrying cost as it has a significantly higher amount of inventory than the other policies.

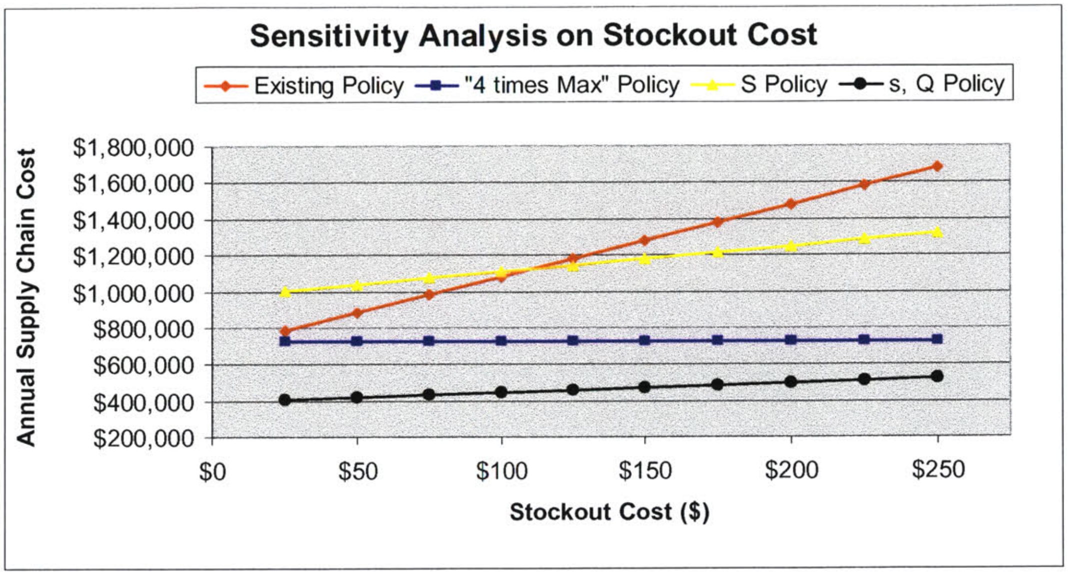


Figure 15: Sensitivity Analysis on Stockout Cost

Again, Figure 15 demonstrates that the *s, Q* policy is the most optimal policy over the entire range of stock out costs. For very high stockout costs, the "4 times max" policy approaches the performance of the *s, Q* policy. It should be noted that for such high stockout costs, the targeted service level for the *s, Q* policy would need to be adjusted. If, for example, the actual stockout cost was $250 as opposed to $78, there would be more incentive to increase the targeted service level and hold more safety stock. The existing inventory policy is the most sensitive to the stockout cost as it has significantly more stockouts than the other 3 policies.

In conclusion, the proposed *s, Q* inventory policy is not only the most optimal policy by over 52% under the particular assumptions made in this model, but also is the most stable inventory policy as compared to the other three reviewed in this analysis. Again, this is because the s, Q policy balances all the cost components rather than focusing on one cost component at the expense of another.

6.1.2 Shortages by Ward

As mentioned earlier, DTD, Inc is contractually obligated to a 98% service level and, at MWH, has been maintaining a 99% service level hospital wide. However, interviews with hospital staff and analysis of the actual data by ward suggest that the existing inventory policies work very well in some wards and not as well in others. For example, as shown in Table 8, wards Cath, Int, and IR all have stockout rates close to 4% while wards 6West and CancerCtr have stockout rates under 0.5%. Some interviewees suggested that these discrepancies may be due to compliance problems associated with a particular ward. For example, in some wards, there may be a higher tendency for nurses to forget to input a transaction when removing material from an APU system.

Ward	Actual Data			Simulation									
					Existing Policy		S Policy		4 times Max Policy		s, Q Policy	
	Picks	Stockouts	Percent	Picks	Stockouts	Percent	Stockouts	Percent	Stockouts	Percent	Stockouts	Percent
5-AICU	17458	150	0.86%	5731	28	0.49%	19	0.33%	0	0.00%	7	0.12%
6WEST	17788	88	0.49%	5780	26	0.45%	9	0.16%	0	0.00%	0	0.00%
CANCERCTR	6392	30	0.47%	2049	10	0.49%	18	0.88%	0	0.00%	3	0.15%
CATH	8614	347	4.03%	2483	102	4.11%	16	0.64%	1	0.04%	9	0.36%
ER	15183	258	1.70%	6463	86	1.33%	36	0.56%	0	0.00%	15	0.23%
INT	5855	251	4.29%	1879	62	3.30%	15	0.80%	0	0.00%	7	0.37%
IR	920	34	3.70%	294	18	6.13%	4	1.36%	0	0.00%	1	0.34%
Total	**72210**	**1158**	**1.60%**	**24678**	**332**	**1.35%**	**117**	**0.47%**	**1**	**0.004%**	**42**	**0.17%**

Table 8: Shortages by Ward for Each Inventory Policy

For that reason, the simulation models performed in this analysis also tracked the stockout performance by ward to determine if the higher stockout rates were, in fact, due to noncompliance issues or a shortcoming of the existing inventory policy. The results can be seen in Table 8.

Under the simulated model, the existing inventory policy still demonstrated a negative bias towards the Cath, Int, and IR wards, which had a stockout rate of 4.11%, 3.30% and 6.13% respectively. This not only further validates the accuracy of the model used in this analysis, but also suggests that the stockout problems in these wards is not due to noncompliance issues, but rather a shortcoming of the existing inventory policy. For the modeled wards, the modeled demand accounted for a 1.35% stockout rate as compared to a 1.6% stockout rate recorded in actual data. This demonstrates that 85% of the shortages are due to the nature of the demand and the existing inventory policies in MWH.

The s, Q inventory policy, meanwhile, did not demonstrate such shortcomings. Under the s, Q policy, all wards had stockout rates less than 0.50%. The S policy also did not demonstrate any large variations across wards, though it did not meet its service level target in the IR ward. Therefore, unlike the existing inventory policy, the proposed supply chain policies not only perform better, but also perform consistently across wards and products.

7 Implementing Supply Chain Differentiation

To reiterate the introduction of this document, the hospital supply chain's purpose is to enable the hospital's strategy of maximizing patient care. It does this by:

- Ensuring product availability
- Minimizing storage space → Maximizing patient care space
- Reducing material handling time and costs for all medical staff (nurses, pharmacists, doctors)
- Minimizing non-liquid assets (inventory)

These four supply chain goals can not all be achieved simultaneously as they are inherently conflicting. For example, one could easily ensure better product availability by stocking large amounts of inventory, but that inherently requires more storage space and more inventory. Likewise, one could ensure better product availability by keeping inventory stored behind locked doors, but that increases the material handling time for the medical staff. So, which goal is most important?

There are several product characteristics which will impact the decision on an appropriate supply chain; and they are unit price, demand, variability, physical size, and criticality. These product characteristics also inherently define the weighting on each of the four supply chain goals. The s, Q inventory policy developed in Chapter 5 account for demand, variability, and unit cost in order to ensure product availability at a given service level and optimize costs. These models can be scaled for any demand pattern, lead time and review period that the particular hospital employs. This chapter will further analyze the characteristics of unit price within MWH as well as the other two product attributes (physical size and criticality) and how they interact with the goals of the hospital supply chain. The particular supply chain policies that will be discussed will be the utilization of automated point of use systems, the length of the inventory review periods, and the targeted service level. Finally, this chapter will summarize the appropriate supply chain policy guidelines to implement for each of the various combinations of product attributes.

7.1 Unit Price and Supply Chain Policy

A product's unit price can be directly mapped to the supply chain goals of minimizing non liquid assets and minimizing material handling time and costs for medical staff. Table 7 displays an analysis of the total value of inventory for a given unit price range as well as the total pieces of inventory for a given unit price range. Station-SKU's having a unit price greater than $100 account for 72% of the total inventory value and only 0.32% of the total pieces of inventory. In addition, these parts account for only 1,894 (12%) of the total 15,061 Station-SKU's in inventory. To reduce inventory value, the hospital should focus on these high dollar Station-SKU's as improvements here will have the highest impact.

Total Inventory Dollars and Pieces by Unit Price

Unit Price	Total Dollars	Percentage	Total Pieces	Percentage
$0.10	$25,353	0.73%	876,243	62.66%
$1.00	$120,294	3.47%	414,405	29.63%
$10.00	$251,973	7.28%	86,862	6.21%
$100.00	$576,049	16.63%	16,391	1.17%
$1,000.00	$1,108,328	32.00%	3,558	0.25%
$2,500.00	$1,030,403	29.75%	786	0.06%
$2,600.00	$351,000	10.13%	135	0.01%
Total	**$3,463,399**		**1,398,380**	

Table 9: Total Inventory Dollars and Pieces by Unit Price

For example, for the Station SKU's that were modeled with a unit cost larger than $100, the inventory value was reduced by 14% with no increase in ordering costs by changing the order period and lead time to 1.5 days instead of 3.5 days. This equates to a $350,000 or 10% reduction in total inventory for the hospital.

High dollar components should have frequent review periods and should be tightly controlled. Therefore, it is reasonable to keep high dollar components stored in closed cabinets (storage bins requiring authorization before deploying inventory), slightly increasing material handling time for medical staff.

However, there is less need to increase material handling time for the 88% of the products that comprise 28% of the inventory value. For these lower cost products, the supply chain policy should be focused solely on the supply chain goal of decreasing medical staff handling time. There is currently a critical nursing shortage in the U.S. that is projected to amount to 600,000 by 2020 (Connelly 2004). Thus hospitals need to maximize their utilization of nurses on patient-care activities.

For example, currently the APU systems require medical staff to login with their ID and password every time they pick a product. Interviewees estimated that this increased picking time from 5 – 10 seconds to 20 - 30 seconds. MWH has an average of 74,000 remove transactions per month. Thus, a 15 second increase in average pick time represents 308 more nurse hours per month (almost 2 FTE's) in material handling. Meanwhile, MWH averages only 745 remove transactions per month for high dollar products (>$100). A 15 second increase in average pick time for these products only results in a negligible 3.1 more nurse hours per month in material handling time.

Current APU systems should be modified so that they can be adapted to meet supply chain requirements. Closed door systems, requiring authorized login, should be used for those products requiring tight control, and open shelf systems, not requiring login information, but equipped with the standard "take" buttons should be used for products not requiring tight control.

7.2 Physical Size and Supply Chain Policy

Product physical size is directly mapped with the supply chain goal of minimizing storage space. Other aspects being equal, SKU's that are large in size, in essence, have larger carrying costs than smaller items. Most wards reviewed in this study had limited capacity, and cabinet space was a major concern. Large components in tight capacity wards should have very frequent and perhaps even continuous review periods. Safety stock can be held in a central store or less capacity-constrained area and the ward can be refilled on an "as needed" basis. Meanwhile, smaller components, especially those of low value, should be refilled less often and order-up-to points should be the bin capacity.

Physical size information also would simplify the configuration process for inventory stored in APU systems. Currently, the APU systems are configured manually, and it is a time-intensive task. With physical size information listed in the product master file, hospitals and suppliers could use computer software to optimally configure cabinets. This would shorten implementation time for implementing new systems and redesigning existing systems.

7.3 Criticality and Supply Chain Policy

The criticality of a product is directly mapped to the supply chain goal of product availability. Perhaps no other industry has a clearer definition of criticality than the hospital industry. Yet neither hospital in this study explicitly made this distinction in establishing service levels and measuring its supply chain performance; rather all products are treated equally. By disregarding criticality, these supply chains are not truly aligned with the hospital's strategy of maximizing patient care.

To account for criticality product master files should be updated to include this attribute. Based on conversations with medical staff, the author suggests a three tiered system (Non Critical, Critical, Highly Critical); however, the categorization can be customized to each ward and hospital. Criticality should not only define targeted service levels, but also should be used in evaluating supply chain performance. Stockouts for critical and highly critical items should either be measured separately or weighted differently in an aggregate analysis.

Similar to unit price, criticality can also be mapped towards the supply chain goal of minimizing material handling time for medical staff. Again, it is reasonable to store critical items in closed APU systems for better control. However, for non critical items, the supply chain should be focused on minimizing handling time; and therefore, these systems should be stored in open shelves.

7.4 Summary

This chapter discussed the four hospital chain goals. Table 10 summarizes the product characteristics that map supply chain goals to supply chain strategies.

Mapping Supply Chain Goals to Product Characteristics and Supply Chain Strategies		
Supply Chain Goal	**Product Characteristic**	**Supply Chain Strategy**
Ensuring Product Availability	Demand; Demand Variability; Criticality	•Implement s, Q Inventory Policy •Differentiate Service Level Based on Criticality
Minimizing Storage Space	Physical Size	•More Frequent Reviews for Large Items •Evaluate Review Period Impact on Minimum Inventory Requirements using Base Stock, S, Inventory Policy
Reducing Material Handling Time for Medical Staff	Unit Price; Criticality	•Place Non-Critical, Low Value Items in Open Shelf APU Systems
Minimizing Inventory Value	Unit Price	•More Frequent Reviews for High Value Items

Table 10: Mapping Supply Chain Goals to Product Characteristics and Supply Chain Strategies

There are three supply chain policies that have been discussed in this research – target service level, length of review period and use of APU systems. Table 11 lists the appropriate supply chain policies to implement for the various combinations of product characteristics that were analyzed in this research. Demand and demand variability were not included in this table as the *s*, *Q* inventory policy developed in chapter 5 is optimal for all demand patterns.

Supply Chain Policies for Various Product Characteristics					
Product Characteristics			**Supply Chain Policy**		
Unit Cost	**Physical Size**	**Criticality**	**APU System**	**Review Period**	**Service Level**
Low High	Small Large	Highly Critical	Closed Door	Very Frequent At Least Daily	Very High (99.9%)
High	Large	Critical	Closed Door	Very Frequent At Least Daily	High (99.5%)
Low	Small	Critical	Closed Door	Frequent (Weekdays)	High (99.5%)
High	Large	Non Critical	Closed Door	Very Frequent At least Daily	Normal (98% - 99%)
Low	Small	Non Critical	Open Shelf	EOQ and Capacity Define Order Frequency	Normal (98% - 99%)

Table 11: Supply Chain Policies for Various Product Characteristics

8 Conclusion

This thesis concludes that the implementation of automated point of use systems has enabled hospitals to develop more sophisticated supply chain policies that can further increase patient care and simultaneously reduce costs. Supply chain policies should be differentiated with respect to a product's demand, variability, unit cost, physical size, and criticality. This differentiation will better align the hospital supply chain with its strategy of maximizing patient care.

Historically, hospitals developed inventory policies based on educated guesses and rules of thumb. With point of use data, hospitals can do away with these antiquated methods and implement statistically appropriate inventory policies. An s, Q inventory policy was developed based on the data provided by one hospital, MWH. This policy improved the hospital's service level from 98.6% to 99.8% and simultaneously reduced material management costs by 52% (~$500,000/yr). The s, Q policy was not only the most optimal solution, but also the most stable solution, and performed consistently across all wards and products.

Moving forward, hospitals should add attributes indicating physical size and criticality information to their product master files. This enhancement will allow hospitals to further differentiate their supply chain policies and better align supply chain implementation and measurement with the hospital's strategy of maximizing care.

A product's unit cost, physical size, and criticality dictate the appropriate supply chain policy to be implemented. For example, high cost, highly critical products should have very frequent review periods, tight control, and very high service level targets. Meanwhile, low cost, non-critical products should have less frequent review periods, loose control, and moderate service level targets. While these distinctions seem obvious, they must be embedded into the supply chain policies and performance metrics. Only then will the supply chain be aligned with its goals of ensuring product availability, minimizing storage space, minimizing medical staff material handling time, and minimizing inventory value.

8.1 Recommendations and Future Research

Though this research developed several tactics for improving supply chain performance within the hospital, the scope was really limited to the hospital itself. Byrnes and Shapiro (1991) described how many companies and industries have created enormous value through deeper inter-company operating ties. Benefits include "cost reductions exceeding 30%, increased sales, improved supply continuity, flexibility, and quicker response to changes in customer needs." It is recommended that hospitals and hospital suppliers further investigate the opportunities in this realm.

For example, in determining the proper order quantity, this research only considered the costs of the hospital. In fact, both the hospital's cost and distributor's costs should be considered in developing the proper order quantity, and the objective should be to minimize the costs of the entire channel, not just one member within the channel.

Furthermore, now that distributors like DTD, Inc have direct access to point of use data, they should investigate methods to improve their forecasting techniques, ordering patterns, and inventory policies within the distribution center. In addition, this information can be relayed directly to the manufacturers. Retail companies such as Wal-Mart and Target have developed sophisticated networks using point of sale data that have reduced costs significantly within their supply chain. Hence, the hospital industry can use the retail industry as a model for such development.

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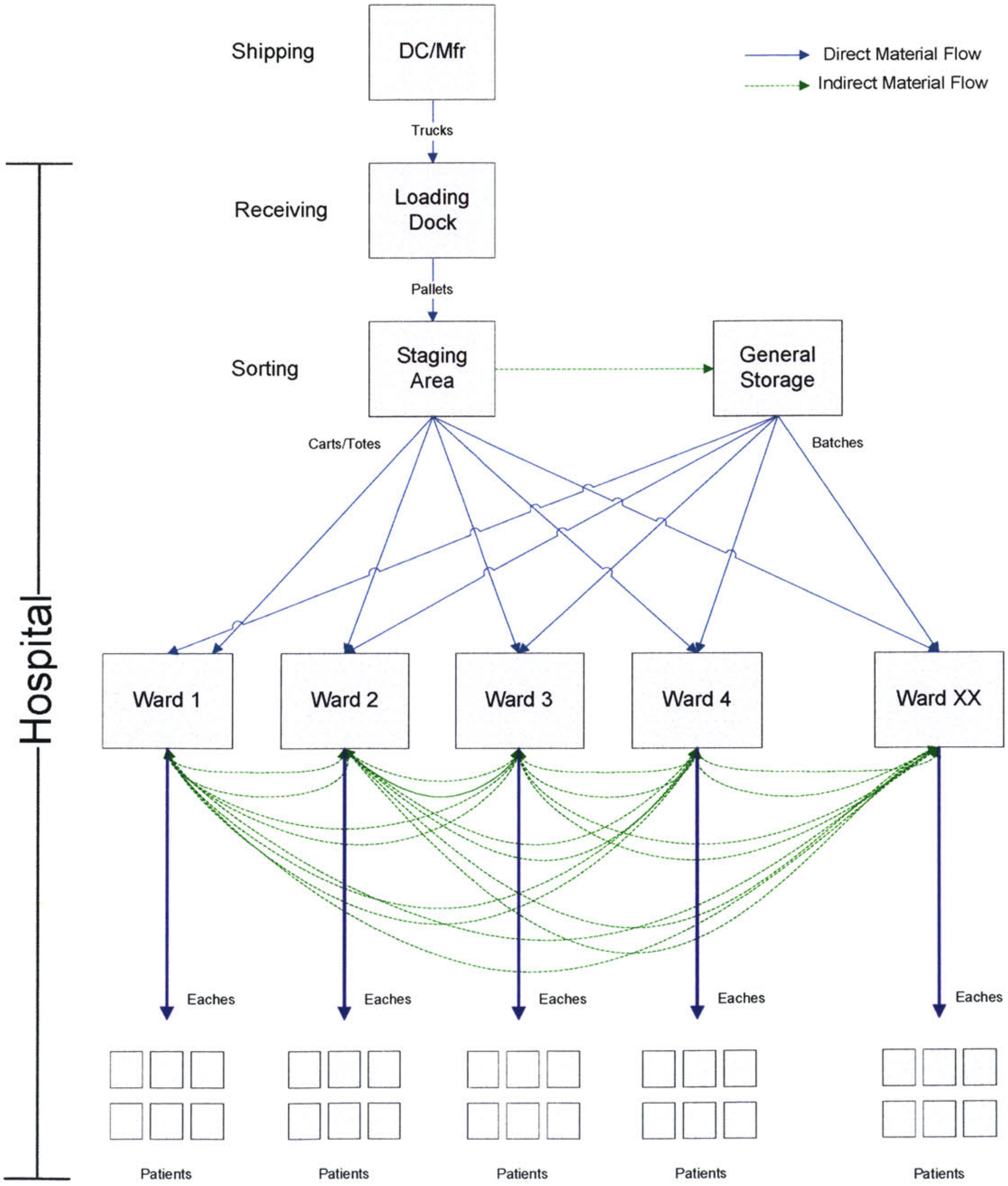
A Appendix A: Interview Schedules

MWH Interview Schedule	
Organization	**Title**
MWH	CEO
MWH	CFO
MWH	Director, Pharmaceutical & Clinical Nutrition
MWH	Executive Director, Information Technology
MWH	Director, Support Systems
MWH	Financial Controller
MWH	Director, Resource Control
MWH	Director, Surgery & Emergency Services
MWH	Director, Nursing Resources
MWH	Director, Medical / Surgical Supplies
MWH	Manager, Cardiac Cath Lab
MWH	SP Lead Technologist in Radiology
MWH	Various Nursing Staff
DTD, Inc	MWH Operations Manager
DTD, Inc	Executive Director, Support Services
DTD, Inc	VP Integrated Services
DTD, Inc	Regional Director of Sales
DTD, Inc	Regional Director of Field Logistics
DTD, Inc	VP Corporate Solutions

WCH Interview Schedule	
Organization	**Title**
WCH	CIO
WCH	Clinical Director, Cardiac Cath Lab
WCH	Supervisor, General Stores
WCH	Director Radiology Services
WCH	Director of Pharmacy
WCH	Financial Controller
WCH	Director of Materials
MWH	Various Nursing Staff
DTD, Inc	WCH Operations Manager
DTD, Inc	VP Corporate Solutions

A Appendix B: Material Flow Diagram for MWH and WCH

Material Flow Diagram for MWH and WCH



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Appendix C: Cyclicality Table

Station	Dept	Cyclicality
2OP-1	2OP	CC
2OP-2	2OP	CC
2OP-3	2OP	CC
4-WEST	4-WEST	R
5-AICU	5-AICU	R
5-NE	5N	R
5-NWEST	5N	R
5WEST-1	5WEST	R
5WEST-2	5WEST	R
6CN-1	6CN	R
6CN-2	6CN	R
6NS-1	6NS	R
6NS-2	6NS	R
6NS-3	6NS	R
6WEST	6WEST	R
7LIVER	7LIVER	C
7NE	7NE	R
7NE-RT	7NE	R
7OHSCU1	7OHSCU	R
7OHSCU2	7OHSCU	R
7SE	7S	R
7SW	7S	R
7SW-RT	7S	R
CANCERCTR	CANCERCTR	C
CATH-A	CATH	CC
CATH-B	CATH	CC
CATH-BACK	CATH	CC
CATH-C	CATH	CC
CATH-D	CATH	CC
CATH-EP	CATH	CC
CATH-FRNT	CATH	CC
CATH-HOLD	CATH	CC
COOPCARE	COOPCARE	C
CWEST-ER	CWEST	R
CWEST-ERO	CWEST	R
CWEST-SS	CWEST	R
DIALYSIS	DIALYSIS	C
ERNORTH-1	ER	R
ERNORTH-2	ER	R
ERNORTH-3	ER	R
ERNORTH-4	ER	R
ERUH-MED	ER	R
ERUH-OB	ER	R
ERUH-O-RT	ER	R
ERUH-TRAMA	ER	R
GIC-1	GI	CC
GIC-2	GI	CC
GIUH-1	GI	CC
GIUH-2	GI	CC
GIUH-4	GI	CC
GIUH-STORE	GI	CC
HELO-PAD	HELO	R
INT-RAD1	INT	CC
INT-RAD2	INT	CC
INT-RAD3	INT	CC
INT-RAD4	INT	CC
IR-NEURO	IR	C
IR-NORTH	IR	C
IR-STENT	IR	C
LDUH-4219	LDUH	R
LDUH-LDPP	LDUH	R
LDUH-LDRP	LDUH	R
LDUH-LDRPE	LDUH	R
LDUH-NRSRY	LDUH	R
LDUH-OR	LDUH	R
LDUH-PHARM	LDUH	R
NICU-1	NICU	R
NICU-4237	NICU	R
PICU-N1	PICU	R
PICU-N2	PICU	R
PICU-RT	PICU	R
PICU-S	PICU	R
PULM	PULM	CC
RADC-FLKIT	RAD	C
RADUH-CHST	RAD	C
RADUH-FLRO	RAD	C
RADUH-QA	RAD	C
RT8-8816	RT	R
RTDEPT-N	RT	R
RTDEPT-N1	RT	R
RTDEPT-S	RT	R
RTDEPT-S1	RT	R
SOLIDORGAN	SOLIDORGAN	CC

*R is regular demand, C is Cyclical demand, CC is highly cyclical demand.

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Appendix D: Cost of Stockout Calculation

$I_{avg} = \$3,495,891$

$LT = 3.5 \text{ Days}$

$D_d = \$27,190$

$X_L = D_d * LT = \$95,165$

$SS = I_{avg} - X_L = \$3,400,726$

$C_C = 20\%$

$N_D = 874,784$

$SL = 99\%$

$N_{SO} = (1 - SL) * N_D = 8,748$

$C_{SO} = SS * C_C / N_{SO} = \$77.75$

I_{avg} = Avg Inventory, LT = Lead Time, D_d = Daily Demand (\$), X_L = Demand over lead time (\$), SS = Safety Stock (\$), C_C = Carrying Cost (annual), N_D = Number of Demands (annual), SL = Service Level, N_{SO} = Number of Stockouts, C_{SO} = Cost of Stockout