Introduction

Life and Money. These two vital concepts dominate the hospital industry, and each hospital must develop a way to balance them within its operations – maximizing Life while minimizing Money. With this notion in mind, this study analyzed the hospital supply chain and concluded that the hospital supply chain enables the hospital’s strategy by:

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

Hospitals have to manage a wide array of products from gauze pads and gloves to stents and catheters. Despite this wide array, the typical hospital treats its products similarly in implementing supply chain policies and measuring supply chain performance. This study proposes that recent technology and supply chain innovations within the hospital industry have enabled hospitals to develop much more sophisticated supply chains. Supply chain policies should be customized according to each product’s unit cost, demand, variability, physical size, and criticality in order to truly align its operations with the hospital strategy of maximizing patient care without incurring prohibitive costs.

To conduct this research, the author worked closely with one of the leading U.S distributors for medical supplies and pharmaceuticals, DTD, Inc (disguised name). In particular, the author studied two hospitals that were in the process of implementing a new service offering from DTD, Inc. which coupled vendor managed inventory (VMI) along with automated point of use devices. This research was divided into two parts – interviews of members within the hospital supply chain and data analysis of hospital demand and inventory policies. The purpose of the interviews was to achieve a clear understanding of the key success factors for a hospital supply chain and shortcomings of existing supply chain policies. Data analysis was used to develop and evaluate an appropriate inventory policy model that would consistently meet targeted service levels while minimizing material management costs.

Hospital Industry and Rising Costs

For the last 30 years, the hospital industry has experienced continuously increasing costs. In 2002, the Center of Medicare and Medicaid Services (CMS) reported that health care expenditures totaled to $1.4 Trillion, or about 14% of the national GDP, as compared to 7% in 1970, and hospital expenditures constitute 30% of this total. Hospital prices have consistently outpaced inflation and are continuing to do so as Standard & Poor’s stated that employers should expect a 12% increase in health care costs in 2005.
These high costs have a negative impact on both hospitals and the economy. With increased costs, hospitals have reduced cash flow which inhibits their ability to invest in better equipment, training, and personnel. Meanwhile, these costs are relayed directly to U.S tax payers as federal government agencies such as Medicare and Medicaid pay for approximately 47% of all healthcare expenses.

Consequently, in recent years, the hospital industry has focused on developing innovative strategies to reduce costs by removing waste from its operations. One of the areas of focus has been increasing supply chain efficiency, as material management costs can amount to anywhere from 17% to 35% of a hospital’s total revenue.

**Hospital Supply Chain Evolution**

In the 1980s, hospitals began implementing innovative supply chain strategies in order to reduce costs and, more importantly, improve service levels. Medical supplies and pharmaceutical distributors such as DTD, Inc began assuming more and more material management functions through stockless and vendor managed inventory (VMI) programs. In addition, automated point of use (APU) systems were developed to better control inventory deployment and fill rates.

*Standard Hospital Supply Chains*

In a standard hospital supply chain, all material operations are controlled by the hospital. Material from the hospital’s various suppliers is delivered in bulk to the hospital’s loading dock and transported to a main store room. Material handlers then transport material from the main store room to various secondary store rooms in wards throughout the hospital as the inventory in those wards diminishes. Typically, hospitals do not track perpetual inventory, but rather use visual cues to decide when to place an order for more material.

The lack of standardized policies, information systems, and proper incentives results in relatively poor supply chain performance. The standard hospital supply chain holds 6 – 8 weeks of inventory and has a 90-95% fill rate. Low fill rates not only adversely impact patient care but also result in costly disruptions to the medical and material staff that have to expedite shortages.

*Stockless Supply Chains*

In order to assist hospitals reduce inventory and increase fill rates, healthcare distributors developed stockless inventory programs. Under a stockless program, the distributor delivers product in pieces rather than bulk. Orders are transmitted from individual wards, and the material is delivered directly to the ward, bypassing the store room. In essence, as compared with the standard supply chain, distributors have assumed the duties of holding inventory and replenishing individual locations. There are significant benefits to both channel partners as some redundant tasks are removed and inventories are better controlled.

*Vendor Managed Inventory*

Distributors also began to offer vendor managed inventory (VMI) services. Under VMI, the distributor hires employees to work in the hospital and assume all material operation duties, including material handling, warehousing, and purchasing. The distributor not only purchases
material from its own facilities, but also from manufacturers and their competitors, as directed by the medical staff. As these distributors have a high incentive to focus on the supply chain efficiency, they implement inventory systems within the hospital operations and focus on optimizing order sizes and inventories within the entire supply chain channel. In addition, VMI has a major impact on the control of unofficial inventories. Unofficial inventories are those inventories that are unaccounted for in the hospital accounting and inventory records.

Automated Point of Use (APU) Systems

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

The Next Step in the Evolution

With the advent of Automated Point of Use systems, the hospital industry has enabled itself to become much more sophisticated in the implementation and measurement of its supply chain policies. First of all, data collected by APU systems can be used to automatically generate statistical appropriate inventory policies rather than the rules of thumb that were used in the past. As mentioned earlier, there is a wide array of products within a hospital; and therefore, there is an inherent flaw to treat them alike and measure supply chain performance at an aggregate level.

Developing an Inventory Policy through Statistical Analysis

This study proposed two inventory policies based on statistical analysis rather than the rules of thumb which are currently used within the hospital. The major advantage of these proposed policies is that they can be customized to a particular product’s characteristics, whereas the current inventory policies are much less flexible. In addition, these inventory policies account for three of the five product characteristics that should be used to determine the appropriate inventory policy – unit cost, demand, and variability.
Existing Policies

Most hospitals, including the two studied in this research, institute an $s, S$ inventory policy, where $s$ is the reorder point, and $S$ is the order-up-to point. Within the healthcare industry, these are dubbed as par levels. Within both hospitals, par levels for medical supplies were arbitrarily chosen by the supply technicians. However, during the time of this research, one hospital was proposing to change their policy such that the par level would be a multiple of the maximum daily usage in the last 6 months. Specifically, they proposed to set “4 times maximum” as the order-up-to point and a “3 times maximum” reorder point. Both the existing inventory policies and this proposed policy will be compared to the inventory policies developed in this study.

Modeling Hospital Demand

In order to develop an appropriate inventory policy for a product, one must first characterize the demand of that product as the volume and variability determine the appropriate stocking levels. For hospitals implementing stockless supply chain policies, the demand needs to be analyzed and modeled on a daily basis. An analysis of the demand demonstrated that over 96.2% of the Station-SKU’s can be classified as slow moving. Hence, traditional demand models, such as moving average and exponential smoothing, are not effective in modeling hospital demand. Hence, this research investigated successful techniques used in spare parts to develop a proper modeling technique for the hospital.

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

Base Stock ($S$) Policy

The first proposed inventory policy minimizes inventory while achieving a targeted service level. This policy is termed as a standard base stock, or $S$ inventory policy, with periodic review. Under this policy, inventory is replenished up to the base stock point, $S$, every time the inventory is reviewed. The inventory level is reviewed every time period $R$, and after an order is placed, the inventory is refilled after a lead time $L$. This policy was used to clearly establish the minimum amount of inventory needed to meet the required service level. This policy is not an optimal policy as it does not consider ordering cost or carrying cost in its calculations, but it can be used in cases where ordering costs and carrying costs are negligible and in cases where hospitals need to determine their minimum capacity requirements.
s, Q Inventory Policy

The second proposed inventory policy is designed to achieve a targeted service level, while optimizing the order pattern. This is termed as an s, Q policy with period review, where s is the reorder point and s + Q is the order-up-to point. The s, Q combines the base stock policy described in the previous section, but also considers order costs and carrying costs in determining the proper order quantity. Here, Q is the economic order quantity (EOQ). The s, Q policy was used to clearly establish the optimal inventory policy, given no capacity constraints, and assumed ordering, carrying costs, and targeted service levels. As this policy considers all of the material management factors, it is very flexible and can be adjusted to fit any product within a hospital, which is essential to designing differentiated supply chain policies.

Inventory Policy Evaluation

Four inventory policies were simulated and compared. They included the existing policy in MWH, the “4 times max” policy as proposed by WCH, the base stock S policy, and the s, Q policy. A model was developed in MS Excel to mimic the ordering rules of each of the four inventory policies. This research analyzed the total costs (ordering cost, carrying cost, and stockout cost) and the stability of each inventory policy.

The results of the simulation can be seen in the table below.

<table>
<thead>
<tr>
<th>Inventory Policy</th>
<th>Order Cost</th>
<th>Carrying Cost</th>
<th>Shortage Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated Existing Policy</td>
<td>$449,220</td>
<td>$234,448</td>
<td>$309,756</td>
<td>$993,424</td>
</tr>
<tr>
<td>Simulated “4 times Max” Policy</td>
<td>$334,860</td>
<td>$393,335</td>
<td>$933</td>
<td>$729,128</td>
</tr>
<tr>
<td>Simulated S Policy</td>
<td>$766,440</td>
<td>$201,551</td>
<td>$109,161</td>
<td>$1,077,152</td>
</tr>
<tr>
<td>Simulated s, Q Policy</td>
<td>$166,920</td>
<td>$260,495</td>
<td>$49,449</td>
<td>$476,864</td>
</tr>
</tbody>
</table>

Table 1: Average Annual Supply Chain Costs for Each Inventory Policy

As can be seen in the table, the s, Q inventory policy had the lowest total annual cost, $476,864. This policy improved the hospital’s service level from 98.6% to 99.8% and simultaneously reduced material management costs by 52% (~$500,000/yr). In addition, analysis demonstrated that the s, Q policy was the most stable policy and most consistent policy across products and wards within the hospital.

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

**Implementing Supply Chain Differentiation**

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

There are several product characteristics which will impact the decision on an appropriate supply chain policy; and they are unit price, demand, variability, physical size, and criticality. These product characteristics also inherently define the relative importance of each of the four supply chain goals. The \( s, Q \) inventory policy accounts for demand, variability, and unit cost in order to ensure product availability at a given service level and optimize costs. These models can be scaled for any demand pattern, lead time and review period that the particular hospital employs. This study also analyzed how other product characteristics such as physical size and criticality interact with the goals of the hospital supply chain. The particular supply chain policies discussed are the utilization of automated point of use systems, the length of the inventory review periods, and the targeted service level.

This research proposed that a hospital should map its supply chain goals to certain product characteristics. For example, hospitals should focus inventory value reduction strategies on high dollar components. Meanwhile, hospitals should allow for less control via APU systems on low dollar, non-critical products as to not consume too much of the medical staff’s time in material handling tasks. Furthermore, hospitals should differentiate service level targets based on product criticality. Table 2 summarizes the product characteristics that map supply chain goals to supply chain strategies.

<table>
<thead>
<tr>
<th>Supply Chain Goal</th>
<th>Product Characteristic</th>
<th>Supply Chain Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensuring Product Availability</td>
<td>Demand; Demand Variability; Criticality</td>
<td>• Implement ( s, Q ) Inventory Policy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Differentiate Service Level Based on Criticality</td>
</tr>
<tr>
<td>Minimizing Storage Space</td>
<td>Physical Size</td>
<td>• More Frequent Reviews for Large Items</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Evaluate Review Period Impact on Minimum Inventory Requirements using Base Stock, ( s, Q ) Inventory Policy</td>
</tr>
<tr>
<td>Reducing Material Handling Time for Medical Staff</td>
<td>Unit Price; Criticality</td>
<td>• Place Non-Critical, Low Value Items in Open Shelf APU Systems</td>
</tr>
<tr>
<td>Minimizing Inventory Value</td>
<td>Unit Price</td>
<td>• More Frequent Reviews for High Value Items</td>
</tr>
</tbody>
</table>

**Table 2: Mapping Supply Chain Goals to Product Characteristics and Supply Chain Strategies**
Finally, Table 3 lists the appropriate supply chain policies to implement for the various combinations of product characteristics that were analyzed in this research.

<table>
<thead>
<tr>
<th>Unit Cost</th>
<th>Physical Size</th>
<th>Criticality</th>
<th>APU System</th>
<th>Review Period</th>
<th>Service Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Small</td>
<td>Highly</td>
<td>Closed Door</td>
<td>Very Frequent At Least Daily</td>
<td>Very High (99.9%)</td>
</tr>
<tr>
<td>High</td>
<td>Large</td>
<td>Critical</td>
<td>Closed Door</td>
<td>Very Frequent At Least Daily</td>
<td>High (99.5%)</td>
</tr>
<tr>
<td>Low</td>
<td>Small</td>
<td>Critical</td>
<td>Closed Door</td>
<td>Frequent (Weekdays)</td>
<td>High (99.5%)</td>
</tr>
<tr>
<td>High</td>
<td>Large</td>
<td>Non Critical</td>
<td>Closed Door</td>
<td>Very Frequent At least Daily</td>
<td>Normal (98% - 99%)</td>
</tr>
<tr>
<td>Low</td>
<td>Small</td>
<td>Non Critical</td>
<td>Open Shelf</td>
<td>EOQ and Capacity Define Order Frequency</td>
<td>Normal (98% - 99%)</td>
</tr>
</tbody>
</table>

Table 3: Supply Chain Policies for Various Product Characteristics

**Conclusion**

This thesis concludes that the implementation of automated point of use systems has enabled hospitals to develop more sophisticated supply chain policies that can further increase patient care and simultaneously reduce costs. With data provided by APU systems, hospitals should develop inventory policies that will further reduce material management costs and simultaneously improve service. In addition, supply chain policies should be differentiated with respect to a product’s unit cost, physical size, and criticality. For example, high cost, highly critical products should have very frequent review periods, tight control, and very high service level targets. Meanwhile, low cost, non-critical products should have less frequent review periods, loose control, and moderate service level targets. While these distinctions seem obvious, they must be embedded into the supply chain policies and performance metrics. Only then will the hospital supply chain be aligned with its goals of ensuring product availability, minimizing storage space, minimizing medical staff material handling time, and minimizing inventory value.

Hospitals and hospital suppliers should further investigate opportunities in creating deeper inter-company operating ties. For example, in determining proper order quantities, both the hospital’s costs and distributor’s costs should be considered, and the objective should be to minimize the costs of the entire channel, not just those of one member within the channel. Furthermore, now that medical supplies and pharmaceutical distributors have direct access to point of use data, they should investigate methods to improve their forecasting techniques, ordering patterns, and inventory policies within the distribution center and manufacturing facility. Retail companies such as Wal-Mart and Target have developed sophisticated networks using point of sale data that have significantly reduced costs significantly their supply chain. Hence, the hospital industry can use the retail industry as a model for such development.