Tailored Hospital Supply Chain for Greater Return on Investment

by

Paul Jenq-Haw Jan

Bachelor of Art in Economics (2001)
University of Chicago

Submitted to the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degree of

Master of Engineering in Logistics

at the

Massachusetts Institute of Technology

June 2006

Signature of Author ....
Engineering Systems Division
12-May 2006

Certified by ....
Christopher Caplice
Executive Director, Master of Engineering in Logistics
Thesis Supervisor

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

Tailored Hospital Supply Chain for Greater Return on Investment

by

Paul Jenq-Haw Jan

Submitted to the Engineering Systems Division
on May 12th, 2006 in Partial Fulfillment of the
Requirements for the Degree of Master of Engineering in Logistics

Abstract

The cost of healthcare has been increasing over the past several years. From 1997 to 2002, the average cost for hospital stays increased 24 percent. The increase in healthcare cost can be explained by malpractice law suits and also by the increase in the cost of medical supplies (26 percent increase from 2000 to 2002). Though the Automated Point of Use (APU) technology and the Vendor Managed Inventory (VMI) are helping hospitals reduce supply chain costs, this research seeks to understand whether the inventory policy exists with the APU-VMI model is optimal.

To achieve an understanding of the behavior under the APU-VMI model, this research seeks to investigate the inventory cost as well as the average order quantity and the deviation of the order quantity, and the replenishment frequency for before and after the introduction of the APU-VMI model. Through this, this research seeks to recommend the optimal inventory policies that hospitals should couple with the APU-VMI model. This combination should enable hospitals to reduce supply costs, and increase the returns on the investment made in implementing the APU-VMI model.

Thesis Supervisor: Christopher Caplice
Title: Executive Director, Master of Engineering in Logistics

Acknowledgements

I would like to thank Dr. Jonathan Byrnes for providing the insightful strategic guidance that makes this thesis possible. Dr. Byrnes has extensive experience in the healthcare industry and provided many useful suggestions that turn this study from idea into reality.

I would also like to thank Dr. Christopher Caplice for his dedication, guidance, and patience in making the writing of this thesis seem all too easy. Dr. Caplice provided wonderful guidance on the analyses performed in this thesis as well as the strategic focus that could be implemented in practice.

Thanks to my wonderful classmates for their support and friendship that made the writing of this thesis possible. Special thanks to Rida, Sangeeth, Louis, and Tai for their assistance with the data analysis. Many thanks also go to Tan and Chandler for keeping me focused.

Most importantly, I would like to thank the staff at C4Y Inc. and CareFirst Hospital. Their dedications to this study made the interviews and data collection process painless and enjoyable.

Dedication

This thesis is dedicated to my parents and girlfriend Claire. The support from my parents made coming to MIT possible. The love and comfort from Claire throughout the writing of the entire thesis made all the frustrations and late nights timeless.

Biographical Note

Paul Jenq-Haw Jan is a candidate for the Master of Engineering in Logistics (MLOG). Prior to attending MLOG, Paul worked as a senior analyst at Accenture. Paul has strong interest in high performance driving and completed the pre-requisite for racing school prior to joining Accenture. Paul intends to attend racing school one year upon graduating from MLOG. Paul received his undergraduate degree in economics from the University of Chicago in 2001.

Table of Contents

List of Tables

List of Figures

1 Introduction

The cost of healthcare has been rising steadily over the past several years. In 2002, the average cost for hospital stays were approximately $17,300 dollars, an increase of 24 percent from 1997. The most common hospital stays were for diseases related to the circulatory system. According to the Agency for Healthcare Research and Quality (2002), these symptoms included coronary atherosclerosis, congestive heart failure, heart attacks and cardiac dysrhythmia, accounting for 17% of all hospital admissions. Figure 1 shows the Top 10 reasons for hospitalization by body system.

Reasons for hospital stay, by body system	Total number of discharges (in thousands)	Percent of all discharges
1. Diseases of the circulatory system	5,990	16.9
2. Pregnancy and childbirth	4,411	12.5
3. Newborns and perinatal conditions	3,970	11.2
4. Diseases of the respiratory system	3,588	10.1
5. Diseases of the digestive system	2,887	8.2
6. Diseases of the musculoskeletal system	2,667	7.5
7. Diseases of the nervous system	2,041	5.8
8. Mental disorders	1,238	3.5
9. Diseases of the kidney and urinary tract	1,126	3.2
10. Diseases of the female reproductive system	984	2.8

Figure 1: Hospital Admission Reasons by Body Type
Source: (AHRQ 1997)

The rise in the cost of healthcare is both substantial and alarming during the period between 1997 and 2002. The increase in the cost of healthcare was double the rate of inflation for the same period according to the data at Bureau of Labor Statistics (2002). What are the factors that caused the cost of healthcare to rise? One possible explanation is the rise of insurance costs due to malpractice lawsuits. Medical liabilities have increased the cost of insurance from 12 percent to 44 percent, depending on state law governing the limit of malpractice coverage. Another explanation could be the increase in cost for medical supplies. In 2004, Healthcare Material Management (HMM) reported that the cost of medical supplies increased 26 percent from 2000 to 2002. The increase can be due to inefficient operations at either the hospitals or the suppliers, as well as the lack of incentives for hospital and suppliers to collaborate to achieve quantity and delivery efficiency.

The alarming increase of the cost of healthcare induced the interest for this study. Specifically, this study looks at how supply chain efficiency through advanced technology, as well as flexible inventory policies, can reduce inventory management costs at a hospital. The goal of this study is to generate greater returns on the investments hospitals make to provide better patient care standards from the supply chain management perspective.

More specifically, this study will investigate the cost-savings that hospitals are likely to experience from two dimensions: technology and inventory policy. Figure 2 shows the two dimensions in a two-by-two matrix.

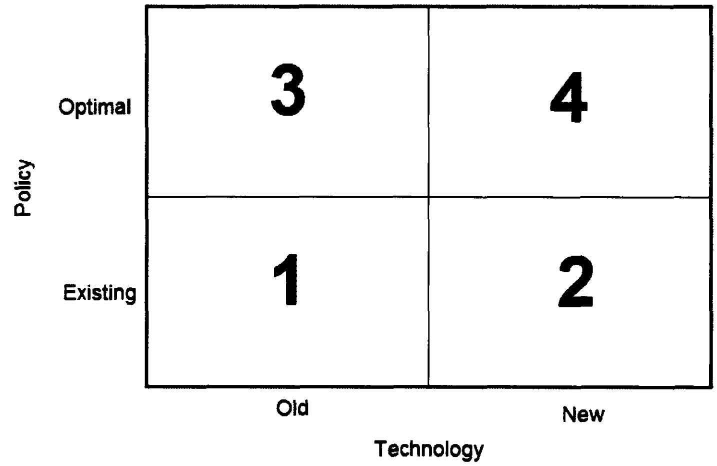

Figure 2: Roadmap to Greater Return on Investment

The policy dimension comprises of the rules and practices surrounding how inventory is managed. The existing inventory policies at many hospitals are inefficient. They are commonly determined based on intuition, whereas the optimal policy would be determined based on consumption data from hospitals.

The technology dimension consists of the automated and computerized systems used to manage inventory. The old refers to technology available at many hospitals today used to conduct inventory management, typically an open store room. All activities such as monitoring the inventory position of hospital supplies, searching for a supply and replenishing supplies at a hospital unit occurs within this store room. The new refers to the paradigm shift in how advancements in technology have transformed the way physicians and nurses execute inventory management activities. With the Automated Point of Use (APU) machines and the Vendor Managed Inventory (VMI) model, nurses and physicians are no longer required to inventory the store room. Furthermore, the search activity is simplified with the use of the APU machines through the electronic interface that allows nurses to search all the units in the hospital for a particular item. Nurses spend less time on ensuring products are in the store room and more time caring for patients.

The current state is in the lower left hand quadrant, indicated by the number 1. Many hospitals determine inventory policy based on demand pattern at a particular period of time and these hospitals have open-cabinet supply rooms that nurses and physicians can retrieve items from without any documentation. This is highly inefficient, as physicians and nurses at a particular hospital unit could decide to increase the par levels sporadically based on one period of consumption rate, which is not a good representation of the overall consumption pattern due to the narrow time frame the demand was observed. This may lead to the overstocking of certain supplies that may only have intermittent surges in demand, thus incurring unnecessary costs to the hospital. This phenomena leads to a decrease in hospital profitability, since one-third of the hospitals in the United States have holding costs greater than their profit margins as percentage of revenue. In other words, holding inventory could cost 11 to 16 percent of the inventory value (Yokl, 2005).

Furthermore, the open-cabinet system creates many unofficial inventories. Because of the lack of accountability - coupled with the fear of shortages - many nurses have incentives to hoard their own stock of supplies in order to deliver high patient care standards. This is costly to many hospitals, as more supplies than what were actually consumed are procured.

The advancement in technology has automated many hospitals inventory management processes (quadrant 2). For example, the University of Maryland Medical System has realized $315,000 in annual savings additional to $100,000 in salary savings by handing the inventory management responsibilities and utilizing the inventory management technology offered by Owens and Minors (HMM, 1998). However, many of these hospitals still operate under the inventory policy that existed prior to the introduction of new technology (quadrant 2).

Therefore, hospitals should be able to reap more cost-savings by reviewing and adjusting the inventory policy after the introduction of the new technology. Hospitals cannot afford to have an existing policy that does not align with the capability of the new technology. As such, reviews need to be conducted to tailor the inventory policy based on the demand pattern demonstrated through the new technology. The inventory policy existing prior to the new technology may not accurately reflect the demand pattern due to lack of data. However, the new technology should have a rich array of data, in addition to the automating of the order process as well as offering a more accurate count of inventory position that could be used to improve the inventory policy to an optimal level (quadrant 4).

However, reviewing the inventory management practice after the implementation of new technology is not the only way to improve the inventory practice at a hospital. DeScioli (2005) demonstrated that hospitals could benefit from having optimal inventory, with volume and price as the segmentation factors, along with the advancement in material management technology. The criticality of products could be another segmentation factor that could help hospitals improves inventory policy. The criticality of a product could be measured based on the tolerance of that product to the stockout timeframe. If a product cannot be stockout even for half hour, then that product can be classified as highly critical. On the contrary, if a product could be stockout for 3 days, then that product can be classified as non-critical.

While having the optimal policy with the appropriate technology (quadrant 4) is the ideal position that a hospital could be in, a hospital cannot get there from the existing process and technology environment (quadrant 1). Depending on the approach and strategy a hospital undertakes with its vendors, the hospital may go from using the handheld scanners that are commonly used today in managing the hospital inventory (quadrant 1) to having the computerized automation such as the Automated Point of Use (APU) machines (quadrant 2) and then to 4, or from quadrant 1 to 3 to 4. If the hospital focuses its attention on improving the inventory policy, then it would migrate from quadrant 1 to 3 and then to 4 if some type of technology is adopted to facilitate the optimal policy. If a hospital chose to focus on implementing new technology to automate the supply chain process, then the hospital would migrate from 1 to 2 and then to 4 if the inventory policy is adjusted accordingly after the technology implementation.

The following chapter will provide a brief overview on the healthcare industry and introduce the medical supply distributor and the large teaching hospital participating in this study. Chapter 3 will provide details on data collected for this study, as well as the current situation at the units chosen for this study. Chapter 4 will investigate in-depth the practices at the units chosen for this study to determine the effectiveness of the policy in place today. Based on the results discovered in Chapter 4, optimal inventory policies will be proposed in Chapter 6. Finally, concluding remarks will reiterate the benefits of having an optimal inventory policy with the use of new technology, as well as include suggestions for future studies.

2 Research Overview

This chapter provides an overview of the healthcare industry, the participating company and hospital, as well as the technological advancement in the hospital material management arena. Further, this chapter will also provide overview of the methodology used for this study. To complete this research, the author worked closely with one of the leading distributors for medical and pharmaceutical supplies, C4Y Inc. C4Y offers a wide array of products to hospitals. It also provides many services to hospitals, including manufacturing procedure-based surgical packs and medical supplies. Some of the services and products that are included in this research are the automated point of use (APU) machines and vendor managed inventory (VMI) model. The author conducted his study at one of the hospitals, CareFirst hospital, serviced by C4Y Inc. The hospital was chosen due to its recent adoption of the APU-VMI model, so the before and after inventory savings could be captured. Data was gathered from CareFirst Hospital and C4Y Inc. to conduct inventory analysis. More information about C4Y Inc. and CareFirst Hospital can be found in Sections 2.2 and 2.3.

2.1 The Healthcare Industry

No other industry has risen faster in cost to service than in the healthcare industry. The Center of Medicare and Medicaid Services (CMS) reported that healthcare spending was roughly \$1.9 trillion in 2004, up from \$1.4 trillion in 2002. This represents an approximate 36 percent increase in healthcare spending. Healthcare spending also outpaced inflation and the Medical Price Index also outpaced the general Consumer Price Index (BLS 2006).

Figure 3 shows that the cost of medical care has far outpaced the Consumer Price Index (not adjusted for seasonality). The inflation rate from 1996 to 2005 was approximately 24 percent, whereas the medical care cost outpaced the Consumer Price Index by more than 50 percent. This data from the Bureau of Labor Statistics (BLS) complimented the earlier assertion that the cost of healthcare has increased over 24 percent from 1997 to 2002.

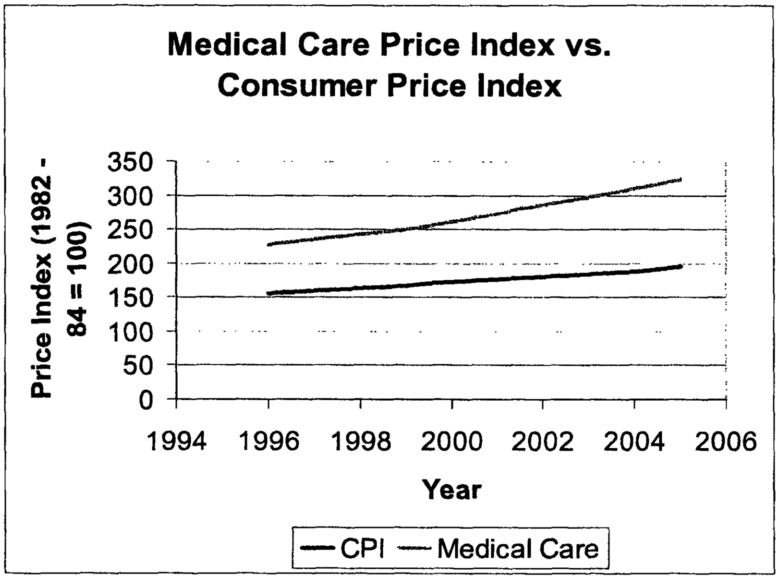

Figure 3: Hospital Price Index vs. Consumer Price Index

The cost of healthcare is expected to increase 2.7 percent every year between 2001 and 2011 (CMS 2002). By 2011, healthcare cost should comprise of approximately 17 percent of the Gross Domestic Product (GDP), see Figure 4. It would be beneficial to keep the cost of healthcare at current or below the current level so that hospitals could achieve a higher profit margin.

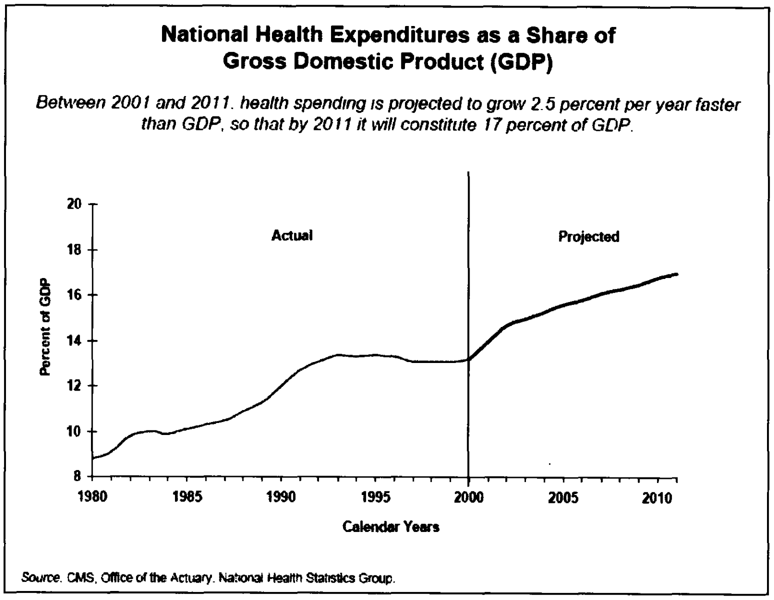

Figure 4: National Health Expenditure as % of GDP

Although healthcare costs have been rising, the healthcare providers' profit margin has not been increasing at the same rate. For instance, for-profit hospitals typically see a profit margin average that is between 3 to 5 percent (CMS 2003). Hospitals should be able to achieve higher profit margins by transforming to quadrant 3 of Figure 2 through an optimal policy and the right technology.

2.1.1 Healthcare Supply Chain Cost

Across the nation, approximately 30% of the hospital expenses are related to supply chain activities (DeJohn, 2006). Inventory, or material, management is defined as the cost of supplies and labor required to manage inventories, material and information flow. According to Figure 5, these activities account for about 80 percent of the expenses of publicly traded hospitals in the US.

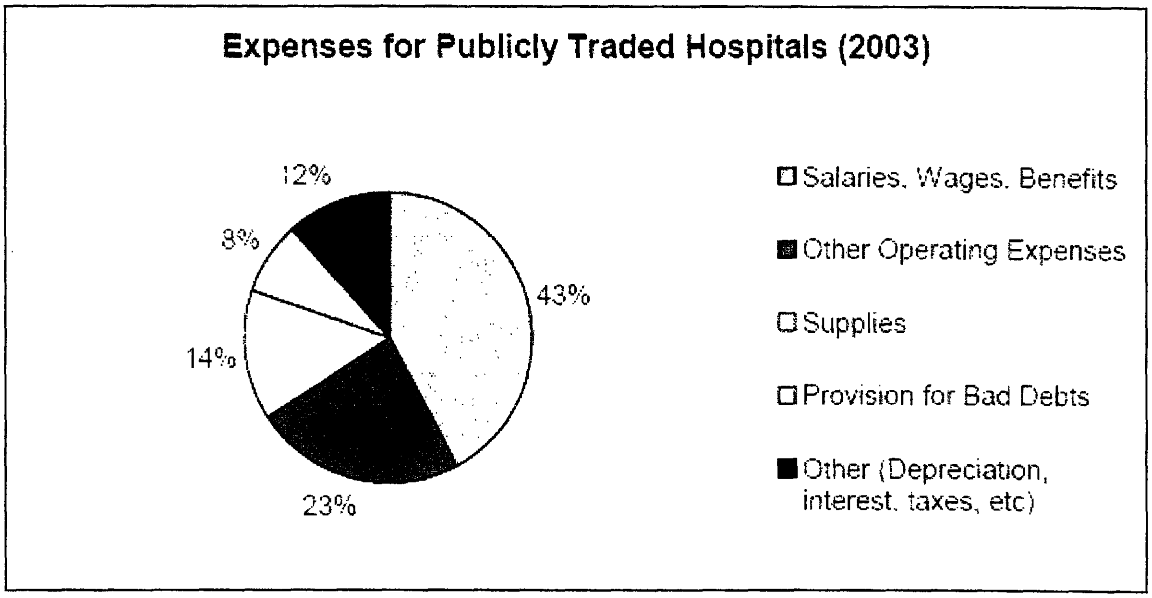

Figure 5: Expenses for Public Traded Hospitals

(Source: CMS 2003)

As mentioned in the introduction, nurses and physicians are often required to perform logistical tasks such as inventorying, ordering, and locating hospital supplies. Reducing the amount of time nurses and physicians perform these non-core activities should increase their productivity in caring for patients, leading to higher revenue for the hospitals as they have more time to treat more patients. The introduction of the APU machines should reduce expenses at hospitals, as demonstrated at the University of Maryland Medical System with the $100,000 salary savings (HMM, 1998). This technology, coupled with VMI (see section 2.4.1 for more details on VMI), should also have significant impact on the hospital supplies and other operating expenses. Hospital staff would no longer need to perform as much logistical work as in the past, and orders would be automated through computers to reduce administrative overhead in procuring supplies.

2.2 C4Y Inc.

C4Y Inc. is one of the industry's largest providers of radiopharmaceuticals used in medical treatment and diagnostic testing. It is the leading manufacturer of infection prevention products, operating more than 50 distribution centers across the United States and the United Kingdom. It provides pharmacy management in over 300 hospitals and has extensive expertise in medication and supply management delivery solutions. C4Y's 2005 annual revenue is approximately $75 billion dollars, with approximately $3 billion in cash flow.

2.3 CareFirst Hospital

CareFirst Hospital is a teaching hospital in the New England Area. It has 257 beds with an ambulatory care center that serves more than 2,500 patients daily. It has a 24-hour, Level II trauma emergency department, inpatient and outpatient surgery center and diagnostic ancillary services. Furthermore, it hosts more than 200 clinical trial protocols and participates in numerous national trials. It has residency and fellowship programs for more than 100 physicians in 19 specialties.

At the time of this research, CareFirst Hospital is in the process of transforming to a vendor managed system. Some of its departments have crossed over to the vendor managed model, while others are scheduled to be converted in the near future. The hospital still retains a central storage room to provide supplies to departments that have not transformed to the vendor managed model, as well as to provide products that are not currently sold through the stockless system.

2.3.1 Supply Chain Practice at CareFirst Hospital

At CareFirst Hospital, inventory management was and is actually a part of the nurse's daily activity. Even with departments that have shifted to the APU-VMI model, some assistant nurses still inventory the supply room to ensure that inventory levels can meet the demand, as well as to help other nurses locate and order supplies. A past study indicated that nurses spent up to 15 minutes each shift searching for supplies and an additional 10 minutes per shift replenishing supplies (Carey, 2006). This is further verified by the interviews conducted at CareFirst by the author. On average, a nurse may record 10 to 12 hours per shift at the hospital. During each shift, a nurse makes approximately 5 trips per shift to the supply room. The author gathered that nurses, on average, could spend up to 3 minutes per visit to the supply room. If supplies are out of stock, then a nurse will spend another 5 to 10 minutes on the phone placing orders. The author gathered that, on average, a nurse could encounter one stock out per week. This is valuable time that the nurse could have spent with patients to improve the quality of their care.

The time nurses spent on inventory management also has financial consequences on CareFirst Hospital. The author estimates that the hospital could incur costs up to $100 a week per nurse performing these logistical tasks. This estimate is based on the average salary of registered nurses and assistant nurses at CareFirst Hospital. If, on average, there are 20 nurses serving a hospital unit, then the hospital incurs $2,000 in salary expenses each week for nurses to perform activities that do not add value to the hospital's bottom line financially.

The inventory management for the material technicians, however, changed in the APU-VMI environment. Prior to the APU-VMI implementation, material technicians were required to perform inventory, picking, and put-away activities at each unit. Picking is where technicians gather items from the central warehouse to replenish the nursing units or stations. From the nurse's perspective, picking means the act of retrieving items from the supply room, or from the APU machines to bring to a patient. Put-away is simply the act of replenishing or re-stocking the nursing unit. The inventory and picking activities takes about 30 to 45 minutes each and the put-away activity takes about 30 minutes for an experienced technician. An inexperienced technician may need an additional 5 to 10 minutes to each activity. Together, a technician could spend up to approximately 2 hour and 20 minutes on each unit to ensure that the unit has the supplies to meet the demand for the day.

2.4 Use of Advanced Technology

In the 1980s, Baxter, a pharmaceutical and medical supply manufacturer, introduced the stockless system as the new paradigm to improve supply chain efficiency. The stockless system is simply a model where the vendor manages the inventory flow, from picking to stocking the supply rooms for a hospital. One of the benefits of the stockless system is the reduction in a hospital's supply chain cost, ranging from the savings in labor cost due to reduced steps in the supply chain to lower inventory costs due to lowered inventory levels at the hospital (Byrnes, 2003). For example, Baxter's stockless ValueLink system was able to provide a one-time $1.9 million savings to Long Beach Memorial in 1993. Furthermore, Long Beach Memorial achieves $1.3 million in savings annually. At Alta Bates Hospital, the ValueLink implementation has reduced the $1 million medical and surgical inventory down to approximately $200,000 (Curt, 1993).

The stockless system evolved into the Vendor Managed Inventory (VMI) model in the late 1990s. Essentially the evolution involved a change in the terminology, but the concept remained the same. The consignment contract and the automated point of use technology are also the by-products of the stockless system that Baxter introduced. Hospitals have continued to benefit from these innovations, with hospital inventories reduced anywhere between 40 to 80 percent (Wilson, Cunningham, and Westbrook 1992). Furthermore, hospital Full Time Equivalents (FTE) are reduced by 45 percent and some hospitals also see annual cost saving between $400,000 and $1,000,000 with 15 - 25 FTE reductions (Rivard-Royer et al 2002). Fill rate also improved as a direct result of VMI, with fill rate at over 99% (Nathan and Trinkaus 1996), as compared to the convention fill rate of 92 percent (Rivard-Royer et al 2002).

2.4.1 Vendor Managed Inventory

The Vendor Managed Inventory (VMI) is the evolution of the stockless system that Baxter invented in the 1980s. VMI is the system by which distributors assume responsibilities of managing the supplies for hospitals. Under the VMI model, hospital personnel no longer need to conduct reviews of inventory levels in the storage room and make orders when the stock levels fall short of the par levels. Instead, a distributor provides the personnel to review and replenish supplies for each unit in a hospital. The distributor orders supplies from its own facilities, as well as from competitors, depending on what is required by the medical staff.

In the case of APU systems, the systems conduct an automatic review each afternoon to determine which items have reached or fallen below the par levels. Orders are generated and sent daily to the distributor. Generally, orders are for one-for-one replenishment to the hospital units. The orders are then delivered the next day to the hospitals, and, depending on the contractual agreement, the supplies are put-away by either the distributor personnel or hospital material management technicians. Replenishment to a hospital unit usually takes place daily.

The replenished products may differ daily, but the high consumption products usually get replenished daily while the low consumption products may get replenished once a month.

The VMI model removes the redundant functions and inventories from the hospital supply chain (Byrnes 2003). Inventory management becomes the sole responsibility of the operations personnel – nurses and physician are no longer required to be accountable for replenishing supplies in their units. The VMI model also provides a mechanism to control the incentives of hoarding (Sjoerdsma 1991). Hoarding is the practice in which nurses keep supplies that are not accounted for in the hospital's inventory accounting system. The hoarding practice guarantees that nurses can provide physicians with supplies on demand, and therefore removes the potential negative consequences of not having the supplies on hand that are needed for a specific procedure or patient. DeScioli (2005) observed that conventional hospitals may have, due to hoarding practice, six times more unofficial inventory than is reported.

2.4.2 Consignment

Many hospitals favor the consignment model in conjunction with the VMI model. Consignment is an agreement where the vendor assumes the ownership of hospital supplies until the point of actual consumption of the supplies. Consignment stabilizes the prices of materials (Sjoerdsma 1991). Sjoerdsam (1991) also noted that consignment maintains sufficient quantities on-site to meet end-user requirements. The policy does not interfere with hospital operations such as that of setting of par - or reorder point - levels, delivery frequency, billing procedures and the like.

Consignment differs from VMI in that under the VMI contracts the vendor only manages the flow of products to the hospitals receiving docks. Hospitals need to pay for the cost of the products at the point of receiving. With consignment, the vendor owns and manages the inventory flow up to the point of consumption. In the case of APU systems, vendors actually manage the flow and stocking of inventory from suppliers to the APU systems. Hospitals do not incur costs for the products until consumption by a patient.

At the time of this research, CareFirst Hospital does not have a consignment agreement with C4Y Inc. CareFirst Hospital incurs costs for products delivered from C4Y Inc. at the point of receiving (hospital receiving docks).

2.4.3 Automated Point of Use Systems

Advancement in technology and hospital supply chains enable hospitals to implement the Automated Point of Use (APU) systems. Figure 6 illustrates two types of APU systems: The OmniSupplier (left) for medical supplies, and the Pyxis Medstation for pharmaceuticals.

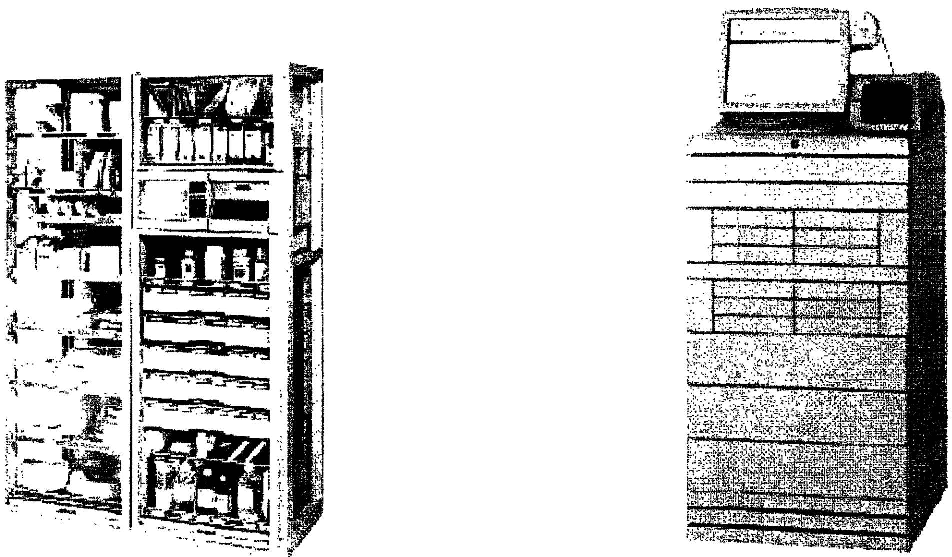

Figure 6: Automated Point of Use System – OmniSupplier® and Pyxis Medstation®

The placement of these machines depend on the characteristic of the units. Sometimes machines are placed near nursing stations, close to patients' rooms, in order to reduce travel time as well as provide patients with timely care. However, machines are also placed in the storage room, replacing open-door cabinets (see Figure 7 and 8).

Figure 7: Conventional Storage Room
(Source: C4Y Inc.)

Figure 8: APU Machines in Storage Room
(Source: C4Y Inc.)

The APU machines operate under a pull model. Nurses retrieve products from each machine by swiping his or her ID through an ID reader to gain access to the machine. Upon opening the door, the system indicates the names of patients that the nurse cares for. Indicator lights activate when the nurses elects the patient's name to guide the nurse in picking the right supplies for that patient. Nurses confirm the retrieval of the supply by pressing the "take" button when retrieving each item. Near the end of each day, each machine automatically performs an inventory level review and places an order based on the established par levels and order-up-to point. In this manner, the APU system provides accountability to the users of the system. It also reduces shrinkage, increases the accuracy of cost capturing, and thus increases the billing accuracy to each patient due to a more accurate mapping of the supplies consumed by each patient.

The APU system also provides transparency into the entire hospital's inventory. The global search capability enables hospital units to search and pull supplies from another unit when shortage is encountered. However, the actual retrieval has to be performed by a nurse within that unit, as the APU system will not allow nurses from other units to register in to the system. Once the supplies are retrieved, the APU system allows nurses to assign the billing for that particular item to the intended patient through a global "search and assign" feature.

In the APU-VMI environment, material technicians are no longer required to perform the inventory and picking activities. These activities are automated by the Automated Point of Use (APU) machines. The computer inside each machine conducts these two activities each afternoon and generates order with specified quantities for items that are at or below the re-order point (set by the hospital unit). The following day, the vendor delivers packages that are pre-picked for each unit to the hospital's receiving dock. Material technicians then deliver the boxes to the specified unit, and replenish the pre-picked items to the APU system.

Typically, the order arrives the day after the order is placed. However, ordering and delivery do not take place over the weekend. The orders for the weekend consumption occur on Monday and are then replenished on Tuesday. The orders submitted on Friday are not filled until Monday since the vendor does not replenish the hospital over the weekend.

On a typical day an experienced technician may require approximately 1 hour to finish restocking a unit. However, the put-away time increases to approximately 2 hours on Tuesday when the replenishment for the weekend consumptions arrive. An inexperienced technician may take up to an hour 30 minutes on a typical day to restock a hospital unit, and up to 3 hours on Tuesday.

The APU-VMI implementation did reduce overall time that material management technicians spend on inventory, picking and put-away activities. On a weekly basis, technicians can save up to 30 minutes of time spent on inventory management. Technicians are no longer required to inventory the department supply rooms and pick supplies from the central supply to stock the department supply rooms. Technicians only need to deliver the boxes (pre-packaged specifically for each APU machine that the orders originated from) to the departments and restock the machines.

Though time was saved from having to perform inventory and picking activities (approximately 1.5 hour total), technicians in general experienced longer put-away time. The increases in put-away time are due to the constraint bin spaces in the APU machines that make it difficult for the technicians to store supplies away. Put-away time increased from approximately 45 minutes in the pre APU-VMI environment to approximately 1 hour in the post APU-VMI environment for an experienced technician. Inexperienced technicians may take up to 1.5 hours to perform the put-away tasks in the APU-VMI environment. On Tuesday, when the order for the weekend arrives, which increase the total material management activity time by approximately 30 minutes for an experienced technician and approximately 1.5 hours for an inexperienced technician.

Despite the longer put-away time, technicians now have more time for other activities that add value to other parts of the hospital. For example, technicians now have more time to perform inventory management activities for other branches of the hospital, such as clinical and sister hospitals in other parts of the city. However, the APU system administrator, who also manages the central supply for the CareFirst Hospital, expresses concerns that there may be an increase in the number of technicians when the hospital has fully implemented the APU-VMI model. The reason is due to the increased amount of time needed to put-away supplies. Further, technicians also require up to 200 to 300 percent more put-away times each Tuesday when the hospital receives the orders that replenish the demand over the weekend.

Furthermore, the quality of life for the technicians also improved from not having to work on the weekends. Prior to the APU-VMI model, technicians are required to work on weekends and holidays so hospital units could be replenished. In the APU-VMI environment, there is no weekend replenishment due to the contracts between CareFirst Hospital and C4Y Inc. Once the entire hospital is transformed to the APU-VMI model, the consensus, according to the interviews conducted by the author, is that technicians do not need to be at the hospital during weekends and holidays.

The following chapter describes the research methodology used in this study. Furthermore, the chapter also discusses the units selected for this study, the demand characteristics of these units, and the inventory policy analysis for the before and after APU-VMI implementation. Optimal policy will be proposed in the chapter follows.

3 Analyzing the Current Situation

CareFirst Hospital contains approximately 199 nursing stations, with 54 stations have been transformed to the APU systems. The first batch of APU systems went live in August, 2005. The other stations continued to operate under the traditional model. C4Y Inc. had scheduled the transformation of the entire hospital, excluding the clinics, to the APU systems by fall of 2006.

The following section discusses the methodology this study used to collect data as well as identify suitable candidates to be included in the study. Based on the criteria identified in the methodology, hospital units were selected for the study (section 3.2). Furthermore, a market basket of items (section 3.4) will then be selected to satisfy the criteria identified in the research methodology section (3.1) in order to observe behaviors at the selected units.

3.1 Research Methodology

This research was divided into two parts to study the benefits of APU and to make inventory policy recommendations that fully utilize the capabilities of the APU-VMI model. To understand the benefits of the APU-VMI model at the CareFirst Hospital, the author conducted interviews with the hospital and C4Y Inc. personnel to understand the inventory management practice before and after the APU-VMI implementation. The author interviewed material management technicians and warehouse and APU system administrators to understand the inventory, picking, and put-away processes for both the before and after APU-VMI implementation. The author also interviewed the purchasing manager at CareFirst Hospital in regards to the procurement activities such as ordering and billing. Specifically, the main questions included:

- ❖ What is the process of placing an order before and after APU-VMI implementation at the Purchasing Department?
- ❖ How long does it take to inventory, pick, and put-away supplies at a typical hospital unit before and after APU-VMI implementation?
- ❖ What is the average salary for the various parties involved in the inventory management process?

Further, the author also interviewed nurses to understand the inventory management process from the nurses' perspective. Typical questions asked included:

- ❖ Describe the process to inventory and retrieve supplies from the supply room before and after APU-VMI implementation.
- ❖ On average, how long does it take to locate supplies from the supply room before and after the APU-VMI implementation?
- ❖ How long does it take to order out-of-stock items from central supply before and after the APU-VMI implementation?

To select hospital units for this study, the author reviewed literature to identify key criteria to identify suitable units. For this study, the author used the most common hospitalization symptoms and the consumption rate as two criteria to identify appropriate units for the study. The first criterion was based on past researches and the consumption rates criterion was based on the actual consumption data at CareFirst Hospital. The author believes these two criteria would capture units that are representatives of other hospital units.

The second part of the research involves investigating the order data at CareFirst. The author collected eleven months of order data that CareFirst generates to vendors such as C4Y Inc. The data was used to identify suitable units to be the representative units for this study. The data was also used to identify the "market baskets" of Stock Keeping Units (SKUs) that would be the representations of items in the selected units.

Based on the data, the author formulated key parameters that to be analyzed in this research. More specifically, the par level, the average quantity per order, and the standard deviation of the quantity are used as key parameters in determining whether an optimal policy is integrated with the APU-VMI model as well as to make recommendations if such integration does not exist. These parameters are keys to model the demand pattern that exists before and after the APU-VMI implementation. Figure 9 shows a sample of the demand pattern that could be generated from the parameters above.

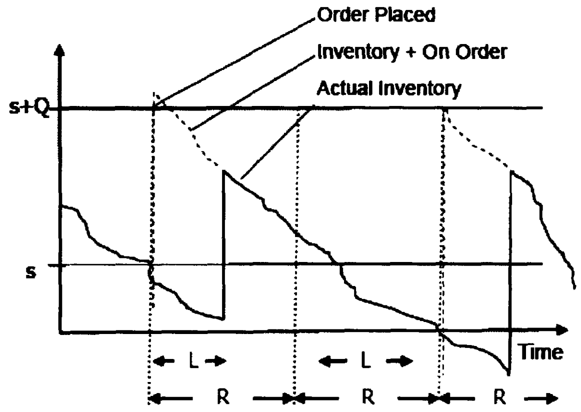

Figure 9: Demand Pattern Illustration

According to Figure 9, the re-order point, s, could be determined by knowing the demand over lead time, the service level, and the variance of the demand over leadtime. The average quantity would help determine the number of items to order, or the Q. The cycle stock could be determined from the average quantity and unit price, or $\left(\frac{AvgQ_i}{2}\right)v_i$ where i represents items $i = 1$ to n in the market basket. The definition and the justification of the market basket usage can be found in Section 3.4.

By modeling the before and after demand patterns, insights could be gained as to whether there is a change in inventory policy, whether the inventory policy under the APU-VMI has reduced the supply chain costs, and whether improvements and which improvements could be made if the policy under the APU-VMI model has not made improvements to the supply chain or has increased the supply chain costs to the hospital.

3.2 The Representative Hospital Units

The primary criteria used to select the representative units for this study are the symptoms of hospitalization and the consumption rate. Because the most common hospital stays were for diseases related to circulatory system, three hospital units were selected: the Cardiac Care Unit (CCU), the Medical Intensive Care Unit (MICU), and the Surgical Intensive Care Unit (SICU). Though the guideline for admitting patients is different, the general themes of the three units include coronary atherosclerosis, congestive heart failure, heart attacks, and cardiac dysrhythmia, which are the characteristics of the diseases related to the circulatory system.

The total of order quantities since January 1st, 2006 at these three units were ranked among the top 10 units that have transformed to the APU-VMI model. The units compared were units that had a go-live date in fiscal year 2005. To make relevant order comparison, only the orders in January through March of 2006 were compared.

From the order data and the characteristics of the units, CCU and MICU were chosen as the representative units to be studied in this research. Furthermore, CCU and MICU are adjacent units, so it would be interesting to see how adjacent units behave under the APU-VMI model. SICU was not chosen for this study due to the overwhelming overlaps between SKUs in each APU system as well as the staged implementation of the APU-VMI model. SICU had three stages in the APU-VMI implementation process as oppose to the one stage implementation at CCU and MICU. CCU and MICU transformed the entire unit to the APU-VMI model with one goal whereas SICU took three attempts to convert the entire unit to the closed cabinet environment. As a result, there were many overlapping SKUs in the nine APU systems that

SICU deployed, as similar SKUs were getting placed into new machines during each implementation stage.

3.3 Product Distribution at the Three Units

Prior to the APU-VMI model, there were approximately 500 distinct items in CCU and MICU respectively. After the APU-VMI implementation, there are now approximately 250 and 310 distinct items in these two units that are in the closed-cabinet systems. Vendor item idenficiation number was not used as the key to identify distinct item due to multiple vendors providing the same item with a different identification. Instead, the item description was used as the primary key to determine the number of distinct items in each unit.

Figure 10 shows the product distribution at CCU for the before and after APU-VMI implementation.

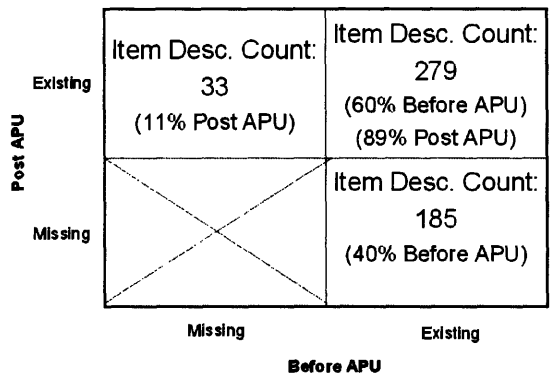

Figure 10: Product Distribution at CCU

Prior to APU-VMI model, there were 464 (279+185) unique item descriptions in CCU. Of these 464 items, 279 are stored in the APU system today, while 185 items are either still in the open space or have been phased out or replaced by similar products. There are 33 items with descriptions that did not exist prior to the APU-VMI model. These items may have replaced part of the 185 items in the lower right hand quadrant of Figure 10 or may be brand new items introduced to CareFirst Hospital for the first time. The complexity involved with reconciling the different SKUs and item descriptions make the items in the lower right hand quadrant and upper left and quadrant in Figure 10 difficult items for this study. For this reason, this research will focus on the 279 items that have matching item descriptions in the before and after APU-VMI environment.

Figure 11 shows the product distribution at MICU for the before and after APU-VMI implementation.

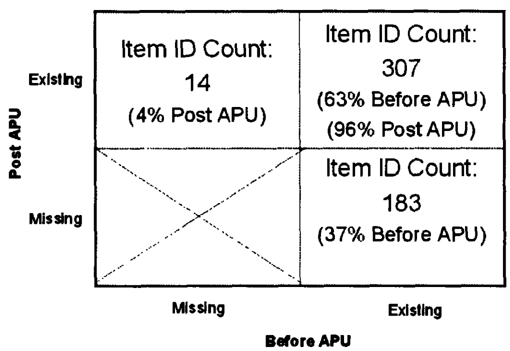

Figure 11: Product Distribution at MICU

Prior to the APU-VMI model, there were 490 items with unique descriptions in MICU. Of these 490 items, 307 are in the closed-cabinet system today. Similar to CCU, there are 183 items that either exist today or have been replaced by similar items by C4Y Inc. There are 14 items with descriptions that did not exist prior to the APU-VMI model. They may have replaced part of the 183 items depicted in the lower right hand quadrant of Figure 11 or may be the brand new items introduced to the CareFirst Hospital for the first time. Like the research on CCU, this research will only focus on items in the upper right hand quadrant of Figure 11 for the consistency in item description for the before and after APU-VMI implementation.

3.4 Market Baskets

From Section 3.3, 279 items and 307 items have been identified for this study at CCU and MICU respectively. However, there are several unit measurements used in the data provided by the C4Y Inc., including boxes, box count, package set, and individual units. Units of measure were not always consistent across items and needed to be standardized to accurately measure the consumption quantity as well as the order quantity.

To standardize 279 and 307 items is an enormous task and the data to perform this is missing for many SKUs. For this reason, representative products are chosen for each unit for this study. These products make up a market basket for each unit.

The main items in the market basket consist of alcohol wipes, IV sets, surgical gloves and masks, sodium chloride and oral airway. The baskets also contain low value items that are less than $2 dollar per item to high value items that are more than $30 dollar per item. Table 1 and 2 shows the characteristics of the CCU market basket and Table 3 and 4 shows the characteristics of the MICU market basket.

Before APU				Post APU				
Description	Par	Unit Cost	Inventory Cost	Par	Unit Cost	Inventory Cost	# Station	Change in Inventory Cost
WIPES,ALCOHOL 200/BX	600	<= $0.1	$5.82	800	<= $0.1	$8.24	1	42%
WATER FOR IRR. 1000ML BOTTLE	12	<= $1	$4.21	28	<= $1	$19.60	1	366%
TUBING, SUCTION, 12'	20	<= $1	$12.32	110	<= $1	$68.20	1	454%
SYRINGE, CATHETER TIP, 60CC	20	<= $1	$8.29	40	<= $1	$12.80	1	54%
SODIUM CHLORIDE .9% 500ML	24	<= $1	$6.42	66	<= $1	$18.48	2	188%
SODIUM CHLORIDE .9% 1000ML	30	<= $1	$9.08	144	<= $1	$90.72	1	899%
SOD CHL 9% IRR. 3000ML BAG	12	<= $10	$24.55	4	<= $10	$16.36	1	-33%
RED CAPS, R-2000B 100/BX	200	<= $1	$26.00	300	<= $1	$42.00	1	62%
Q-TIP, 6" COTTON (STERILE) 100/BX	100	<= $0.1	$3.07	100	<= $0.1	$3.08	1	0%
MASK, SURGICAL, ASEPTEX 50/BX	50	<= $1	$7.33	100	<= $1	$15.00	1	105%
KIT, PACEMAKER INTRODUCER	2	> $100	$239.60	2	> $100	$239.60	1	0%
IV SET, PRIMARY, CNVT PIN,11961	10	<= $10	$37.11	60	<= $10	$203.40	1	448%
IV SET, OMNI-FLOW, SECONDARY	30	<= $10	$45.38	144	<= $10	$231.84	1	411%
GLOVE, SURGEON, 7 40/BX	40	<= $1	$11.14	80	<= $1	$23.20	1	108%
DRESSING, TEGADERM 2 3/8X2 3/4	25	<= $1	$5.67	100	<= $1	$23.00	1	306%
DEXTROSE 5% 500ML BAG	12	<= $1	$3.32	16	<= $1	$5.68	2	71%
DEXTROSE 5% 1000ML BAG	8	<= $1	$2.93	8	<= $1	$5.84	1	99%
CENTRAL VEIN KIT, TRIPLE LUMEN	4	<= $100	$142.61	8	<= $100	$270.24	1	89%
CATH,IV,AUTOGAURD, 20G X 1.0"	8	<= $10	$12.39	15	<= $10	$23.25	1	88%
ALCOHOL,ISO 70%,16OZ,BLUE TINT CS/24	2	<= $1	$1.84	5	<= $1	$4.60	1	150%
AIRWAY, ORAL, 90MM	1	<= $1	$0.65	5	<= $1	$3.40	1	423%

Table 1: Inventory Cost and Unit Cost at CCU (Before vs. After)

Table 1 shows the par levels and the unit cost pattern at CCU for the before and after APU-VMI implementation. A majority of the par level increased in the APU-VMI environment. The range of unit cost remained the same for all the items. The exact costs were disguised for confidentiality.

Table 2 shows the order pattern at CCU for the before and after APU-VMI environment. Overall, the demand per day (calculated based on the quantity ordered and the number of days in the timeframe observed) as well as the number replenished decreased in the APU-VMI environment. The average quantity per order decreased for majority of the items after the crossover and led to the decrease in the cycle stock in the post APU-VMI implementation.

	Demand Pattern - Before						Demand Pattern - After						
Description	Order Total	D /Day	Replenishment	Avg Q	Stdev	Cycle Stock Cost	Destination	Order Total	D /Day	Replenishment	Avg Q	Stdev	Cycle Stock Cost
WIPES,ALCOHOL 200/BX	18,800	106.21	37	508	138	$2.46	S_CCU_2	10,000	74.07	31	323	152	$1.66
WATER FOR IRR. 1000ML BOTTLE	314	1.77	94	3	1	$1.17	S_CCU_2	286	2.12	56	5	3	$1.79
TUBING, SUCTION, 12'	1,174	6.63	111	11	5	$3.26	S_CCU_2	1,139	8.44	76	15	10	$4.65
SYRINGE, CATHETER TIP, 60CC	288	1.63	16	18	4	$3.73	S_CCU_2	121	0.90	9	13	4	$2.15
SODIUM CHLORIDE .9% 500ML	788	4.45	90	9	4	$2.34	S_CCU_2	370	2.74	27	14	5	$3.84
							S_CCU_1	410	3.04	56	7	3	$0.00
SODIUM CHLORIDE .9% 1000ML	1,327	7.50	132	10	3	$3.05	S_CCU_2	1,233	9.13	61	20	13	$6.37
SOD CHL 9% IRR. 3000ML BAG	23	0.13	5	5	3	$9.41	S_CCU_2	2	0.01	2	1	0	$2.05
RED CAPS, R-2000B 100/BX	7,800	44.07	51	153	50	$9.94	S_CCU_1	3,500	25.93	25	140	76	$9.80
Q-TIP, 6" COTTON (STERILE) 100/BX	800	4.52	8	100	0	$1.54	S_CCU_2	400	2.96	4	100	0	$1.54
MASK, SURGICAL, ASEPTEX 50/BX	550	3.11	11	50	0	$3.67	S_CCU_1	900	6.67	14	64	31	$4.82
KIT, PACEMAKER INTRODUCER	5	0.03	3	2	1	$99.83	S_CCU_1	2	0.01	2	1	0	$59.90
IV SET, PRIMARY, CNVT PIN,11961	464	2.62	50	9	2	$17.22	S_CCU_2	287	2.13	37	8	5	$13.15
IV SET, OMNI-FLOW, SECONDARY	1,406	7.94	83	17	6	$12.81	S_CCU_2	1,453	10.76	67	22	12	$17.46
GLOVE, SURGEON, 7 40/BX	200	1.13	5	40	0	$5.57	S_CCU_1	240	1.78	3	80	0	$11.60
DRESSING, TEGADERM 2 3/8X2 3/4	820	4.63	30	27	14	$3.10	S_CCU_1	1,021	7.56	15	68	17	$7.83
DEXTROSE 5% 500ML BAG	51	0.29	14	4	1	$1.01	S_CCU_2	32	0.24	10	3	1	$1.14
							S_CCU_1	36	0.27	10	4	1	$0.00
DEXTROSE 5% 1000ML BAG	73	0.41	21	3	1	$1.27	S_CCU_2	49	0.36	15	3	1	$1.19
CENTRAL VEIN KIT, TRIPLE LUMEN	131	0.74	43	3	1	$54.31	S_CCU_1	140	1.04	29	5	1	$81.54
CATH,IV,AUTOGAURD, 20G X 1.0"	210	1.19	21	10	9	$7.75	S_CCU_1	197	1.46	19	10	2	$8.04
ALCOHOL,ISO 70%,16OZ,BLUE TINT CS/24	20	0.11	11	2	0	$0.84	S_CCU_2	4	0.03	2	2	0	$0.92
AIRWAY, ORAL, 90MM	20	0.11	17	1	0	$0.39	S_CCU_2	29	0.21	8	4	1	$1.23

Table 2: Order Pattern at CCU (Before vs. After)

Overall, the inventory cost increased in the APU-VMI environment for the items in the CCU market basket. The replenishment frequency decreased and the quantity per order increased in the APU-VMI model. The combination of less frequent order and greater quantity per order caused the variance of quantity between orders to increase in the closed-cabinet environment.

Table 3 and 4 below shows the par levels, ranges of unit cost, and order pattern at MICU for the before and after APU-VMI implementation.

Before APU				Post APU				
Description	Par	Unit Cost	Inventory Cost	Par	Unit Cost	Inventory Cost	# Station	Change in Inventory Cost
WIPES,ALCOHOL 200/BX	600	<= $0.1	$5.82	800	<= $0.1	$8.24	1	42%
WATER FOR IRR 500ML BOTTLE	16	<= $1	$5.73	32	<= $1	$23.68	1	313%
TUBE, SALEM SUMP, 18 FRENCH	4	<= $10	$21.34	6	<= $10	$25.92	1	21%
TISSUE, POP-UP, 2PLY(200BX/CS)	16	<= $1	$3.36	40	<= $1	$8.40	1	150%
SYRINGE, CATHETER TIP, 60CC	20	<= $1	$8.29	80	<= $1	$25.60	1	209%
SODIUM CHLORIDE .9% 500ML	40	<= $1	$10.70	69	<= $1	$19.32	2	81%
KIT, CATH, SUCTION, 14 FRENCH	30	<= $1	$14.70	25	<= $1	$12.25	1	-17%
IV SET, PRIMARY, CNVT PIN,11961	20	<= $10	$74.22	92	<= $10	$311.88	1	320%
IV SET, PLUM, PRIMARY,11943	25	<= $10	$166.20	95	<= $10	$656.45	1	295%
IV SET, OMNI-FLOW, SECONDARY	25	<= $10	$37.82	144	<= $10	$231.84	1	513%
GOWN, ISOLATION 10/PK	100	<= $1	$55.12	100	<= $1	$5.51	1	-90%
GLOVE, SURGEON, 7 1/2 40/BX	40	<= $1	$11.14	40	<= $1	$11.60	1	4%
DRESSING, KERLIX SPONGE, 4 X 4	16	<= $1	$20.66	42	<= $1	$13.44	2	-35%
DEXTROSE 5% 500ML BAG	12	<= $1	$3.32	12	<= $1	$8.52	1	157%
DEXTROSE 5% 1000ML BAG	12	<= $1	$4.39	8	<= $1	$5.84	1	33%
CHEST TUBE, 28 FRENCH	1	<= $10	$5.07	5	<= $10	$22.45	1	343%
BLOOD GAS SYRINGE,SAMPLER 3	25	<= $1	$5.72	120	<= $1	$27.60	1	383%
BITESTICK, EPISTIX	1	<= $100	$37.37	10	<= $100	$7.40	1	-80%
AIRWAY, ORAL, 80MM	4	<= $1	$2.63	5	<= $1	$1.85	1	-30%
AIRWAY, NASAL, 28FR	1	<= $10	$3.78	6	<= $10	$13.14	1	248%

Table 3: Par Levels and Unit Cost at MICU (Before vs. After)

Table 3 shows the par levels and the unit cost pattern at MICU for the before and after APU-VMI implementation. The majority of the items experienced an increase in the inventory cost in the APU-VMI environment. The range of unit cost remained the same for all the items. Full analysis of the increase in the par levels is shown in Section 4.2.

	Demand Pattern - Before						Demand Pattern - After						
Description	Order Total	D /Day	Replenishment	Avg Q	Stdev	Cycle Stock Cost	Destination	Order Total	D /Day	Replenishment	Avg Q	Stdev	Cycle Stock Cost
WIPES,ALCOHOL 200/BX	19,800	125.32	43	460.47	166.39	$ 2.23	S_MICU_2	16,800	106.33	52	323.08	143.64	$ 0.92
WATER FOR IRR 500ML BOTTLE	390	2.47	76	5.13	1.84	$ 1.84	S_MICU_2	316	2.00	65	4.86	2.42	$ 1.79
TUBE, SALEM SUMP, 18 FRENCH	107	0.68	28	3.82	0.55	$ 10.19	S_MICU_2	106	0.67	29	3.66	0.90	$ 7.90
TISSUE, POP-UP, 2PLY(200BX/CS)	573	3.63	51	11.24	3.71	$ 1.18	S_MICU_2	274	1.73	19	14.42	11.00	$ 1.52
SYRINGE, CATHETER TIP, 60CC	151	0.96	9	16.78	6.78	$ 3.48	S_MICU_2	114	0.72	10	11.40	4.67	$ 1.82
SODIUM CHLORIDE .9% 500ML	718	4.54	67	10.72	4.77	$ 2.87	S_MICU_2	492	3.11	38	12.95	8.02	$ 3.64
							S_MICU_1	294		33	8.91	2.98	$ -
KIT, CATH, SUCTION, 14 FRENCH	1,160	7.34	58	20.00	8.16	$ 4.90	S_MICU_2	445	2.82	65	6.85	3.54	$ 1.68
IV SET, PRIMARY, CNVT PIN,11961	314	1.99	26	12.08	4.75	$ 22.41	S_MICU_2	324	2.05	34	9.53	4.05	$ 16.13
IV SET, PLUM, PRIMARY,11943	1,334	8.44	85	15.69	6.23	$ 52.17	S_MICU_2	1,074	6.80	69	15.57	8.64	$ 53.81
IV SET, OMNI-FLOW, SECONDARY	627	3.97	45	13.93	5.67	$ 10.54	S_MICU_2	1,719	10.88	80	21.49	12.78	$ 17.30
GOWN, ISOLATION 10/PK	11,200	70.89	120	93.33	25.45	$ 25.72	S_MICU_2	1,150	7.28	24	47.92	41.70	$ 13.19
GLOVE, SURGEON, 7 1/2 40/BX	400	2.53	10	40.00	0.00	$ 5.57	S_MICU_2	320	2.03	7	45.71	15.12	$ 6.45
DRESSING, KERLIX SPONGE, 4 X 4	661	4.18	67	9.87	4.05	$ 6.37	S_MICU_1	354	2.24	45	7.87	4.13	$ 2.53
DEXTROSE 5% 500ML BAG	40	0.25	10	4.00	1.49	$ 1.11	S_MICU_2	45	0.28	12	3.75	1.06	$ 1.04
							S_MICU_1	14		11	1.27	0.47	$ -
DEXTROSE 5% 1000ML BAG	75	0.47	17	4.41	1.28	$ 1.62	S_MICU_2	35	0.22	14	2.50	0.76	$ 0.95
CHEST TUBE, 28 FRENCH	2	0.01	2	1.00	0.00	$ 2.54	S_MICU_2	10	0.06	4	2.50	1.00	$ 5.61
BLOOD GAS SYRINGE,SAMPLER 3	871	5.51	42	20.74	6.04	$ 2.37	S_MICU_2	1,313	8.31	37	35.49	18.30	$ 4.11
BITESTICK, EPISTIX	3	0.02	3	1.00	0.00	$ 18.69	S_MICU_2	4	0.03	4	1.00	0.00	$ 18.69
AIRWAY, ORAL, 80MM	35	0.22	12	2.92	1.31	$ 0.96	S_MICU_2	69	0.44	21	3.29	0.78	$ 0.71
AIRWAY, NASAL, 28FR	2	0.01	2	1.00	0.00	$ 1.89	S_MICU_2	12	0.08	3	4.00	1.73	$ 4.38

Table 4: Order Pattern at MICU (Before vs. After)

Like CCU, the par levels at MICU increased in the APU-VMI environment. The biggest increase was 513 percent. The unit cost range remained the same for the items in MICU's market basket. Some items, such as sodium chloride, are stored in multiple APU machines. This practice contributes to the increase in par levels in the APU-VMI model as observed due to duplicate stocking of the same item in the same location (hospital unit supply room).

Table 4 shows the order pattern for the before and after APU-VMI implementation at MICU. As in the case of CCU, the daily demand decreased in the APU-VMI environment. The average quantity per order for a majority of the items decreased as well, which led to the decrease in the cycle stock.

Generally, the characteristics of the items in CCU and MICU's market baskets consist of alcohol wipes, IV sets, surgical gloves and masks, sodium chloride and oral airway. The baskets also contain low and high value items as well as items that are stored in multiple APU machines. Together, the market baskets realistically represent the characteristics, consumption, and storage behavior of all the products in these two units.

The par levels increased for majority of the items in the CCU and MICU's market baskets. One contributing factor for this phenomenon is due to the duplicate stocking of the same items in different APU machines that belong to the same hospital unit. The variance of quantity between orders also increased in the APU-VMI model, which suggests that the APU-VMI model may create or amplify the bullwhip effect to the upstream suppliers. The detailed analysis of this is presented in Chapter 5.

The following chapter will analyze the market basket for CCU and MICU in more detail. The reasons behind the decline in the daily demand will be investigated in the following chapter.

4 Before and After Analysis

The market baskets depicted in Section 3.4 for CCU and MICU are further analyzed in the following sections. The key parameters mentioned in Section 3.1 (the par levels, the average quantity per order and the standard deviation of the quantity per order) will be calculated so the before - and after - APU-VMI environment could be compared within a standardized and defined manner. The goal is to determine whether the cycle stock and the par levels increased in the APU-VMI environment.

4.1 CCU Market Basket

The CCU market basket consists of 21 unique items that existed before and after the APU-VMI implementation. This was determined based on the item description and not by the unique identification number that are assigned to products by the vendors. The main items in the market basket consist of alcohol wipes, IV sets, surgical gloves and masks, sodium chloride and oral airway. The baskets also contain low value items that are less than $2 dollar per item to high value items that are more than $30 dollar per item. The most expensive item included in the CCU market basket is approximately $119 dollars, which is approximately 50 percent of the most expensive item in the CCU unit in the APU-VMI environment.

As mentioned in Chapter 3, the unit measures of the items are not standardized in the data provided by C4Y Inc. In order to compare the par levels and the cycle stock in the same unit of measurement, the unit for the quantity measure needs to be adjusted. As such, the unit measure of quantity has been adjusted to the individual item level and the unit cost reflects the individual item cost. Furthermore, there are also some duplicate items in the CCU unit. To observe the impact this practice has on the par levels and the cycle stock, two items that reside in multiple APU stations after the APU-VMI implementation are included in the market basket.

Table 5 shows the before and after inventory cost for the market basket items.

	Total Inventory Cost
Before	$609.73
After	$1,328.53

Table 5: Inventory Cost at CCU

The total inventory cost is determined by aggregating the product of the par level for each item and its unit price. This is essentially the aggregate amount of the cost of inventory for the individual items in Table 1.

On the aggregate, Table 5 indicates that the par levels increased in the APU-VMI environment. The increase in the par levels at CCU is reflective of the decentralized supply chain model under the APU-VMI environment. As mentioned in Chapter 2, each APU system has its own par level for all the items in that system. The central warehouse no longer replenishes CCU on a daily basis, and CCU can only depend on the central warehouse for emergency orders in case of a stockout. Furthermore, due to the 5 day replenishment schedule, CCU needs to have enough inventory to meet the demands over the weekend.

The lack of weekend deliveries has proven to be a problem at CCU as about half of the items in the market basket have higher stockout percentages on the weekends in the APU-VMI environment. Further, some items also have high stockout percentages on Monday, Tuesday, and Friday (Table 6).

Item Description	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.	% Change in Inventory Cost	Change in Cycle Stock	Change in # of day of supply
WIPES,ALCOHOL 200/BX	22.22%	11.11%	0.00%	0.00%	22.22%	22.22%	22.22%	42%	-33%	-0.4
WATER FOR IRR. 1000ML BOTTLE	46.15%	23.08%	7.69%	0.00%	0.00%	0.00%	23.08%	366%	52%	0.5
TUBING, SUCTION, 12'	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	454%	43%	0.2
SYRINGE, CATHETER TIP, 60CC	0.00%	50.00%	50.00%	0.00%	0.00%	0.00%	0.00%	54%	-42%	3.9
SODIUM CHLORIDE .9% 500ML	18.18%	45.45%	18.18%	9.09%	0.00%	9.09%	0.00%	188%	64%	3.0
SODIUM CHLORIDE .9% 1000ML	0.00%	0.00%	0.00%	50.00%	50.00%	0.00%	0.00%	899%	109%	0.9
SOD CHL 9% IRR. 3000ML BAG	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-33%	-78%	32.1
RED CAPS, R-2000B 100/BX	30.43%	8.70%	17.39%	4.35%	21.74%	8.70%	8.70%	62%	-1%	1.9
Q-TIP, 6" COTTON (STERILE) 100/BX	33.33%	0.00%	0.00%	0.00%	0.00%	0.00%	66.67%	0%	0%	11.6
MASK, SURGICAL, ASEPTEX 50/BX	0.00%	0.00%	14.29%	28.57%	28.57%	28.57%	0.00%	105%	32%	-6.4
KIT, PACEMAKER INTRODUCER	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0%	-40%	8.5
IV SET, PRIMARY, CNVT PIN,11961	0.00%	0.00%	50.00%	0.00%	0.00%	50.00%	0.00%	448%	-24%	0.1
IV SET, OMNI-FLOW, SECONDARY	16.67%	11.11%	8.33%	22.22%	11.11%	11.11%	19.44%	411%	36%	-0.1
GLOVE, SURGEON, 7 40/BX	50.00%	0.00%	0.00%	0.00%	0.00%	0.00%	50.00%	108%	108%	9.6
DRESSING, TEGADERM 2 3/8X2 3/4	0.00%	0.00%	50.00%	0.00%	0.00%	0.00%	50.00%	306%	152%	3.1
DEXTROSE 5% 500ML BAG	33.33%	0.00%	0.00%	0.00%	66.67%	0.00%	0.00%	71%	12%	0.9
DEXTROSE 5% 1000ML BAG	10.00%	20.00%	20.00%	10.00%	10.00%	0.00%	30.00%	99%	-6%	0.6
CENTRAL VEIN KIT, TRIPLE LUMEN	33.33%	16.67%	16.67%	0.00%	0.00%	16.67%	16.67%	89%	50%	0.5
CATH,IV,AUTOGAURD, 20G X 1.0"	50.00%	0.00%	0.00%	0.00%	0.00%	0.00%	50.00%	88%	4%	-1.3
ALCOHOL,ISO 70%,16OZ,BLUE TINT CS/24	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	150%	10%	51.4
AIRWAY, ORAL, 90MM	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	423%	218%	6.5

Table 6: Stockout Percentage by Day of Week – CCU

The stockout percentage for each item shown in Table 6 is calculated by aggregating the number of stockout for each day of the week and divide by the total number of stockout for that item from November 2005 to March 2006. The stockout count for each item comes from the actual demand data recorded by the APU system. As mentioned in Chapter 2, the APU system records the actions, such as take and put-away, that a nurse or a technician performs. As the actions are recorded, the APU system inventories the items in the machines to adjust and update the inventory levels. At the same time, the stockout occurrence is flagged if a product has zero inventory on hand. The percentage shown in Table 6 is simply the ratio of total stockout for each day of the week and the total stockout count from November 2005 to March 2006.

The stockout problem exists for Monday and Tuesday can be the byproduct of the stockout problem over the weekend. The consumptions over the weekend do not get replenished until Tuesday since the order for the weekend consumptions happens on Monday afternoon. On Monday, CareFirst Hospital only receives Friday's order, which is insufficient to cover the consumptions over Saturday and Sunday. As a result, some products experienced high stockout probabilities on Monday in addition to the weekend. The stockout effect carries over to Tuesday for some products, and then decreases over the course of the week. Stockout occurrence picks up again near the end of the week, and the cycle repeats itself in a dead spiral manner.

The stockout problem may have led to the increase in the days of supply per order for majority of the items in the APU-VMI environment. Figure 12 below shows the days of supply per order for the items in the CCU market baseket.

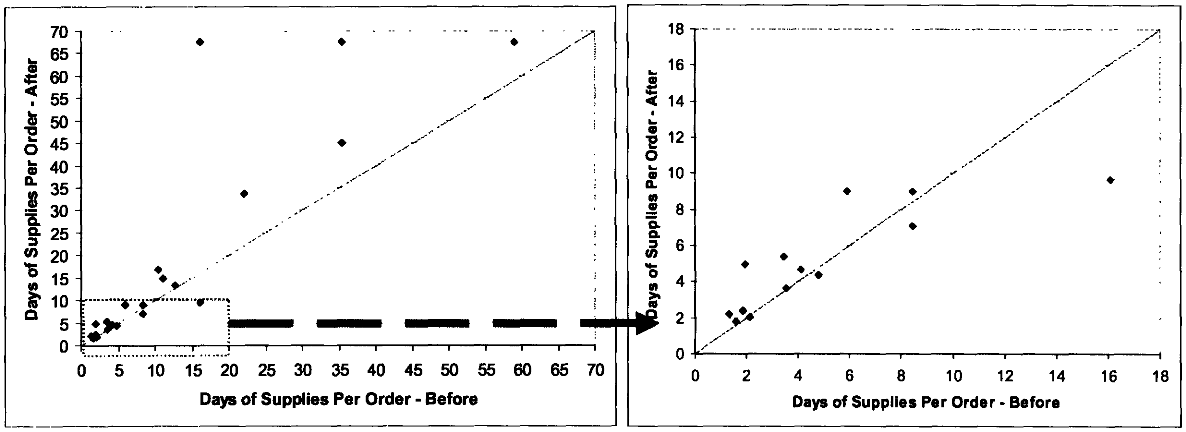

Figure 12: Days of Supplies Per Order - CCU

The days of supply per order is calculated as $\frac{AvgQ}{AvgD}$ for all the items in the CCU market basket.

The average quantity is calculated by aggregating the quantity for all the orders and divides it by the number of orders. The average demand is calculated by dividing the summation of the order quantity over a period of time by the number of days in that timeframe.

The days of supply equation shows the demand (in days) that an order needs to fulfill. Essentially, the days of supply translate the ordering pattern (quantity per order and order frequency) into a single number that is easy to convey the existing inventory policy at each hospital unit. This will also shows the effects on the ordering pattern at each hospital unit without the weekend delivery.

The increase in days of supply per order leads to the increase in cycle stock, as the unit cost did not increase in the APU-VMI environment. The weekend stockout problem seems less problematic for items with an increase of at least1 day in the days of supply per order. Some of these items have no stockout problems for any days of the week, some have problem during the weekend, and a few have stockout occurrence throughout the week. Increasing the days of supply per order seems to be an effective method in reducing the stockout occurrence at CCU.

The increase in the days of supply per order for majority of the items (17) at CCU may be the effect of the lack of weekend replenishment. CCU increases the quantity per order so that the order that is scheduled to arrive on Friday will cover the weekend consumption. In the past, CCU may just place order to the central warehouse with quantity that meets one day's demand since the warehouse is obligated to replenish the hospital units on weekends. However, in the APU-VMI environment, CCU no longer has the reliance on the central warehouse for daily replenishment. Instead, it relies on C4Y to replenish the orders placed the day before. Couple the lack of weekend delivery with the minimal reliance on the central warehouse (as the APU-VMI model is relieving the hospital staff from performing the basic supply chain activities so that higher value-add activities may be conducted), CCU now needs to have a quantity per order that would meet at least three days of demand since the APU system is set to order the same quantity each time an order is placed. This increase the lead-time for products to be replenished at the hospital units and thus the quantity per order is increase to ensure that the demands over the longer lead-time can be met.

Furthermore, APU system's ability to record the actions taken by nurses could also explain the increase in the number of days of supply per order. In the past, nurses were able to retrieve items without any formal documentation. As such, nurses hoard inventory to insure that the most critical items to that nurse will not stockout. However, in the APU-VMI environment, the system records any activities performed on the system. This could greatly reduce the amount of unofficial inventory since nurses can no longer retrieve items from the closed-cabinet system without providing the reason for the retrieval. The reduction in the unofficial inventory, at the same time, also reduces the overall inventory available to CCU. Nurses can no longer build up a personal inventory since all the actions need to be accounted for by a reason (i.e. supply patient rooms) or by a patient. As such, the stockout occurrences that were avoided by using the unofficial inventory can now only be avoided if supplies are in the APU machines. But the APU-VMI model reduced the number of locations where supplies are kept due to the losses of personal inventory and reduces the overall inventory position – official and unofficial – at CCU. As a result, CCU increases the quantity per order in hope to minimize the stockout occurrence.

Lastly, the increase in the day of supplies per order may also be the effect of the decrease in the frequency in which the CCU unit is getting restocked. Figure 13 shows the comparison of the replenishment frequency for the before and after APU-VMI environment.

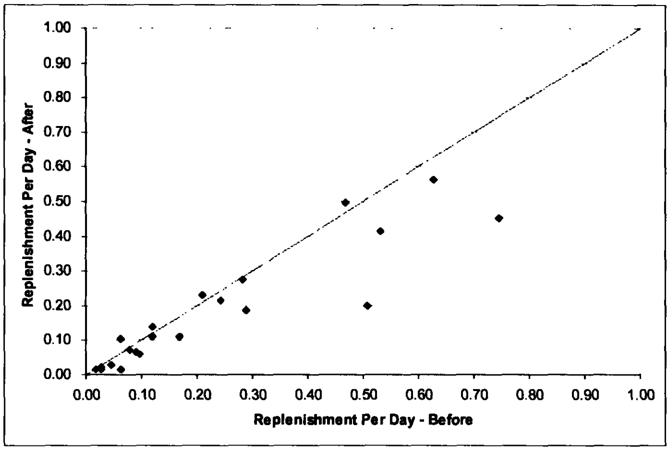

Figure 13: Before and After Replenishment Frequency Comparison – CCU

As Figure 13 shows, the replenishment frequency decreases for majority of the items in the CCU market basket. The decrease in the rate at which CCU is being replenished can cause the quantity per replenishment to increase. This is especially critical if the stockout occurrence is to be minimized.

With the higher average quantity ordered and the less order frequency, the coefficient of variation for the average quantity per order also increased for approximately half of the items in CCU's market basket. Figure 14 compares the coefficient of variation for the before and after APU-VMI implementation.

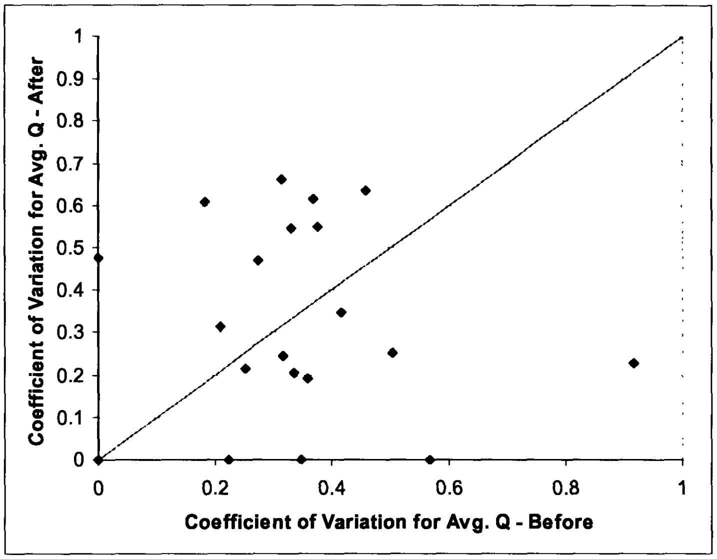

Figure 14: Coefficient of Variation for the Avg. Q – CCU Before and After APU-VMI

Coefficient of variation measures the degree of variation in the order quantity for the before and after APU-VMI implementation. Figure 14 shows that the change in the coefficient of variation was evenly divided. Approximately half of the items experienced an increase in coefficient of variation after the APU-VMI implementation while the other half experienced a decrease in the order quantity variation. The items that have an increase in the coefficient of variation have a decrease in the days of supply per order. On the contrary, the items that have a decrease in the coefficient of variation have an increase in the days of supply per order. The increase in the days of supply per order seems to minimize the variability between orders. However, the increase in the days of supply per order does not seem to reduce the stockout occurrence. The items with an increase in days of supply also experienced higher stockout occurrence in the APU-VMI environment, whereas the items with a decrease in days of supply experienced minimal stockout occasions.

As observed in Figure 14, although only about half of the items experienced an increase in the coefficient of variation, the increase in the variance between orders could make the vendor carry more inventories at its warehouse to meet the intermittent large order quantity. The quantity per order for the same item is more volatile after the APU-VMI implementation and vendor needs to increase its par level in order to insure against the likelihood of not being able to fulfill an order. This would result in the bullwhip effect upstream to the hospital's vendor and possibly to the vendor's suppliers. The detail of the bullwhip effect analysis from the hospital to the vendor warehouse is discussed in Chapter 5.

In summary, the majority of the items in the CCU market basket experienced increase in par level, cycle stock, and the quantity per order. The increase in par level as well as the increase in the quantity per order may be due to the reduced number of locations that supplies are kept. The old system granted nurses an easy access to build personal inventory, in which nurses were able to 'own' a set of personal supplies that is stored at a location other than the supply room. The APU-VMI model eliminated those personal supplies due to the accountability measure that the APU system enforces and reduces the supply point to just the closed-cabinet system at CCU. This led the nursing unit to increase the par levels as well as the quantity per order to avoid stockout occurrence. Further, the par level and the quantity per order are also increased to ensure that the weekend demand can be met. The lost of weekend replenishment and the reduced replenishment frequency make carrying higher amount of inventory and cycle stock even more critical to ensure against stockout occurrence.

The increase in the days of supply per order reduces the coefficient of variation between orders. Having more days of inventory in-stock seems to reduce – and some incidences eliminate – the variability of quantity between orders. This may have the effect of reducing the bullwhip effect upstream and enable the vendor to build a more accurate forecast. However, this does not seem to be an effective strategy in reducing the number of stockout occurrences.

4.2 MICU Market Basket

Similar to CCU, a market basket of products was chosen to be the representative products for MICU. The MICU market basket consists of 20 unique items: alcohol wipes, IV sets, glove surgeons, chest tubes and nasal airway. There are also high and low value items in the basket. Similar to CCU, two items were chosen to represent the products that existed before and after the APU-VMI implementation by matching the item description.

According to the market basket, the unit price for the products at MICU did not change much after the APU-VMI implementation (see Table 3). The inventory cost, however, increased for the items in the MICU market basket (Table 7).

	Total Inventory Cost	
Before	$	497.38
After	$	1,440.93

Table 7: Total Inventory Cost - MICU

The inventory cost at MICU increased by almost 300 percent after the APU-VMI implementation while the range of prices did not change. This suggests that the par level increased dramatically since price has been fairly constant for before and after the APU-VMI implementation.

Similar to CCU, the increase in the par levels at MICU seems to suggest that it is also used as a method to reduce the number of stockout occurrences. The items in MICU's market basket experienced higher probability of stockout over the weekend than the items in the CCU market basket, as shown in Table 8.

Item Description	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.	% Change in Inventory Cost	Change in Cycle Stock	Change in # of day of supply
WIPES,ALCOHOL 200/BX	18.18%	9.09%	18.18%	0.00%	9.09%	27.27%	18.18%	42%	-59%	-0.6
WATER FOR IRR 500ML BOTTLE	31.82%	13.64%	4.55%	0.00%	18.18%	22.73%	9.09%	313%	-2%	0.4
TUBE, SALEM SUMP, 18 FRENCH	44.44%	0.00%	22.22%	11.11%	0.00%	0.00%	22.22%	21%	-23%	-0.2
TISSUE, POP-UP, 2PLY(200BX/CS)	16.67%	0.00%	0.00%	16.67%	16.67%	33.33%	16.67%	150%	28%	5.2
SYRINGE, CATHETER TIP, 60CC	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	209%	-48%	-1.8
SODIUM CHLORIDE .9% 500ML	26.67%	26.67%	6.67%	6.67%	6.67%	13.33%	13.33%	81%	27%	1.8
KIT, CATH, SUCTION, 14 FRENCH	18.75%	18.75%	0.00%	6.25%	12.50%	31.25%	12.50%	-17%	-66%	-0.3
IV SET, PRIMARY, CNVT PIN,11961	0.00%	0.00%	0.00%	0.00%	33.33%	33.33%	33.33%	320%	-28%	-1.4
IV SET, PLUM, PRIMARY,11943	33.33%	20.00%	6.67%	0.00%	0.00%	6.67%	33.33%	295%	3%	0.4
IV SET, OMNI-FLOW, SECONDARY	25.00%	16.67%	4.17%	8.33%	8.33%	12.50%	25.00%	513%	64%	-1.5
GOWN, ISOLATION 10/PK	26.32%	15.79%	15.79%	0.00%	15.79%	15.79%	10.53%	-90%	-49%	5.3
GLOVE, SURGEON, 7 1/2 40/BX	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	4%	16%	6.8
DRESSING, KERLIX SPONGE, 4 X 4	0.00%	21.43%	7.14%	14.29%	14.29%	21.43%	21.43%	-35%	-60%	1.2
DEXTROSE 5% 500ML BAG	33.33%	0.00%	66.67%	0.00%	0.00%	0.00%	0.00%	157%	-6%	-2.6
DEXTROSE 5% 1000ML BAG	0.00%	0.00%	0.00%	0.00%	50.00%	50.00%	0.00%	33%	-41%	2.0
CHEST TUBE, 28 FRENCH	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	343%	121%	-39.5
BLOOD GAS SYRINGE,SAMPLER 3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	383%	73%	0.5
BITESTICK, EPISTIX	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-80%	0%	-13.2
AIRWAY, ORAL, 80MM	25.00%	0.00%	25.00%	0.00%	0.00%	0.00%	50.00%	-30%	-26%	-5.6
AIRWAY, NASAL, 28FR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	248%	132%	-26.3

Table 8: Stockout Percentage By Day of Week - MICU

Contrary to CCU, a higher percentage of the items in the MICU market basket encounter stockout during the weekdays. Approximately 10 of the items in the MICU market basket experienced at least 2 stockouts during the weekdays and these items have one of the highest increases in the par levels. These items make up the 9 items that experienced increase in the quantity per order at MICU.

When the cycle stock level, the par level, and the days of supply per order increases, the stockout problem seems to be minimal or none for the MICU market basket items. However, when one of these three factor decreases, stockout problem arises. The stockout problem seems to be more severe when at least two of the three factors experienced a decrease. This seems to suggest that MICU has mastered the strategy to cope with the stockout problem for some of the items, but not for others. Furthermore, this also suggests that the inventory policy is inefficient, as some items with stockout problem have par levels and cycle stock levels decreased. The days of supply per order increased for some of these items, and this seems to be used as a way to reduce the stockout occurrence as well. But the increase in the days of supply for these items did not, however, help reduce the stockout occurrence.

The increase and decrease in the number of days of supply per order is evenly split at MICU as shown in Figure 15. Generally, the items with an increase in the quantity per order have more stockout days during the week than the items with a decrease in the days of supply per order. The par levels for majority of the items, regardless of the quantity per order after the APU-VMI implementation, increased.

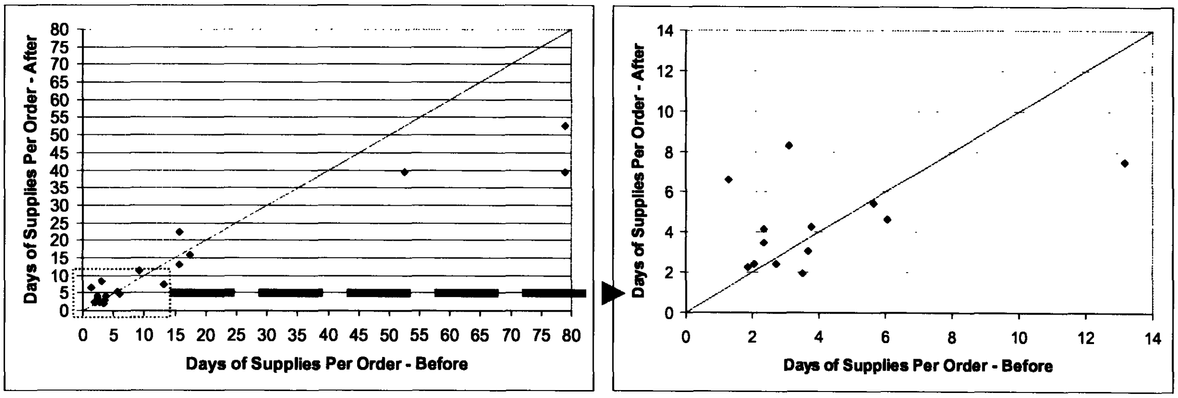

Figure 15: Days of Supplies Per Order - MICU

Approximately half of the items in the MICU market basket experienced an increase in the number of days of supply per order. In other words, the quantity per order is increased in the APU-VMI environment for these items. These items also have one of the highest increases in the par level for the items in the MICU market basket.

Similar to CCU, the increases in the quantity per order suggests that MICU is ordering more to avoid stockout on weekends as well as to meet the demand over the longer lead-time period. The accountability and the ability to possess personal inventory factors discussed in Section 4.1 also seem to increase the quantity per order at MICU. The reduced number of locations where supplies are kept – official and unofficial – may have triggered the increase in the days of supply per order for half of the items in the MICU market basket, just as is the case with majority of the items in the CCU market basket.

The other half of the items in the market basket experienced a decrease in the days of supply per order. The par levels for these items also increased but the cycle stock was mixed. Though this phenomenon was also observed at CCU, MICU has a higher proportion of items having this behavior than CCU. One possible explanation of this occurrence suggests that the par level is increased on the system level, where the stockout of some items (items with increase in quantity per order) led the unit to increase the par levels for all. In other words, the high probability of stockout occurrence for the items with increase in the days of supply per order may trigger the increase in the par levels for the items that have a decrease in the days of supply per order.

A careful look at the items with a decrease in the days of supply per order indicates that the inventory policy is ineffective. Two out of the three items with the highest decrease in the days of supply per order (3 outlier points in Figure 15) experienced increase in par levels and cycle stock. The items with lower decrease in the days of supply per order (points closer to the diagonal line in Figure 15) all experienced stockout problem throughout the week, and with higher stockout probability on the weekends. The demand for these items seems to be higher than the supply, and yet the days of supply per order was not adjusted accordingly and led to the stockout problem.

The even distribution of the items with an increase and a decrease in the days of supply per order is synonymous to the replenishment frequency at MICU. The items with increase in the replenishment frequency experienced decrease in the days of supply per order, and vice versa. The less frequently an item is order, the more quantity per order. The replenishment frequency, as a result, is evenly split between the items with an increase and a decrease in the frequency of replenishment in the before and after APU-VMI environment, as shown in Figure 17.

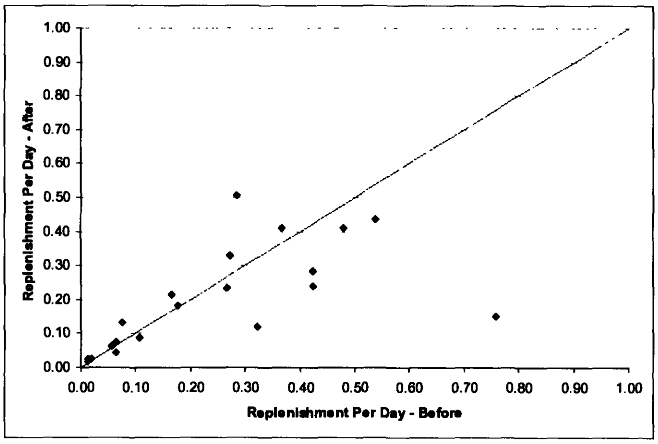

Figure 16: Daily Replenishment Frequency - MICU

The replenishment frequency and the days of supply per order seems to suggest that MICU is taking advantage of the flat charge of $2 dollar per line of order regardless of order quantity. This was evident for the items with a decrease replenishment frequency and an increase in the days of supply per order. This order pattern seems to be taking advantage of the line charge without the quantity limitation. The less replenishment frequency, the less CareFirst needs to pay for ordering supplies.

However, half of the items in MICU's market basket are having higher replenishment frequency in the APU-VMI environment. These items also experienced a decrease in the days of supply per order. The stockout problem is mixed for this group of items – some have no stockout occurrence while others have high stockout occasions. Though higher frequency of replenishment can reduce the number of stockout occurrence, the increase in the days of supply per order can achieve the same result with lowered cost associated of ordering the supplies.

The evenly spread pattern of the increase and the decrease in the days of supply per order and the replenishment frequency, however, led to the increase in the coefficient of variation of the average quantity per order for majority of the items. Majority of the items experienced an increase in the coefficient of variation for the average quantity per order regardless of whether there is an increase in the days of supply per order. Figure 17 shows the variation behavior for the before and after APU-VMI implementation for the items in the MICU market basket.

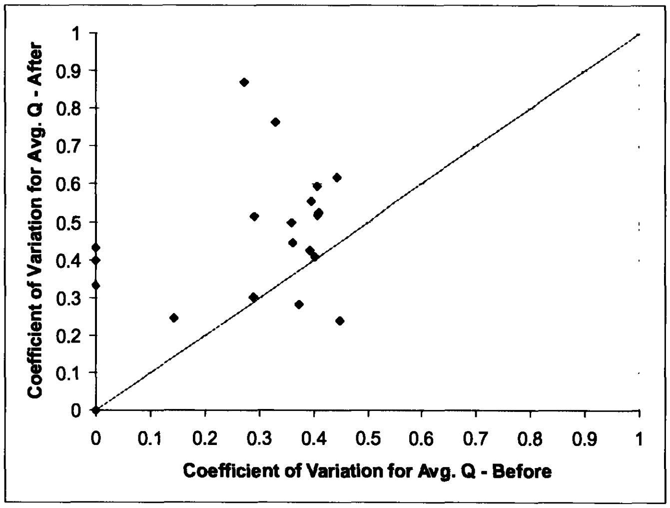

Figure 17: Quantity Standard Deviation Comparison – MICU

The higher variability in the quantity between orders for the items with an increase in the days of supply per order seems to suggest that the quantity has been adjusted to meet the demand at the hospital unit. The adjustment may also be used as an attempt to reduce the stockout occurrence. The phenomena shown by the items with a decrease in the days of supply per order suggests that the demand may still outpace the supply (order quantity), and the increase in the variability between order quantities is to reduce the difference between the demand and supply gap as well as to minimize stockout occurrence.

Similar to CCU, the inventory cost increased for the market basket items at MICU in the APU-VMI environment. The behavior observed from the items in MICU's market basket suggests that the hospital unit may have the tendency to increase the par level system-wide due to the stockout problems experienced by some of the items. Furthermore, the relationship between the days of supply per order and the number of stockout occurrence at the item level suggests that MICU does not have an effective inventory policy in the APU-VMI environment.

Overall, the par levels, the cycle stock, the days of supply between orders, and the variance of quantity between orders have increased for majority of the items for both CCU and MICU's market basket. All of these factors seem to have been used as ways to ensure sufficient supplies are in the nursing units to meet the demand over a longer lead-time between replenishment as well as to reduce the stockout occurrence, especially over the weekend. The settings (such as the level of par and cycle stocks) for these factors seemed to be inconsistent and do not accurately represent the demand signals. At times, the par levels and cycle stock along with the days of supply per order decreased while the data suggests that the stockout occurrence is apparent for any day of the week. Other times, these factors are increased with the stockout occasions observed to be minimal. This inconsistency can cause hospital units to have more inventory for some products and not enough inventory for others. This can cause hospital units to incur unnecessary inventory cost for items that did not experience stockout problem. The hospital can also incur stockout costs for items that are not available at time of consumption.

The unsynchronized supply and demand pattern also suggests that the hospital units do not have the right inventory policy for the decentralized environment. Furthermore, the settings of the par level and cycle stock as well as the days of supply ordered suggest that the hospital units may not be setting the inventory policy holistically. As observed at CCU and MICU, the par levels, cycle stock, and the days of supply per order may increase for items with minimal stockout occurrence. At times, one of the three factors may be increased for items with minimal stockout problem, and other times one of the three factors may be decreased for items with high stockout occurrence. These two phenomena were more apparent in MICU's market basket.

The phenomenon that was apparent at both CCU and MICU is that the increase in the days of supply per order seems to be one way that hospital units are using to reduce the order costs. Currently, CareFirst Hospital gets charged for approximately $2 dollar per line of order regardless of the quantity amount on that line. As such, orders with greater quantity and less frequency can reduce the cost of ordering material at CareFirst Hospital.

The other phenomenon that was apparent at both units is that the par levels seems to increase on a system-wide level. Par level increased for items that experienced stockout on both weekdays and weekends. However, par level also increased for items that experienced minimal stockout on either weekdays or weekends. As such, a careful review of the demand pattern is needed to ensure that the right par level is set for each product. As mentioned earlier, carrying inventory could cost 11 to 15 percent of the cost of the items. Reducing the par level on items that do not show stockout problem could increase the return on the investment made on the APU-VMI model at CareFirst Hospital.

The increase in the variability of quantity per order suggests that the APU-VMI environment may amplify the demand upstream and create the bullwhip effect. The variation for quantity between orders increased for majority of the items in MICU's market basket, and the variation increased for approximately half of the items in CCU's market basket. The bullwhip effect creates distorted demand signals to supply chain partners, and is not effective for any party in the supply chain. The two units observed in this study suggest that the bullwhip effect may exist in the APU-VMI environment, and is analyzed further in chapter 5.

5 The Bullwhip Effect

The bullwhip effect phenomenon is described as the distorted order signals to the suppliers due to order quantity greater than that of sales between the downstream parties to the upstream supplier (Lee el at 1997). The amplification to the upstream supplier signals the manufacturers to overproduce as well as adjust inventory policy to hold more inventories in order to meet demand from downstream customers. The effect would ripples upwards to the raw materials provider and affects the inventory policy for all channel participants.

There are four common causes of bullwhip effect – demand signal processing, the rationing game, order batching and price variation (Lee el at 1997). Demand signal processing occurs when past demand information is used as input to forecast for future demand and that demand is non-stationary. For example, let's consider the demand for IV solutions in a hospital. The demand is non-stationary, depends on patients' care needs and conditions of the market (in this case the environment where we live in). The IV solutions usage in the past is used to predict the demand in the next period. If the demand surged in the current period, then the forecasted demand for next month will be distorted, because the demand from current month may not be representative of a typical month. As a result, the hospital places more orders for IV solutions for next period in anticipation of a higher demand. In reality, the demand in the next period may be half the quantity ordered. This would cause the hospital to reduce order for the following period to reduce the excess inventory of IV solutions. This ordering practice at the hospital level sends a distorted signal upstream to its suppliers and cause suppliers to have the sine-like wave inventory pattern, with the suppliers having approximately one sine-wave length behind that of the hospital demand pattern.

The rationing game occurs when a shortage is anticipated and a strategic purchasing decision is taken to reduce the impact of shortage. Under this scenario, shortage is anticipated at the manufacturer and retailers are aware of the shortage situation. In order to hedge against shortage at the retail level, retailers place orders in excess to demand, with the assumption that the supply of the product is unlimited from the manufacturer. This way, retailers are hedged against stockout and poor customer service level during the period that the manufacturer is anticipating shortage of supplies.

Order batching is accumulating orders for the same item into a bulk quantity to reduce order costs and the frequency of orders. This is the typical case of the periodic review model, where quantity is ordered to satisfy the order-up-to level every R periods. Order variance is created through this model, as the quantity per order is dependent on the demand prior to review period. When this scenario is multiplied by a factor of x to simulate the behavior of multiple retailers on one supplier, when coupled with correlated and balanced ordering (Lee el at 1997), the supplier can expect to see great variances of orders between multiple periods.

Price variation refers to the behavior of purchasing with the goal of avoiding price fluctuations. This behavior can take place when prices are anticipated to rise in the near future, or supplier offer discounts based on quantity ordered. In the discount case, layers of unit prices are published to the consumer, and a unit discount is applied to all units based on the quantity ordered.

The current inventory policy practice at the CareFirst Hospital resembles that of the demand signal processing phenomena. Though the inventory policy is based on par level with an order-up-to threshold, the par level is set based on the historical demand pattern, with the exception that par level is rarely adjusted in decreasing matter; the par level is generally adjusted in increasing direction based on most recent demand pattern.

The bullwhip effect may exist in the APU-VMI environment due to the increase in the variance of quantity ordered at the CareFirst Hospital. The average quantity per order and the time between orders seem to be different between the before and after APU-VMI implementation. Table 9 and 10 shows the average and the coefficient of variation for the quantity per order and the time between orders for the before and after APU-VMI implementation.

Item Description		Q Before	Q After	T Before	T After
#65 - WIPES,ALCOHOL 200/BX	Avg	2.54	1.61	4.78	4.93
	CV	0.27	0.47	0.48	0.92
#3650 - WATER FOR IRR. 1000ML BOTTLE	Avg	3.34	5.11	1.89	2.80
	CV	0.37	0.61	0.61	0.55
TUBING, SUCTION, 12'	Avg	10.32	14.99	1.55	2.04
	CV	0.47	0.63	0.52	0.58
SYRINGE, CATHETER TIP, 60CC	Avg	18.00	13.44	9.31	14.67
	CV	0.21	0.32	0.64	1.05
SODIUM CHLORIDE .9% 500ML	Avg	8.76	9.40	1.94	1.87
	CV	0.42	0.51	0.58	0.90
SODIUM CHLORIDE .9% 1000ML	Avg	10.05	20.21	1.29	2.52
	CV	0.31	0.66	0.71	0.59
SOD CHL 9% IRR. 3000ML BAG	Avg	4.60	1.00	14.00	24.50
	CV	0.57	-	1.23	1.41
RED CAPS, R-2000B 100/BX	Avg	152.94	140.00	3.35	5.72
	CV	0.33	0.55	0.51	0.57
Q-TIP, 6" COTTON (STERILE) 100/BX	Avg	100.00	100.00	17.25	29.75
	CV	-	-	0.56	0.81
MASK, SURGICAL, ASEPTEX 50/BX	Avg	50.00	64.29	13.91	11.21
	CV	-	0.48	0.91	1.18
KIT, PACEMAKER INTRODUCER	Avg	1.67	1.00	5.00	27.50
	CV	0.35	-	1.40	1.41
IV SET, PRIMARY, CNVT PIN,11961	Avg	9.28	7.76	3.46	4.14
	CV	0.18	0.61	0.58	0.55
IV SET, OMNI-FLOW, SECONDARY	Avg	16.94	21.69	2.10	2.34
	CV	0.38	0.55	0.66	0.66
GLOVE, SURGEON, 7 40/BX	Avg	40.00	80.00	27.60	36.67
	CV	-	-	0.76	0.88
DRESSING, TEGADERM 2 3/8X2 3/4	Avg	27.33	68.07	5.47	8.60
	CV	0.50	0.25	0.88	0.58
DEXTROSE 5% 500ML BAG	Avg	3.64	3.40	11.71	7.65
	CV	0.32	0.26	1.16	1.23
DEXTROSE 5% 1000ML BAG	Avg	3.48	3.27	8.33	10.20
	CV	0.25	0.22	0.65	1.24
CENTRAL VEIN KIT, TRIPLE LUMEN	Avg	3.05	4.83	4.07	5.31
	CV	0.36	0.19	0.77	0.68
CATH,IV,AUTOGAURD, 20G X 1.0"	Avg	10.00	10.37	8.00	7.84
	CV	0.92	0.23	0.99	0.52
ALCOHOL,ISO 70%,16OZ,BLUE TINT CS/24	Avg	1.82	2.00	12.91	50.50
	CV	0.22	-	1.03	1.41
AIRWAY, ORAL, 90MM	Avg	1.18	3.63	8.41	15.88
	CV	0.33	0.21	1.01	0.84

Table 9: Average and Coefficient of Variation of Q and T - CCU

The average quantity per order (Q) represents the typical size of an order. It is calculated by aggregating the quantity for all the orders and divides it by the number of orders in the same timeframe. The time between orders is simply the day(s) elapsed between subsequent orders for an item.

Table 9 and 10 shows the average and the coefficient of variation for the quantity per order for the before and after APU-VMI implementation at CCU and MICU. The average and the coefficient of variation for the time between orders are also shown in these two tables. The average for Q and T represents the average quantity per order and the average time between orders for an item.

Table 9 shows the average quantity per order increased for many of the items and decreased for some of the items. The coefficient of variation, on the other hand, increased for a majority of the items. The average time between orders decreased for many items while the coefficient of variation increased for a majority of the items.

Table 10 below shows the same information for the market basket at MICU. Unlike CCU, the majority of the average quantity per order decreased in the APU-VMI environment. The coefficient of variation for the order quantity, however, increased for majority of the items. The average time between orders was evenly split – approximately half of the items experienced a decrease while the other half experienced an increase. The coefficient of variation for the time between orders increased for a majority of the items.

Item Description		Q Before	Q After	T Before	T After
WIPES,ALCOHOL 200/BX	Avg	460.47	323.08	3.53	3.13
	CV	0.36	0.44	0.57	0.75
WATER FOR IRR 500ML BOTTLE	Avg	5.13	4.86	2.07	2.48
	CV	0.36	0.50	0.67	0.68
TUBE, SALEM SUMP, 18 FRENCH	Avg	3.82	3.66	5.29	5.69
	CV	0.14	0.25	0.66	0.67
TISSUE, POP-UP, 2PLY(200BX/CS)	Avg	11.24	14.42	3.04	4.53
	CV	0.33	0.76	0.68	1.08
SYRINGE, CATHETER TIP, 60CC	Avg	16.78	11.40	16.22	14.50
	CV	0.40	0.41	0.97	0.68
SODIUM CHLORIDE .9% 500ML	Avg	10.72	11.07	2.34	2.31
	CV	0.45	0.59	0.55	1.81
KIT, CATH, SUCTION, 14 FRENCH	Avg	20.00	6.85	2.67	2.46
	CV	0.41	0.52	0.82	0.81
IV SET, PRIMARY, CNVT PIN,11961	Avg	12.08	9.53	5.85	4.71
	CV	0.39	0.43	0.60	0.74
IV SET, PLUM, PRIMARY,11943	Avg	15.69	15.57	1.82	2.54
	CV	0.40	0.56	0.60	0.63
IV SET, OMNI-FLOW, SECONDARY	Avg	13.93	21.49	3.42	2.08
	CV	0.41	0.59	0.86	0.59
GOWN, ISOLATION 10/PK	Avg	93.33	47.42	1.28	9.23
	CV	0.27	0.78	0.80	1.36
GLOVE, SURGEON, 7 1/2 40/BX	Avg	40.00	45.71	14.30	23.57
	CV	-	0.33	0.70	0.81
DRESSING, KERLIX SPONGE, 4 X 4	Avg	9.87	7.87	2.33	3.67
	CV	0.41	0.53	0.70	0.68
DEXTROSE 5% 500ML BAG	Avg	4.00	2.57	15.40	6.65
	CV	0.37	0.59	0.87	1.11
DEXTROSE 5% 1000ML BAG	Avg	4.41	2.50	9.12	11.07
	CV	0.29	0.30	1.31	2.26
CHEST TUBE, 28 FRENCH	Avg	1.00	2.50	59.00	39.75
	CV	-	0.40	1.41	1.76
BLOOD GAS SYRINGE,SAMPLER 3	Avg	20.74	35.49	3.60	4.51
	CV	0.29	0.52	0.81	0.77
BITESTICK, EPISTIX	Avg	1.00	1.00	33.33	38.50
	CV	-	-	1.50	0.93
AIRWAY, ORAL, 80MM	Avg	2.64	3.29	10.21	8.19
	CV	0.53	0.24	0.85	0.76
AIRWAY, NASAL, 28FR	Avg	1.00	4.00	6.00	34.33
	CV	-	0.43	1.41	1.71

Table 10: Average and Coefficient of Variation for Quantity and Time - MICU

The average and the coefficient of variation for the quantity per order and the time between orders suggest that the bullwhip effect may have been amplified in the APU-VMI environment, where the variation of the quantity per order increased after the APU-VMI implementation. Two statistical tests are conducted for this research to determine the significance of this variability as well as the degree of the variability, which will be discussed in the following section.

5.1 Statistical Test for Significance in the Before and After Variability

We tested for the significance of the variability in the order quantity and the time between orders for before and after APU-VMI implementation. More specifically, the ANOVA for single factor is used to test for the variance between two groups of samples having one independent variable. For example, a product, or the independent variable, have order quantity for before and after the APU-VMI implementation, and the before and after quantity are the two groups of samples for this product. The same test is also applied to test for variance in the time between orders. Again the product is the independent variable, and the times between each order for the before and after APU-VMI implementation are the group samples in this test scenario.

Once the ANOVA single factor test confirms the significance of the variability between the quantity per order and the time between orders, the t-test is used to determine the degree of variability. According to the Center for Social Research Method, the t-test is simply a ratio between the signal and the noise of two data group. The signal is the difference between group means, and the noise is the variability of the groups.

The following sections discuss the test setups for CCU and MICU as well as the outcome of the two tests.

5.1.1 F-Test and T-Test at CCU

As mentioned earlier, the F-test is used to test for the variance between the quantity per order as well as the time between orders for the before and after APU-VMI values. To conduct the F-test, a null and an alternate hypothesis need to be stated, and they are:

$$H_o : \sigma_{Q,Before} = \sigma_{Q,After}$$
$$H_a : \sigma_{Q,Before} \neq \sigma_{Q,After}$$

$$H_o : \sigma_{T,Before} = \sigma_{T,After}$$
$$H_a : \sigma_{T,Before} \neq \sigma_{T,After}$$

In the first set of the hypothesis, the null hypothesis states that the variances of quantity per order are the same for the before and after APU-VMI implementation and the alternative hypothesis states that the variances of quantity per order are different for the before and after APU-VMI implementation. The second set of hypothesis has similar null and alternate hypothesis, except that the test applies to time between orders instead of quantity per order. Table 11 shows the result of the F-test and unit cost for the items in CCU's market basket.

	Qty			Time			
Item Description	df	F	P-value	df	F	P-value	Unit Cost
#65 - WIPES,ALCOHOL 200/BX	1	27.73	0.00	1	0.02	0.88	$ 0.01
#3650 - WATER FOR IRR. 1000ML	1	23.75	0.00	1	15.33	0.00	$ 0.70
TUBING, SUCTION, 12'	1	17.32	0.00	1	9.67	0.00	$ 0.62
SYRINGE, CATHETER TIP, 60CC	1	7.76	0.01	1	1.55	0.23	$ 0.32
SODIUM CHLORIDE .9% 500ML	1	0.99	0.32	1	0.13	0.72	$ 0.56
SODIUM CHLORIDE .9% 1000ML	1	41.56	0.00	1	22.19	0.00	$ 0.63
SOD CHL 9% IRR. 3000ML BAG	1	3.40	0.12	1	0.33	0.59	$ 4.09
RED CAPS, R-2000B 100/BX	1	0.78	0.38	1	17.27	0.00	$ 0.14
Q-TIP, 6" COTTON (STERILE) 100/BX	1	65535.00	N/A	1	1.73	0.22	$ 0.03
MASK, SURGICAL, ASEPTEX 50/BX	1	2.38	0.14	1	0.26	0.61	$ 0.15
KIT, PACEMAKER INTRODUCER	1	2.40	0.22	1	1.13	0.37	$ 119.80
IV SET, PRIMARY, CNVT PIN,11961	1	4.46	0.04	1	2.16	0.14	$ 3.39
IV SET, OMNI-FLOW, SECONDARY	1	9.74	0.00	1	1.07	0.30	$ 1.61
GLOVE, SURGEON, 7 40/BX	1	65535.00	N/A	1	0.24	0.64	$ 0.29
DRESSING, TEGADERM 2 3/8X2 3/4	1	74.46	0.00	1	4.15	0.05	$ 0.23
DEXTROSE 5% 500ML BAG	1	0.00	1.00	1	0.02	0.89	$ 0.71
DEXTROSE 5% 1000ML BAG	1	0.46	0.51	1	0.28	0.61	$ 0.73
CENTRAL VEIN KIT, TRIPLE LUMEN	1	33.10	0.00	1	0.93	0.34	$ 33.78
CATH,IV,AUTOGAURD, 20G X 1.0"	1	4.25	0.06	1	0.26	0.62	$ 1.55
ALCOHOL,ISO 70%,16OZ,BLUE TINT	1	0.38	0.55	1	3.82	0.08	$ 0.92
AIRWAY, ORAL, 90MM	1	118.21	0.00	1	2.91	0.10	$ 0.68

Table 11: F-Test Results – CCU

The df stands for degrees of freedom, which expresses the number of options available within a variable. The F-value is used to determine the P-value. The P-value is level of confidence that the difference in variability is significant. For this test, the significant level is set at 0.05, so any P-value below or equal to 0.05 demonstrates the difference is significant and that the null hypothesis should be rejected.

The significance of the average quantity per order is mixed for CCU. Approximately half of the items in the CCU market basket has P-value of less than or equal to 0.05. In other words, half of the items in the market basket displayed the tendency for causing bullwhip effect as the variance of the quantity between orders is high.

The test for the time between orders, however, did not demonstrate the same result as that of quantity per order. There are 5 items with P-value less than or equal to 0.05. Out of these 5 items, the P-value for the average quantity per order for 4 of these items are also less than or equal to 0.05. The combination of the high variance in the average quantity per order and the time between orders forms the ideal scenario of bullwhip effect. However, the sample is too small to conclude that the order patterns at CCU are causing the bullwhip effect.

The F-test has shown that the many items have higher variability between quantities per order in the APU-VMI environment. The time between orders remained relatively the same as a whole. Together, the test results for the quantity and the time is inconclusive to reject the null hypothesis, as only half of the items showed significance in the quantity per order and less than half showed significance in the time between orders.

To determine the degree of variability, the t-test is used. The null and alternate hypotheses for the t-test are:

$$H_o : \bar{Q}_{Before} > \bar{Q}_{After}$$

$$H_a : \bar{Q}_{Before} \leq \bar{Q}_{After}$$

$$H_o : T_{Before} > T_{After}$$

$$H_a : T_{Before} \leq T_{After}$$

The first set of hypothesis has a null hypothesis that the average quantity per order before the APU-VMI implementation is greater than the average quantity per order in the APU-VMI environment. The alternate hypothesis is that the average quantity prior to APU-VMI implementation is less than or equal to the average quantity per order in the APU-VMI environment. The second set of hypothesis is a similar hypothesis for the time between orders for before and after APU-VMI implementation.

Table 12 below shows the t-test results and the unit cost for the items in the market basket.

Item Description	Qty		Time		Unit Cost
	df	P(T<=t) one-tail	df	P(T<=t) one-tail	
#65 - WIPES,ALCOHOL 200/BX	61	0.00	43	0.45	$ 0.01
#3650 - WATER FOR IRR. 1000ML	65	0.00	90	0.00	$ 0.70
TUBING, SUCTION, 12'	102	0.00	123	0.00	$ 0.62
SYRINGE, CATHETER TIP, 60CC	15	0.01	9	0.17	$ 0.32
SODIUM CHLORIDE .9% 500ML	152	0.16	143	0.36	$ 0.56
SODIUM CHLORIDE .9% 1000ML	63	0.00	82	0.00	$ 0.63
SOD CHL 9% IRR. 3000ML BAG	4	0.02	1	0.38	$ 4.09
RED CAPS, R-2000B 100/BX	35	0.22	30	0.00	$ 0.14
Q-TIP, 6" COTTON (STERILE) 100/BX	65535	NA	3	0.20	$ 0.03
MASK, SURGICAL, ASEPTEX 50/BX	13	0.05	22	0.31	$ 0.15
KIT, PACEMAKER INTRODUCER	2	0.09	1	0.28	$ 119.80
IV SET, PRIMARY, CNVT PIN,11961	43	0.03	72	0.08	$ 3.39
IV SET, OMNI-FLOW, SECONDARY	96	0.00	134	0.15	$ 1.61
GLOVE, SURGEON, 7 40/BX	65535	NA	3	0.35	$ 0.29
DRESSING, TEGADERM 2 3/8X2 3/4	23	0.00	27	0.03	$ 0.23
DEXTROSE 5% 500ML BAG	23	0.26	22	0.17	$ 0.71
DEXTROSE 5% 1000ML BAG	33	0.22	18	0.30	$ 0.73
CENTRAL VEIN KIT, TRIPLE LUMEN	66	0.00	54	0.07	$ 33.78
CATH,IV,AUTOGAURD, 20G X 1.0"	23	0.43	31	0.47	$ 1.55
ALCOHOL,ISO 70%,16OZ,BLUE TINT	10	0.08	1	0.30	$ 0.92
AIRWAY, ORAL, 90MM	9	0.00	10	0.09	$ 0.68

Table 12: T-Test Results - CCU

Similar to the F-test, the P-value in the t-test is the level of confidence that the null hypothesis can be rejected. The threshold is set to 0.05 just like the F-test. According to Table 12, there are

12 items with P-value less than or equal to 0.05 for the average quantity per order test and only 4 for the time between orders test. For the average quantity per order, approximately half of the items have a confidence level that can reject the null hypothesis. Similar to the F-test, the test result here is mixed – some items have a high degree of variability between quantities per order while other items do not have the variability characteristic.

The null hypothesis that the time between orders before the APU-VMI implementation is greater than the time between orders after the APU-VMI implementation is, however, not rejected. There are only 4 items with significant level of confidence that the null hypothesis is incorrect and is not enough to reject the null hypothesis for the market basket. Therefore, the time between orders in the APU-VMI environment is less than the time between orders prior to the APU-VMI model.

The results of the F-test and the t-test were mixed to make a conclusive remark that the bullwhip effect exists in the APU-VMI environment. However, items with significant P-value in the F-test also showed significance in the t-test for both the average quantity per order and the time between orders. These items may distort the demand signal upstream to the hospital vendor, but the overall effect these items have on the hospital unit is inconclusive from this test.

The following section analyzes the quantity per order and the time between orders variability significance at MICU.

5.1.2 F-Test and T-Test at MICU

The F-test and t-test are used to determine the variability and the degree of variability for the quantity per order and the time between orders for the before and after APU-VMI environment. The hypotheses for the F-test are:

$$H_o : \sigma_{Q,Before} = \sigma_{Q,After}$$
$$H_a : \sigma_{Q,Before} \neq \sigma_{Q,After}$$

$$H_o : \sigma_{T,Before} = \sigma_{T,After}$$
$$H_a : \sigma_{T,Before} \neq \sigma_{T,After}$$

The result of the F-test is demonstrated in Table 13 below.

	Qty			Time			
Item Description	**df**	**F**	**P-value**	**df**	**F**	**P-value**	**Unit Cost**
WIPES,ALCOHOL 200/BX	1	18.65	0.00	1	0.78	0.38	$ 0.01
WATER FOR IRR 500ML BOTTLE	1	0.56	0.45	1	2.53	0.11	$ 0.74
TUBE, SALEM SUMP, 18 FRENCH	1	0.71	0.40	1	0.17	0.68	$ 4.32
TISSUE, POP-UP, 2PLY(200BX/CS)	1	3.33	0.07	1	3.22	0.08	$ 0.21
SYRINGE, CATHETER TIP, 60CC	1	4.13	0.06	1	0.08	0.78	$ 0.32
SODIUM CHLORIDE .9% 500ML	1	0.13	0.72	1	0.00	0.95	$ 0.56
KIT, CATH, SUCTION, 14 FRENCH	1	139.42	0.00	1	0.31	0.58	$ 0.49
IV SET, PRIMARY, CNVT PIN,11961	1	5.01	0.03	1	1.58	0.21	$ 3.39
IV SET, PLUM, PRIMARY,11943	1	0.01	0.91	1	10.83	0.00	$ 6.91
IV SET, OMNI-FLOW, SECONDARY	1	14.12	0.00	1	12.90	0.00	$ 1.61
GOWN, ISOLATION 10/PK	1	65.32	0.00	1	47.83	0.00	$ 0.55
GLOVE, SURGEON, 7 1/2 40/BX	1	1.47	0.24	1	1.74	0.21	$ 0.28
DRESSING, KERLIX SPONGE, 4 X 4	1	6.46	0.01	1	11.92	0.00	$ 0.64
DEXTROSE 5% 500ML BAG	1	6.39	0.02	1	5.87	0.02	$ 0.55
DEXTROSE 5% 1000ML BAG	1	24.21	0.00	1	0.08	0.78	$ 0.76
CHEST TUBE, 28 FRENCH	1	4.00	0.12	1	0.09	0.78	$ 4.49
BLOOD GAS SYRINGE,SAMPLER 3	1	24.31	0.00	1	1.62	0.21	$ 0.23
BITESTICK, EPISTIX	1	65,535.00	NA	1	0.03	0.88	$ 37.37
AIRWAY, ORAL, 80MM	1	3.05	0.09	1	0.65	0.43	$ 0.43
AIRWAY, NASAL, 28FR	1	5.40	0.10	1	0.42	0.56	$ 2.19

Table 13: F-Test Results – MICU

There are 9 items with P-values less than or equal to 0.05 for the quantity per order test, and 5 for the time between orders. Similar to CCU, approximately half of the items showed high variability between order quantities. However, the sample is not big enough to make a conclusive decision as to whether the items in MICU show high variability between order quantities.

The null hypothesis for the time between orders, however, is not rejected because less than half of the items have a confidence level greater than 95 percent that variability in the time between orders exists. As a result, the null hypothesis can be accepted.

The t-test is also conducted for the market basket at MICU due to the variability in the quantity per order. The hypothesis for the t-test is:

$$H_o : \bar{Q}_{Before} > \bar{Q}_{After}$$
$$H_a : \bar{Q}_{Before} \leq \bar{Q}_{After}$$

$$H_o : T_{Before} > T_{After}$$
$$H_a : T_{Before} \leq T_{After}$$

The result of the t-test is demonstrated in Table 14.

	Quantity		Time		
Item Description	df	P(T<=t) one-tail	df	P(T<=t) one-tail	Unit Cost
WIPES,ALCOHOL 200/BX	84	0.00	93	0.19	$ 0.01
WATER FOR IRR 500ML BOTTLE	118	0.23	124	0.06	$ 0.74
TUBE, SALEM SUMP, 18 FRENCH	47	0.20	55	0.34	$ 4.32
TISSUE, POP-UP, 2PLY(200BX/CS)	20	0.12	20	0.11	$ 0.21
SYRINGE, CATHETER TIP, 60CC	14	0.03	13	0.39	$ 0.32
SODIUM CHLORIDE .9% 500ML	128	0.36	84	0.47	$ 0.56
KIT, CATH, SUCTION, 14 FRENCH	76	0.00	116	0.29	$ 0.49
IV SET, PRIMARY, CNVT PIN,11961	49	0.02	54	0.11	$ 3.39
IV SET, PLUM, PRIMARY,11943	120	0.46	116	0.00	$ 6.91
IV SET, OMNI-FLOW, SECONDARY	118	0.00	53	0.00	$ 1.61
GOWN, ISOLATION 10/PK	38	0.00	30	0.00	$ 0.55
GLOVE, SURGEON, 7 1/2 40/BX	6	0.18	8	0.14	$ 0.28
DRESSING, KERLIX SPONGE, 4 X 4	93	0.01	69	0.00	$ 0.64
DEXTROSE 5% 500ML BAG	17	0.01	11	0.04	$ 0.55
DEXTROSE 5% 1000ML BAG	27	0.00	18	0.40	$ 0.76
CHEST TUBE, 28 FRENCH	3	0.03	2	0.40	$ 4.49
BLOOD GAS SYRINGE,SAMPLER 3	43	0.00	71	0.11	$ 0.23
BITESTICK, EPISTIX	65535	NA	3	0.44	$ 37.37
AIRWAY, ORAL, 80MM	19	0.07	22	0.23	$ 0.43
AIRWAY, NASAL, 28FR	2	0.05	2	0.25	$ 2.19

Table 14: T-Test Results - MICU

There are 12 items with a P-value less than or equal to 0.05 for the quantity and 4 for the time variable. The majority of the items that showed significance in the F-test also showed significance in the t-test for the average quantity per order and the time between order variables.

As a whole, it is inconclusive as to whether the items in MICU's market basket show the bullwhip effect. Though majority of the items with high variability also showed high degree of variability for both the Q and the T variables, the sample size is not big enough to make a conclusive remark for the unit as a whole.

As a whole, the bullwhip effect seems to exist for some products in both the CCU and MICU's market baskets. Some products in both units have higher variability in the quantity per order in the APU-VMI environment. Majority of these items also have higher variability in the time between orders. Together, these items create the ideal bullwhip effect at both units. The distorted signals from these items, however, may not be significant enough to alter the inventory policy at the vendor and its suppliers. As such, the assumption that the bullwhip effect exists in the APU-VMI environment is inconclusive.

6 Implementing the Optimal Policy

As discussed in Chapter 4, the existing inventory policy at the Cardiac Care Unit (CCU) and Medical Intensive Care Unit (MICU) are inefficient. Based on the analysis of the par and the cycle stock levels, along with the days of supply per order and the variability of the quantities per order, the inventory policy at both units are inconsistent with the demand pattern. As mentioned in Chapter 4, the par and cycle stock levels seem to be adjusted on a system-wide level. The days of supply per order are not consistent with the par and cycle stock levels, and it does not seem to correlate with the stockout frequencies observed at both units.

CareFirst Hospital could benefit greatly if the par levels are adjusted based on demand history instead of being based on short-term demand signal. Furthermore, C4Y Inc. and CareFirst together could improve the supply chain between the two to deliver more cost savings to both organizations.

The following section discusses the policy changes that CareFirst should consider in order to utilize the capability of the APU system. Further, the relationship between CareFirst and C4Y Inc. improvement will be discussed so more benefits can be realized from the APU-VMI model.

6.1 Policy Changes at CareFirst

As discovered in Chapter 4, the par levels at both CCU and MICU more than doubled after the APU-VMI implementation. The variance of quantities per order increased for some items at CCU and for majority of the items at MICU. The following sections discuss areas that can potentially alleviate the high par level and the inconsistent inventory policy at both units.

6.1.1 Adjusting the Par Levels

The existing practice of adjusting par levels are based on the single period demand signal as discussed in Chapter 4. If a stockout occasion arises for any item, the par level for that item is very likely to be increased by nursing units to avoid stockout in the future. This practice substantially increased the par levels over time.

Optimizing the par level at the local level is ineffective. Nursing units should not adjust par levels based on short-term stockout signal. Instead, nursing units should engage professionals such as C4Y Inc. to investigate the demand pattern similar to the one demonstrated in Chapter 4 over a period of time to determine the root cause of stockout, and what the optimal par level should be based on the service level that the nursing unit aims to achieve.

DeScioli (2005) suggested using an s,Q policy in the APU-VMI environment. The s,Q policy that whenever the inventory position reaches the re-order point(s) or falls below it, quantity Q is ordered. The re-order point here is synonymous to the par level in the APU-VMI environment. To demonstrate the savings that can be achieved by using an optimal policy, the par level is calculated using the formula $s = x_L + k\sigma_L$ where x_L is the demand over lead time; k is the factor corresponds to a particular service level; and σ_L is the variance of the demand over the lead time.

Using 99 percent as the service level, the new par level and the potential savings are calculated for the market basket items in CCU (see Table 15).

Item Description	Par Level (Existing)	Total Inventory Cost (Existing)	Par Level (Optimal)	Total Inventory Cost (Optimal)	Total Inventory Cost Savings
WIPES,ALCOHOL 200/BX	800	$8.24	545	$5.61	$2.63
WATER FOR IRR. 1000ML BOTTLE	28	$19.60	12	$8.48	$11.12
TUBING, SUCTION, 12'	110	$68.20	40	$24.65	$43.55
SYRINGE, CATHETER TIP, 60CC	40	$12.80	13	$4.30	$8.50
SODIUM CHLORIDE .9% 500ML	66	$18.48	18	$9.87	$8.61
SODIUM CHLORIDE .9% 1000ML	144	$90.72	52	$32.64	$58.08
SOD CHL 9% IRR. 3000ML BAG	4	$16.36	1	$4.09	$12.27
RED CAPS, R-2000B 100/BX	300	$42.00	256	$35.91	$6.09
Q-TIP, 6" COTTON (STERILE) 100/BX	100	$3.08	4	$0.14	$2.94
MASK, SURGICAL, ASEPTEX 50/BX	100	$15.00	97	$14.56	$0.44
KIT, PACEMAKER INTRODUCER	2	$239.60	1	$119.80	$119.80
IV SET, PRIMARY, CNVT PIN,11961	60	$203.40	17	$56.37	$147.03
IV SET, OMNI-FLOW, SECONDARY	144	$231.84	50	$80.65	$151.19
GLOVE, SURGEON, 7 40/BX	80	$23.20	3	$0.77	$22.43
DRESSING, TEGADERM 2 3/8X2 3/4	100	$23.00	60	$13.82	$9.18
DEXTROSE 5% 500ML BAG	16	$5.68	3	$1.85	$3.83
DEXTROSE 5% 1000ML BAG	8	$5.84	3	$1.86	$3.98
CENTRAL VEIN KIT, TRIPLE LUMEN	8	$270.24	4	$141.91	$128.33
CATH,IV,AUTOGAURD, 20G X 1.0"	15	$23.25	9	$13.82	$9.43
ALCOHOL,ISO 70%,16OZ,BLUE TINT CS/24	5	$4.60	1	$0.92	$3.68
AIRWAY, ORAL, 90MM	5	$3.40	2	$1.66	$1.74

Table 15: Total Stock Saving with Optimal Model - CCU

The service level chosen to calculate the optimal policy is based on the current service level provided by C4Y Inc. at CareFirst Hospital. The optimal total stock is calculated using the equation shown above. The demand over lead-time is calculated using the average order per day multiply by 1.5 in lead-time to account for the demand over the weekend. The 1.5 days in lead-time is calculated by taking the average of the lead-time for each weekday - one day lead-time for Monday through Thursday and 3 days of lead-time for Friday. The average order per day is treated as the demand per day since the data set spreads throughout several months and the demand pattern can be inferred from the order data. The standard deviation of the demand over lead-time is calculated using the standard deviation of the order quantity per day.

The savings in the optimal environment ranged from approximately $1 dollars for the low value items to approximately $150 dollars for the more expensive items. The range of savings can also depend on the level of services provided. The difference in cost between different service levels are demonstrated in Figure 18.

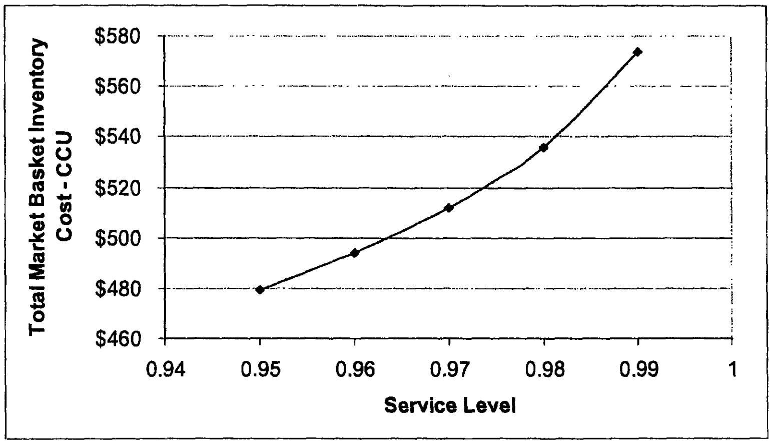

Figure 18: CSL Sensitivity Analysis - CCU

Figure 18 shows that the total inventory cost decreases with each decreasing service level. The biggest decrease is between 99 and 98 percent service level. The difference in cost, along with the product characteristics, could serve as a criterion in determining the optimal policy for that particular product so that higher savings can be achieved by reducing the cost of carrying inventory.

Similar savings are also observed at MICU, as shown in Table 16.

Item Description	Par Level (Existing)	Total Inventory Cost (Existing)	Par Level (Optimal)	Total Inventory Cost (Optimal)	Total Inventory Cost Savings
WIPES,ALCOHOL 200/BX	800	$8.24	569	$3.24	$2.42
WATER FOR IRR 500ML BOTTLE	32	$23.68	10	$7.31	$17.95
TUBE, SALEM SUMP, 18 FRENCH	6	$25.92	4	$15.39	$4.58
TISSUE, POP-UP, 2PLY(200BX/CS)	40	$8.40	34	$7.14	$5.04
SYRINGE, CATHETER TIP, 60CC	80	$25.60	14	$4.59	$17.31
SODIUM CHLORIDE .9% 500ML	69	$19.32	28	$15.46	$8.62
KIT, CATH, SUCTION, 14 FRENCH	25	$12.25	14	$7.01	-$2.45
IV SET, PRIMARY, CNVT PIN,11961	92	$311.88	15	$49.52	$237.66
IV SET, PLUM, PRIMARY,11943	95	$656.45	35	$240.68	$490.25
IV SET, OMNI-FLOW, SECONDARY	144	$231.84	53	$84.91	$194.02
GOWN, ISOLATION 10/PK	100	$5.51	130	$71.44	-$49.61
GLOVE, SURGEON, 7 1/2 40/BX	40	$11.60	46	$13.01	$0.46
DRESSING, KERLIX SPONGE, 4 X 4	42	$13.44	15	$9.75	-$7.22
DEXTROSE 5% 500ML BAG	12	$8.52	3	$1.90	$5.20
DEXTROSE 5% 1000ML BAG	8	$5.84	2	$1.89	$1.45
CHEST TUBE, 28 FRENCH	5	$22.45	3	$13.22	$17.38
BLOOD GAS SYRINGE,SAMPLER 3	120	$27.60	65	$14.95	$21.88
BITESTICK, EPISTIX	10	$7.40	1	$37.37	-$29.97
AIRWAY, ORAL, 80MM	5	$1.85	3	$1.24	-$0.78
AIRWAY, NASAL, 28FR	6	$13.14	5	$11.05	$9.36

Table 16: Total Inventory Cost Saving with Optimal Policy - MICU

Similar to CCU, the service level used to calculate the optimal stocking level is 99 percent. Figure 19 shows the sensitivity of the cost to different service levels at MICU.

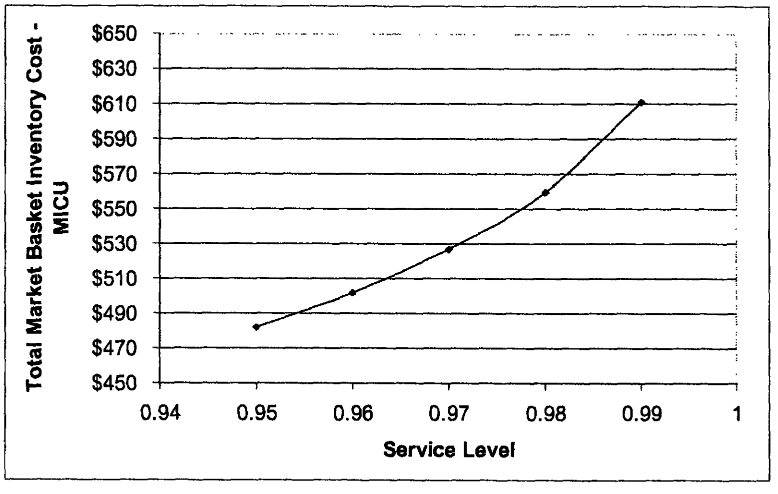

Figure 19: CSL Sensitivity Analysis - MICU

Similar to CCU, the cost decreases with each decrease in the service level. The sensitivity between cost and service level at MICU, however, is not as great as that observed at CCU.

Therefore, MICU can probably continue to be served by the 99 percent service level that is currently in place today.

Further, the par levels for the entire unit should be optimized as a whole, instead of narrowing the focus on individual machines. Currently, each APU system has its own par level for all the items stored in the system. If an item is stored in multiple machines within a unit, that item has the possibility of getting two different par values, one for each machine. This practice introduces excess stocks in the inventory that does not align with the demand pattern, as shown in Table 17 and 18 for CCU and MICU respectively.

Table 17 shows that 5 percent of the products in Machine 1 also exists in Machine 2, and that 2 percent of the products in Machine 2 exists in Machine 1. The percentage differs because the number of items in each machine is different.

Table 18 shows the product overlap distribution for MICU. The percentage of overlapped items is higher in MICU than CCU. This creates higher par levels at MICU in the APU-VMI model, and thus incurs higher inventory cost due to the duplicate items.

The diagonal (from upper left to lower right) represents the products in Machine 1 and Machine 2 respectively. As such, the overlap percentage is 100 percent.

	Machine 1	Machine 2
Machine 1	100%	5%
Machine 2	2%	100%

Table 17: Product Overlaps Percentages – CCU

	Machine 1	Machine 2
Machine 1	100%	75%
Machine 2	27%	100%

Table 18: Product Overlaps Percentages - MICU

Furthermore, the nursing units could collaborate with the logistic professionals to optimize the policy further by considering the criticality of products. Nursing units could rank items currently stocked in the APU system based on the amount of time nurses and physicians can manage without the items. The ranking could be accomplished on a scale from 1 to 5, for example. One could indicate that there would not be any negative effect if an item is stockout for 3 days (or that there is a substitutable item available); two could indicate the same scenario but with a 2 day of stockout duration. The scale could go up with decreasing tolerance stockout duration, with 5 as having no substitute items available and is critical for the items to be available it whenever demanded.

The numerical attributes could then be used by the logistician to segment the products to provide the optimal par level, delivery quantity and delivery cycle to the unit. Logisticians can use different service levels for products that are ranked in each of the 5 scales. Logisticians could then group the scales together and assign a service level to that grouping to observe the difference in costs of having a service level per scale and a service level per group. Then logisticians could apply the optimal inventory model – the s,Q model – for each of the service levels defined for each scale or group. This way, the inventory policy is tailored by the criticality of a product's characteristic and the supply chain cost should decrease with this flexible approach.

6.1.2 Optimize the Quantity per Order

Chapter 5 revealed that approximately half of the items in the CCU and MICU market baskets have higher variability in the APU-VMI environment compare to the open-cabinet system. Some items are taking advantage of the flat order cost ($2 dollar per line of order regardless of quantity per line of order) and have low stockout frequency while other items are not taking advantage of the flat order cost (less quantity per order with more frequent orders) and have high stockout frequencies. Optimizing the right quantity per order based on the order cost and the demand pattern (based on the order data) should help CareFirst reduce the cost per order as well as reduce the stockout frequencies for items that have high stockout occurrences. The cycle stock cost, however, will increase due to more on-hand inventory.

Similar to the par level, the optimal quantity per order can be calculated based on the s,Q model. DeScioli (2005) suggested that the s,Q policy is an optimal policy in the APU-VMI environment. The Q is calculated based on the Economic Order Quantity (EOQ) as $\sqrt{\frac{2AD}{vr}}$, where the A is the order cost, D is the demand (annual), v is the unit cost of a product, and r is the inventory carrying cost (annual). Order cost is estimated at $2 dollar per line of order regardless of the quantity per order; demand is the daily order quantity calculated from the order data from C4Y Inc.; the unit price for the product is the selling price from the vendor, and the inventory carrying cost is estimated at 10 percent annually. Using the information in Table 1 through 4, the optimal order quantity is calculated for each item in the CCU and MICU market basket.

Description	Existing			Optimal		
	Order Total	# of Replenishment	Q	EOQ	Optimal Replenishment	Order Cost Saving
WIPES,ALCOHOL 200/BX	10,000	31	323	10,176	1	$ 60.03
WATER FOR IRR. 1000ML BOTTLE	286	56	5	209	1	$ 109.26
TUBING, SUCTION, 12'	1,139	76	15	443	3	$ 146.85
SYRINGE, CATHETER TIP, 60CC	121	9	13	201	1	$ 16.80
SODIUM CHLORIDE .9% 500ML	370	27	14	265	1	$ 51.21
SODIUM CHLORIDE .9% 1000ML	1,233	61	20	457	3	$ 116.60
SOD CHL 9% IRR. 3000ML BAG	2	2	1	7	1	$ 2.00
RED CAPS, R-2000B 100/BX	3,500	25	140	1,633	2	$ 45.71
Q-TIP, 6" COTTON (STERILE) 100/BX	400	4	100	1,177	1	$ 6.00
MASK, SURGICAL, ASEPTEX 50/BX	900	14	64	800	1	$ 25.75
KIT, PACEMAKER INTRODUCER	2	2	1	1	1	$ 1.00
IV SET, PRIMARY, CNVT PIN,11961	287	37	8	95	3	$ 67.96
IV SET, OMNI-FLOW, SECONDARY	1,453	67	22	310	5	$ 124.63
GLOVE, SURGEON, 7 40/BX	240	3	80	297	1	$ 4.38
DRESSING, TEGADERM 2 3/8X2 3/4	1,021	15	68	688	1	$ 27.03
DEXTROSE 5% 500ML BAG	32	10	3	69	1	$ 18.00
DEXTROSE 5% 1000ML BAG	49	15	3	85	1	$ 28.84
CENTRAL VEIN KIT, TRIPLE LUMEN	140	29	5	21	7	$ 44.68
CATH,IV,AUTOGAURD, 20G X 1.0"	197	19	10	116	2	$ 34.62
ALCOHOL,ISO 70%,16OZ,BLUE TINT CS/24	4	2	2	22	1	$ 2.00
AIRWAY, ORAL, 90MM	29	8	4	67	1	$ 14.00

Table 19: Order Cost Savings with Optimal Q - CCU

Table 19 shows the savings in order cost that CareFirst hospital could achieve with order policy based on the EOQ value. The order total shown in Table 19 is the actual quantity ordered from the hospital unit to the vendor for each item in the APU-VMI environment. The savings was calculated based on the difference in the number of replenishment in the APU-VMI model today and the replenishment frequency with the EOQ value. The replenishment frequency in the optimal policy is calculated by dividing the order total observed since the inception of the APU system by the EOQ value.

The optimal Q clearly reduced the order frequencies that CareFirst needs to generate and thus reduces the order cost. However, the Q suggested in Table 19 is not realistic due to the large quantity per order for some items. The limited space in the APU machines constraints the amount of supplies that can be stored inside the machines. As such, the optimal Q needs to be revised by taking the space constraint into consideration.

To take the space constraint as a constraint factor, the sum of the existing par level and the standard order quantity in the APU machines are taken as the maximum quantity that the APU machines can hold for each item (Table 20).

Description	Total Quantity Constraint (Unit)
WIPES,ALCOHOL 200/BX	1,400
WATER FOR IRR. 1000ML BOTTLE	52
TUBING, SUCTION, 12'	195
SYRINGE, CATHETER TIP, 60CC	60
SODIUM CHLORIDE .9% 500ML	116
SODIUM CHLORIDE .9% 1000ML	264
SOD CHL 9% IRR. 3000ML BAG	6
RED CAPS, R-2000B 100/BX	500
Q-TIP, 6" COTTON (STERILE) 100/BX	110
MASK, SURGICAL, ASEPTEX 50/BX	150
KIT, PACEMAKER INTRODUCER	3
IV SET, PRIMARY, CNVT PIN,11961	104
IV SET, OMNI-FLOW, SECONDARY	246
GLOVE, SURGEON, 7 40/BX	90
DRESSING, TEGADERM 2 3/8X2 3/4	150
DEXTROSE 5% 500ML BAG	7
DEXTROSE 5% 1000ML BAG	12
CENTRAL VEIN KIT, TRIPLE LUMEN	12
CATH,IV,AUTOGAURD, 20G X 1.0"	22
ALCOHOL,ISO 70%,16OZ,BLUE TINT CS/24	8
AIRWAY, ORAL, 90MM	7

Table 20: Capacity Constraint - CCU

Taking the capacity constraint as the maximum quantity that can be stored less the optimal par level computed earlier, the revised order quantity is computed and shown in Table 21.

	Existing			Optimal - With Space Constraint		
Description	Order Total	# of Replenishment	Q	Q	Optimal Replenishment	Order Cost Saving
WIPES,ALCOHOL 200/BX	10,000	31	323	855	12	$ 38.62
WATER FOR IRR. 1000ML BOTTLE	286	56	5	40	7	$ 97.66
TUBING, SUCTION, 12'	1,139	76	15	155	7	$ 137.33
SYRINGE, CATHETER TIP, 60CC	121	9	13	47	3	$ 12.80
SODIUM CHLORIDE .9% 500ML	370	27	14	98	4	$ 46.48
SODIUM CHLORIDE .9% 1000ML	1,233	61	20	212	6	$ 110.38
SOD CHL 9% IRR. 3000ML BAG	2	2	1	5	0	$ 2.00
RED CAPS, R-2000B 100/BX	3,500	25	140	244	14	$ 21.25
Q-TIP, 6" COTTON (STERILE) 100/BX	400	4	100	106	4	$ 0.42
MASK, SURGICAL, ASEPTEX 50/BX	900	14	64	53	17	$ (6.01)
KIT, PACEMAKER INTRODUCER	2	2	1	2	1	$ 2.00
IV SET, PRIMARY, CNVT PIN,11961	287	37	8	87	3	$ 67.43
IV SET, OMNI-FLOW, SECONDARY	1,453	67	22	196	7	$ 119.17
GLOVE, SURGEON, 7 40/BX	240	3	80	87	3	$ 0.50
DRESSING, TEGADERM 2 3/8X2 3/4	1,021	15	68	90	11	$ 7.29
DEXTROSE 5% 500ML BAG	32	10	3	4	7	$ 5.44
DEXTROSE 5% 1000ML BAG	49	15	3	9	5	$ 19.63
CENTRAL VEIN KIT, TRIPLE LUMEN	140	29	5	8	18	$ 22.10
CATH,IV,AUTOGAURD, 20G X 1.0"	197	19	10	13	15	$ 7.88
ALCOHOL,ISO 70%,16OZ,BLUE TINT CS/24	4	2	2	7	1	$ 2.86
AIRWAY, ORAL, 90MM	29	8	4	5	6	$ 3.27

Table 21: Order Cost Savings Revised - CCU

Similarly, the optimal Q computed using EOQ is computed to observe the savings in order cost (Table 22).

	Existing			Optimal		
Description	Order Total	# of Replenishment	Q	Q	Optimal Replenishment	Order Cost Saving
WIPES,ALCOHOL 200/BX	16,800	43	460	16,397	1	$ 101.95
WATER FOR IRR 500ML BOTTLE	316	76	5	198	2	$ 126.80
TUBE, SALEM SUMP, 18 FRENCH	106	28	4	47	2	$ 53.52
TISSUE, POP-UP, 2PLY(200BX/CS)	274	51	11	345	1	$ 36.41
SYRINGE, CATHETER TIP, 60CC	114	9	17	180	1	$ 18.74
SODIUM CHLORIDE .9% 500ML	492	67	11	282	2	$ 72.52
KIT, CATH, SUCTION, 14 FRENCH	445	58	20	288	2	$ 126.91
IV SET, PRIMARY, CNVT PIN,11961	324	26	12	93	3	$ 61.06
IV SET, PLUM, PRIMARY,11943	1,074	85	16	119	9	$ 119.95
IV SET, OMNI-FLOW, SECONDARY	1,719	45	14	312	6	$ 148.98
GOWN, ISOLATION 10/PK	1,150	120	93	436	3	$ 42.73
GLOVE, SURGEON, 7 1/2 40/BX	320	10	40	322	1	$ 12.01
DRESSING, KERLIX SPONGE, 4 X 4	354	67	10	224	2	$ 86.84
DEXTROSE 5% 500ML BAG	45	10	4	86	1	$ 22.95
DEXTROSE 5% 1000ML BAG	35	17	4	65	1	$ 26.92
CHEST TUBE, 28 FRENCH	10	2	1	14	1	$ 6.60
BLOOD GAS SYRINGE,SAMPLER 3	1,313	42	21	719	2	$ 70.35
BITESTICK, EPISTIX	4	3	1	3	1	$ 5.44
AIRWAY, ORAL, 80MM	69	12	3	121	1	$ 40.86
AIRWAY, NASAL, 28FR	12	2	1	22	1	$ 4.93

Table 22: Order Cost Savings with Optimal Q - MICU

Due to the space constrains in the APU machines (Table 23), the optimal Q is revised based on the maximum amount of supplies that the APU machines can store (Table 24).

Description	Total Quantity Constraint (Unit)
WIPES,ALCOHOL 200/BX	1,400
WATER FOR IRR 500ML BOTTLE	56
TUBE, SALEM SUMP, 18 FRENCH	9
TISSUE, POP-UP, 2PLY(200BX/CS)	70
SYRINGE, CATHETER TIP, 60CC	120
SODIUM CHLORIDE .9% 500ML	123
KIT, CATH, SUCTION, 14 FRENCH	45
IV SET, PRIMARY, CNVT PIN,11961	155
IV SET, PLUM, PRIMARY,11943	168
IV SET, OMNI-FLOW, SECONDARY	256
GOWN, ISOLATION 10/PK	170
GLOVE, SURGEON, 7 1/2 40/BX	50
DRESSING, KERLIX SPONGE, 4 X 4	73
DEXTROSE 5% 500ML BAG	20
DEXTROSE 5% 1000ML BAG	12
CHEST TUBE, 28 FRENCH	7
BLOOD GAS SYRINGE,SAMPLER 3	200
BITESTICK, EPISTIX	15
AIRWAY, ORAL, 80MM	7
AIRWAY, NASAL, 28FR	9

Table 23: Capacity Constraint - MICU

	Existing			Optimal - With Space Constraint		
Description	Order Total	# of Replenishment	Q	Q	Optimal Replenishment	Order Cost Saving
WIPES,ALCOHOL 200/BX	16,800	43	460	951	18	$ 68.67
WATER FOR IRR 500ML BOTTLE	316	76	5	48	7	$ 116.87
TUBE, SALEM SUMP, 18 FRENCH	106	28	4	6	17	$ 23.73
TISSUE, POP-UP, 2PLY(200BX/CS)	274	51	11	45	6	$ 25.89
SYRINGE, CATHETER TIP, 60CC	114	9	17	110	1	$ 17.92
SODIUM CHLORIDE .9% 500ML	492	67	11	102	5	$ 66.37
KIT, CATH, SUCTION, 14 FRENCH	445	58	20	34	13	$ 103.54
IV SET, PRIMARY, CNVT PIN,11961	324	26	12	144	2	$ 63.49
IV SET, PLUM, PRIMARY,11943	1,074	85	16	140	8	$ 122.70
IV SET, OMNI-FLOW, SECONDARY	1,719	45	14	214	8	$ 143.93
GOWN, ISOLATION 10/PK	1,150	120	93	75	15	$ 17.36
GLOVE, SURGEON, 7 1/2 40/BX	320	10	40	17	19	$ (24.78)
DRESSING, KERLIX SPONGE, 4 X 4	354	67	10	61	6	$ 78.45
DEXTROSE 5% 500ML BAG	45	10	4	17	3	$ 18.84
DEXTROSE 5% 1000ML BAG	35	17	4	10	3	$ 21.09
CHEST TUBE, 28 FRENCH	10	2	1	5	2	$ 3.91
BLOOD GAS SYRINGE,SAMPLER 3	1,313	42	21	151	9	$ 56.57
BITESTICK, EPISTIX	4	3	1	14	1	$ 6.00
AIRWAY, ORAL, 80MM	69	12	3	5	14	$ 13.05
AIRWAY, NASAL, 28FR	12	2	1	5	2	$ 1.55

Table 24: Revised Order Cost Savings - MICU

Having an optimal order quantity (with space constraints) indeed can reduce CareFirst's supply chain cost. CCU and MICU can achieve approximately $740 and $945 dollars respectively in savings from order less frequently. These are the results for approximately 20 items from each unit over the November 2005 to March 2006 timeframe. The savings in order cost is great at both units, as CCU and MICU have approximately 300 items and 320 items respectively.

The increase in the amount of quantity per order increases the level of cycle stock. The cycle stock cost increases as well. However, the savings realized from order less frequently still outweighs the increase in the cycle stock cost for majority of the items in CCU and MICU (Table 25 and 26).

Description	Cycle Stock (APU-VMI)	Cycle Stock (Optimal)	Change in Cycle Stock Cost
WIPES,ALCOHOL 200/BX	$1.66	$4.41	$2.74
WATER FOR IRR. 1000ML BOTTLE	$1.79	$13.96	$12.17
TUBING, SUCTION, 12'	$4.65	$48.13	$43.48
SYRINGE, CATHETER TIP, 60CC	$2.15	$7.45	$5.30
SODIUM CHLORIDE .9% 500ML	$3.84	$27.54	$23.71
SODIUM CHLORIDE .9% 1000ML	$6.37	$66.84	$60.47
SOD CHL 9% IRR. 3000ML BAG	$2.05	$10.23	$8.18
RED CAPS, R-2000B 100/BX	$9.80	$17.05	$7.25
Q-TIP, 6" COTTON (STERILE) 100/BX	$1.54	$1.63	$0.09
MASK, SURGICAL, ASEPTEX 50/BX	$4.82	$3.97	($0.85)
KIT, PACEMAKER INTRODUCER	$59.90	$119.80	$59.90
IV SET, PRIMARY, CNVT PIN,11961	$13.15	$148.10	$134.95
IV SET, OMNI-FLOW, SECONDARY	$17.46	$157.70	$140.25
GLOVE, SURGEON, 7 40/BX	$11.60	$12.66	$1.06
DRESSING, TEGADERM 2 3/8X2 3/4	$7.83	$10.34	$2.51
DEXTROSE 5% 500ML BAG	$1.14	$1.56	$0.42
DEXTROSE 5% 1000ML BAG	$1.19	$3.45	$2.26
CENTRAL VEIN KIT, TRIPLE LUMEN	$81.54	$131.73	$50.19
CATH,IV,AUTOGAURD, 20G X 1.0"	$8.04	$10.14	$2.10
ALCOHOL,ISO 70%,16OZ,BLUE TINT CS/24	$0.92	$3.22	$2.30
AIRWAY, ORAL, 90MM	$1.23	$1.55	$0.32

Table 25: Change in Cycle Stock Cost - CCU

Description	Cycle Stock (APU-VMI)	Cycle Stock (Optimal)	Change in Cycle Stock Cost
WIPES,ALCOHOL 200/BX	$0.92	$2.71	$1.79
WATER FOR IRR 500ML BOTTLE	$1.79	$17.76	$15.96
TUBE, SALEM SUMP, 18 FRENCH	$7.90	$13.36	$5.47
TISSUE, POP-UP, 2PLY(200BX/CS)	$1.52	$4.76	$3.24
SYRINGE, CATHETER TIP, 60CC	$1.82	$17.48	$15.66
SODIUM CHLORIDE .9% 500ML	$3.64	$28.71	$25.07
KIT, CATH, SUCTION, 14 FRENCH	$1.68	$8.24	$6.56
IV SET, PRIMARY, CNVT PIN,11961	$16.13	$243.31	$227.18
IV SET, PLUM, PRIMARY,11943	$53.81	$485.36	$431.56
IV SET, OMNI-FLOW, SECONDARY	$17.30	$172.21	$154.92
GOWN, ISOLATION 10/PK	$13.19	$20.67	$7.48
GLOVE, SURGEON, 7 1/2 40/BX	$6.45	$2.33	-$4.12
DRESSING, KERLIX SPONGE, 4 X 4	$2.53	$19.75	$17.22
DEXTROSE 5% 500ML BAG	$1.04	$4.84	$3.80
DEXTROSE 5% 1000ML BAG	$0.95	$3.85	$2.90
CHEST TUBE, 28 FRENCH	$5.61	$10.98	$5.37
BLOOD GAS SYRINGE,SAMPLER 3	$4.11	$17.43	$13.33
BITESTICK, EPISTIX	$18.69	$261.59	$242.91
AIRWAY, ORAL, 80MM	$0.71	$1.02	$0.32
AIRWAY, NASAL, 28FR	$4.38	$5.90	$1.53

Table 26: Changes in Cycle Stock Cost - MICU

On the aggregate, the cycle stock cost increased by approximately $560 dollars at CCU, and by approximately $1,178 at MICU. The increase was based on the data from November 2005 to March 2006. The savings at CCU from order less frequently outweighs the cost of having on-hand inventory ($180 dollars in saving). However, MICU's cost increased by approximately $233 dollars due to having more quantities on hand. At the item level, majority of the savings in order cost due to order less frequently exceeds the increase in the cycle stock cost at both units. The items with one of the highest increase in cycle stock costs are the items with consumptions between 300 to 1700 units since inception of APU-VMI model. These items have unit costs range from $2 to $6 dollars, whereas the typical units cost for items having similar consumption pattern is less than $1. Thus, the policy needs to be adjusted based on the unit cost and the demand behavior of the item to maximize the total savings.

6.1.3 Trust between Units

As mentioned in Section 3.1, CCU and MICU are adjacent units at CareFirst Hospital with only two large doors separating them. Interviews with nurses at both units indicate that both units do share supplies in the event of stockout. Nurses at MICU indicated that nurses at CCU travel to MICU more often to request for supplies than the reverse. However, nurses at CCU are not allowed to access the MICU APU system without the approval of a nurse from MICU. As such, there are many overlapping items in all the APU systems in both units, each with its own par level.

Because of the proximity of these two locations, the placement of the APU system can probably be optimized so that they are equal distances from the patient rooms at each unit. That way, duplication of items across multiple systems could potentially be reduced to just one system. Then the par value would be reduced to one value and dramatically decrease the inventory cost.

Further, the reduction of duplicate items across different systems should decrease the order variance for some of the products observed in Chapter 5. In current practice each APU system conducts an inventory count each day early in the afternoon and generates an order. So if there are four machines across CCU and MICU, four distinct orders are generated. There is a high likelihood that the same items could be ordered on the same day or different days from both units and that the quantity per order differs with each unit and order. From the vendor's perspective, the order quantity for that item may be 10 today for CCU only, 20 combined for CCU and MICU the day after and 0 the next day. Then, CCU may not have any order for this item for a period of time, while MICU continues to have orders ranging from 5 to 10 items per day. Several days later, CCU may place an order for 20 of this item, while MICU orders 10 on that day. The combined order quantity is 30 for that day. Over time, the vendor may see order pattern ranging from 0 to 30. As a result, vendors need to have an inventory to meet the intermittent demand similar to the case with CCU described above.

If the order origin is reduced to one system, then the variation between order quantities may be reduced due to the pooling of the demand to a single source. The variability of the demand should decrease in the pooled environment and should lead to the decrease in the order variability. As such, vendor (C4Y Inc.) can better forecast the needs from CCU and MICU. In return, vendors may optimize their own internal inventory policy and delivery frequency that may result in the reduction of costs (i.e. order and transportation) to CareFirst.

6.2 Vendor Hospital Relationship

Although a higher inventory cost at the hospital does not incur costs to the vendor, the incentives exist for the vendor to improve the inventory situation at the hospital because they can reap the savings that hospitals achieve, as explained in the following sections. The following sections discuss three potential strategies that vendors should consider in building a win-win relationship with the hospitals in the vendor managed inventory environment.

6.2.1 Replenishment Frequency

With the vast amount of demand data from the APU machines, vendors could help hospitals assess the costs and benefits of having more frequent deliveries versus carrying inventory at the hospital level with less delivery frequency. Less delivery frequency may mean a greater quantity per delivery, which translates into more inventory at the vendor warehouse. Vendors know its internal cost of carrying inventory as well as the transportation cost of delivering products to hospitals. By collaborating closely with the hospital, vendors could determine the optimal

delivery and inventory policy at both the hospital, vendor warehouse so it can achieve savings when the hospital and the vendor's inventory and transportation costs are accounted for in the optimization model. This could help the hospital and the vendor achieve a win-win situation where greater savings could be realized, and that these savings could be distributed among the vendor and the hospitals.

6.2.2 Holistic View in Optimizing Inventory

The optimization of inventory to reduce order variance discussed in Section 6.1 can be extended to the hospital and also upstream to the vendor warehouse level. By optimizing at the hospital level, vendors would be better equipped to determine its own inventory carrying policy and the orders it needs to make to the upstream suppliers. By leveling the sporadic demand pattern from the hospital, vendors can dramatically reduce the inventory costs at its warehouse because the vendor can better forecast the demand pattern at the hospital. It could also help the vendor reduce its order cost because the vendor is now able to buy bulk quantities from its suppliers using the demand data from the hospitals.

Furthermore, if the vendor has demand data from all the hospital that the warehouse is serving, it could further reduce the inventory cost at its warehouse. Vendors now have reliable information that can help construct a more robust forecast without relying on carrying extra inventory to meet the intermittent and sporadic order patterns from hospitals. Further, the vendor could better plan its ordering strategy with its suppliers due to the apparent demand from hospitals by buying bulk quantity which gives the vendor more purchasing power in negotiations for purchasing price. Vendors also save on transportation costs because they can negotiate rates with transportation companies with the large shipments.

The end result of the holistic optimization can help vendors achieve savings that it can potentially pass down to the hospitals as reduction in the purchase price. Hospitals also benefit from this approach because it could potentially reduce the inventory cost as well as the order cost at the hospital level.

6.2.3 Trust between Vendor and Hospital

The proposed improvements above would not be possible if trust does not exist between the hospital and the vendor. Vendors rely on accurate information from the hospitals to improve the demand forecast from the hospitals and to plan its own supply chain strategy. Vendors need to convince the hospitals that greater benefits can be realized in the win-win state. This can be achieved through detailed contracts on how the benefits would be shared between the vendors and hospitals. This level of trust needs to be built at the executive levels, and the executives at each party need to convince their employees that the collaboration would move both organizations to a better place.

The optimal policy has demonstrated to be effective in reducing the inventory cost and the order cost for the market basket items at CCU and MICU. With the service level at 99 percent, CCU could potentially gain approximately $936 dollars in savings (savings in safety and order costs less the increase in cycle stock) for the items in the market basket. MICU could see approximately $712 dollars in savings (savings in safety and order costs less the increase in cycle stock) for the items in its market basket. The reduction in the inventory carrying and order costs could also reduce the stockout cost. The par levels and the order quantity are optimized to meet the demand pattern inferred through the order data and thus there should be sufficient amount of supplies to meet the demand.

Though the optimal inventory policy shows savings in the APU-VMI model, the inventory policy should be reviewed periodically in the first year or two after the APU-VMI implementation. This would ensure that the policy adjusts to the variability in the demand.

Coupling the optimal policy and the right relationship with its vendor, CareFirst hospital should see more savings in its supply chain through channel integration (Byrnes 1991). Through trust among hospital units and between hospital and vendor, as well as a holistic view in designing the optimal inventory policy, the integration allows the supply chain partners to share valuable information that could potentially improve the inventory policy as a whole. At the end, the overall profitability should increase and the profits could be distributed among the channel partners.

7 Conclusion

To reiterate the focus of this research: hospitals should implement inventory policy that compliments the new technologies that are available to improve the supply chain efficient at the hospitals. Hospitals need to advance from the existing technology and policy towards an optimal and capable technology and policy (Figure 1) that delivers savings and efficiency to the hospital's supply chain.

By operating under the APU-VMI model with an ineffective inventory policy, the inventory cost per item can cost CCU approximately $31 dollars on average, with -$27 as the lower bound and $90 dollars as the upper limit that CCU needs to pay to have additional inventory on=hand. At MICU, the inventory cost per item is $60 dollars on average, with $14 as the lower bound and $106 dollars as the upper bound. Using the average as the standard measure, CCU incurs an additional $9,700 dollars in inventory cost in the APU-VMI environment, and approximately $18,000 at MICU.

Both units, however, experienced a decrease in cycle stock on average. At CCU, the cycle stock decreased by approximately $0.1 on average, and the cycle stock decreased by approximately $0.8 at MICU. Generally, CCU experienced cycle stock cost ranges from -$11 to $12 dollars per item, and -$4.8 to $3.3 dollars per item at MICU. Using the average as the standard measure, CCU incurs savings of $31 dollars in cycle stock cost, and approximately $250 dollars in savings at MICU. However, CCU incurs an additional $3,750 dollars in cycle stock cost and an additional $1,030 dollars in cycle stock cost at MICU if the high-end of the cost range is used as the standard measure. This indicate that additional savings are possible through the improvement of inventory policy.

To reach that goal, hospitals need to establish long-term relationship with immediate vendors. Vendor Managed Inventory (VMI) is a concept that paves the way for this type of relationship. As demonstrated through this research, the VMI model has removed the material management activities from the material technicians in that the technicians no longer need to perform the inventory and picking activities. The VMI model has empowered the technicians to perform value-added activities such as serving and managing the needs of sister branches in the nearby county. The APU-VMI model has also reduced the unit cost of products slightly due to the consolidated purchase from a single vendor.

Though some cost-saving benefits have been observed in the APU-VMI environment, the model also introduced the proliferation of par levels at the nursing unit level. The APU-VMI model decentralized the inventory management practice at a hospital from the central warehouse to the individual nursing units. Nursing units are required to build their own stocks of supplies to meet the demand. As such, inventory cost rose dramatically in the APU-VMI environment. The problem is compounded by duplicate stocking of the same product in different APU systems within the same unit, as demonstrated through the data from CCU and MICU. As such, the benefit of the VMI model has not been fully realized.

The analysis in Chapter 6 shows that the incoherent inventory policy at CCU and MICU (observed in Chapter 4) can be improved through the use of an optimal inventory model that compliments the APU-VMI model. Both units observed savings by optimize the par level and the order quantity for the items in the market baskets.

When the vendor and hospital can come to terms on common goals, both parties can further reap the benefits of the APU-VMI model. As discussed in this research, hospital units could reduce the overall par levels if neighboring units can establish trust to share supplies. This will also reduce the variability in the order pattern because the order patterns from multiple units are aligned. Further, more savings can be realized if the vendor and hospital collaborate to optimize the hospital-to-vendor supply chain. Overall par levels should decrease at the hospital which would reduce the inventory cost for the hospital. Vendors would have a more accurate forecast of the hospital demand, which could potentially reduce the inventory cost at the vendor warehouse. With a better forecast, the vendor could establish a better relationship with its suppliers in negotiating for better terms on pricing, delivery schedule, and higher service level. Hospitals may save on order costs due to less lines of order and vendor may save on purchasing as well as ordering costs due to quantity discounts from its suppliers. At this point, the hospital would have an optimal policy that compliments the APU technology. Vendors would also have an optimal policy that integrates well with the hospitals that it serves.

7.1 Future Research

To achieve the holistic optimization mentioned earlier is not an easy task as developing the trust among supply chain partners is a difficult task. As such, developing practical performance metrics that the hospital and vendor can follow to develop the deeper relationship should enable both parties to reach the win-win state faster.

The optimization of the inventory policy with the APU-VMI model should combine the space constraint that the APU system imposes with the characteristics of a product. Space should be maximized for the highly utilized and critical products. This research has demonstrated that the savings from less frequent order outweighs the cost of having more inventory on-hand. Having highly utilized and non-substitutable products in stock can increase patient care standard as well as reduce the cost of stockout.

Further, the vendor should consider the impact to the inventory policy at the warehouse that serves multiple hospitals under the APU-VMI model. There should be more adoption of the APU-VMI model by the hospitals in the near future and the vendor needs to understand the likely impacts of having the warehouse serving multiple APU-VMI hospitals. As such, a simulation model could be built to simulate the impact of multiple APU-VMI hospitals on a warehouse's internal inventory policy.

Lastly, the two suggestions above should be reviewed with a greater number of items. This research selected approximately 20 items as the representative items and demonstrated the benefit of having optimal policy. More items should be included in the market basket to ensure that every impact and effect of the APU-VMI model is captured and analyzed.

Bibliography

Achabal, Dale D., McIntyre, Shelby H., Smith, Stephen A., Kalayanam, Kirthi (2000), "A Decision Support System for Vendor Managed Inventory", Journal of Retailing, Vol. 76(4), pg 430-454.

Byrnes, Jonathan L.S., Shapiro, Roy D. (1991), "Intercompany Operating Ties: Unlocking the Value In Channel Restructuring", *Harvard Business School Working Paper*, No 92-058.

Brynes, Jonathan L.S. (2003), "Profit from Customer Operating Partnerships", *Harvard Business School Working Knowledge.*

Center for Medicare & Medicaid Services (CMS 2003), "Acute Care Hospital", *Health Care Industry Market Update.*

Curt, Werner (1993), "Long Beach, Alta Bates raise eyebrows with vendor switch", *Hospital Materials Management*, Vol. 18, Iss. 5, pg. 1 - 3.

DeJohn, Paula (2006), "Managing logistic costs pays off in lowering overall supply expense", *Hospital Materials Management*, Vol. 31, No. 5, pg. 1-2.

DeScioli, Derek T. (2005), "Differentiating the Hospital Supply Chain For Enhanced Performance", *Massachusetts Institute of Technology.*

Hospital Materials Management (2004), "Supply costs have rise 26% in two years, outpacing medication costs, study shows", Vol. 29, No. 10, pg. 4.

Hospital Materials Management (1998), "For a big urban hospital, letting distributor do the walking – and stocking – pays off", Vol. 23, No. 11, pg. 3.

Lee, Hau L., Padmanabhan, V., Whang, Seunjin (1997), "Information Distortion in a Supply Chain: The Bullwhip Effect", *Management Science*, Vol. 43, No.4.

Nathan, J. and Trinkaus, J. (1996), "Improving health care means spending more time with patients and less time with inventory management system", *Hospital Material Management Quarterly*, Vol. 15, No3, pg 57.

Rivard-Royer, H., Landry, S., Beaulieu, M. (2002), "Hybrid stockless: A case study: Lessons for health-care supply chain integration", *International Journal of Operations & Production Management,* Vol. 22, No. 4, pg. 412.

Sjoerdsma, B.A., (1991), "Consignment: Present and Future", *Hospital Materiel Management Quarterly*, Vol 13, No 1, pg 6.

Valestin, David R. (2001), "Automated Point of Use: Productivity Improvement", *Hospital Material Management Quarterly*, No. 22, pg. 3.

Yokl, Robert T. Sr. (2005), "Less is more when storing inventory", *Hospital Materials Management*, Vol. 30, No.8, pg 2 – 5.