Inventory Management Issues in Health Care Supply Chains

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Abstract

Supply chain management is the process of efficiently integrating suppliers, manufacturers, warehouses, and stores so that merchandise is produced and distributed in right quantities, to the right locations, and at the right time in order to minimize system wide costs while satisfying service-level requirements. This document outlines and discusses issues related to inventory management within the health care supply chain. In particular, this report discusses the areas that show great opportunity for reducing cost and improving service and the techniques that could help to achieve these goals.

First, an overview of the health care industry and the reforms that have been made in the last two decades is presented. Then, alternative models to the traditional GPO based organization of the health care value chain are discussed. Then, a comprehensive literature review of applications of inventory management within the health care value chain is presented. Finally, several areas of healthcare in which there is great potential for improvement but little research are presented.

The first proposed topic of future research concerns the adoption of new products into the hospital, especially if the new product relates to a new technology or if the new product significantly affects the rest of the supply chain. The second proposed topic concerns the use of better demand forecasts to improve service while reducing inventory. Because of scheduled surgeries and other known events, a large portion of future demand can be determined exactly. Therefore, inventory management techniques that take advantage of derived demand should be investigated for application within the health care value chain.

Introduction

Supply chain management is the process of efficiently integrating suppliers, manufacturers, warehouses, and stores so that merchandise is produced and distributed in right quantities, to the right locations, and at the right time in order to minimize system wide costs while satisfying service-level requirements. In the retail environment, this process is well known and has been in use for a long time. Certain organizations such as Wal-Mart and Dell have managed to streamline their supply chain networks to become industry leaders. The term "supply chain management" can be conveniently divided into two areas: inventory management and distribution. Besides these two areas, there are many other decisions critical to streamlining the process, such as facility location, material procurement, and adapting to changes in the system and environment. Even though inventory management and distribution is not new in the retail environment, in the healthcare industry this has been traditionally considered as an area of low value. Recent studies have shown that tremendous cost savings and potential revenue can be generated with the enhanced management of distribution and inventory. It was estimated that a hospital could reduce its total expenses by at least two percent through better inventory management and distribution of finished medical materials. This represents a percentage of total expenses, not just the amount providers spend on supplies and pharmaceuticals (Schneller, 2006).

The past 15 to 20 years have seen an increase in research focusing on operational issues relating to supply chain management. Most of the research has been related to multi-echelon inventory models. Multi-echelon inventory management refers to the management of inventory and coordination of distribution processes in more than one level of the supply chain network. These ideas were first implemented in the retail and manufacturing industries, but have since spread to the health care industry. The recent trends in efficient distribution, such as just-in-time (JIT) deliveries and reductions in the amount of inventory held, has caused many industries, including the health care industry, to focus more on streamlining their supply chain in an effort to be more competitive while still meeting the requirements of their customers. These changes are more evident in the health care industry, an industry that has not traditionally seen distribution and inventory management as a competitive advantage.

The purpose of this document is to outline and discuss issues related to inventory management within the health care supply chain. In particular, this document first presents a

brief discussion of the organization of various supply chain operating models within the health care industry. In Section 2, a review of recent inventory management research, especially as it relates to the health care supply chain, is presented. Finally, topics for future research which seek to improve inventory management within the health care supply chain are presented.

Health Care Supply Chains

During the 1990s, the developments in health care encompassed vertical and horizontal integration, managed care pressures, changes in federal reimbursement, the rise of e-commerce, and the passage of the Health Insurance Portability and Accountability Act (HIPAA) in 1996. There have also been many other changes since and examples are listed below:

- Provider organizations such as hospitals and hospital systems vertically integrated into the health insurance business, such as starting up their own Health Maintenance Organizations (HMOs) and ambulatory care practices, in the process of developing Integrated Delivery Networks or IDNs. Attempts to integrate downstream towards the patients to capture a greater portion of patient flows and insurance premiums lead to the development HMOs. Initially such attempts were futile and providers had to integrate upstream with the wholesalers and distributors to improve their financial position.

- Every major player along the value chain horizontally consolidated to form large organizations. Hospitals merged to form hospital systems or joined other systems. GPOs started catering to different systems and distributors started building warehouses where demands from various systems are consolidated.

- The rise of e-commerce had a major effect on the way the trading partners communicated with each other. Web technology speeded up transactions and provided better visibility of products and information across the supply chain, which resulted in more efficient execution of processes.

A typical healthcare supply chain is a complex network consisting of many different parties at various stages of the value chain. According to Burns (2002), the three major types of players are: Producers (product manufacturers), Purchasers (group purchasing organizations, or GPOs, and wholesalers/distributors), and health care providers (hospital systems and integrated delivery networks, or IDNs). This chain is shown in Fig 1.
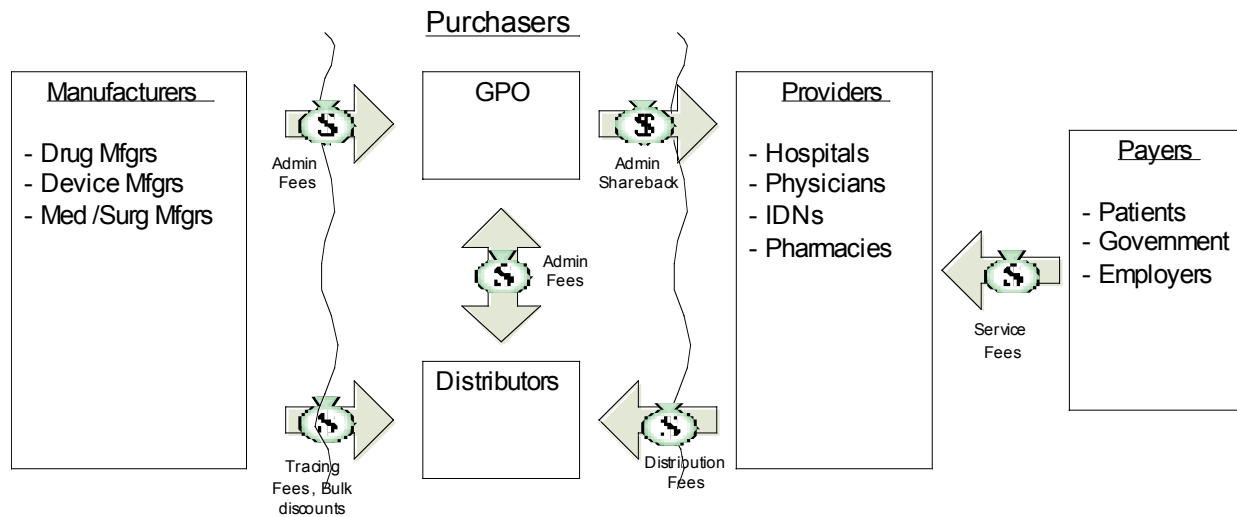
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Figure 1 Health care value chain (Adapted from ROi, Mercy case study and Burns, 2002)

Manufacturers make the products; GPOs and distributors aggregate a large number of hospitals in an attempt to leverage the economies of scale while funding their operations through administration fees and distribution fees; the provider, such as hospitals, consume the products while providing patient care; and finally the payers, such as the individual patient and his employer, pay for the services of the provider. Within the health care value chain, the products (drugs, devices, supplies, etc.) are transported, stored, and eventually transformed into health care services for the patient.

The health care value chain as described above has various inherent flaws. Third party GPO's negotiate on behalf of providers but are funded by administration fees paid by the manufacturer, usually based on a percent of sales. This arrangement raises the question as to how aggressively a GPO will truly negotiate. The more aggressively a GPO negotiates, the lower the GPO's revenue potential from the manufacturer. Major full-service distributors tend to operate on a percent of sales distribution fee as well. Hence the distribution fee for a small sized fast moving item could cost the hospital many times more than a bulky slow moving item. Another issue is that many distributors are also major manufacturers, allowing them to leverage the margin on self-manufactured products to discount the distribution fee. The distributors, in such situations, can also cut the inventory levels of competing product, with full knowledge that they can support stock-out substitutions with highly profitable self-manufactured goods. If this happens very often, the hospital may be forced to switch to the readily available distributor of

manufactured goods even if they are considered inferior. These issues should not be blamed fully on the purchasers since the hospitals are willing to pay the extra amount for these services every day. The main issue is that most health care providers have been unwilling to challenge the traditional model for fear of the risk associated with throwing away a well-established model.

An example of a health care system that has benefited from streamlining their inventory and distribution process is the Sisters of Mercy Health System. The St. Louis based Mercy Health System created a new supply chain division called Resource Optimization and Innovation (ROi) to establish the supply chain as an area of value for the business. ROi has simplified the health care supply chain by reducing its dependence on third party intermediaries, such as GPO's and distributors. The ROi created its own GPO, which purchases products directly from suppliers for all products, eliminating the need for third-party GPO's. The ROi also receives products directly from suppliers to its warehouse and ships them directly to its hospitals, eliminating the need for third-party distributors. The result is a new model that has more closely linked the makers and users of health care products in a way that provides greater value for the essential trading parties. ROi converted Mercy's supply chain from a cost center to revenue center. ROi currently produces revenue in excess of $153 million. ROi also produces an annual value to the Mercy hospitals of over $16 million in net benefit.

In a traditional distribution model, suppliers ship their products to distributors. At the distributor's warehouse, the products are packed into pallets and shipped to each hospital's warehouse. The hospital warehouse then receives the pallets, breaks them down into smaller quantities, and stores the products until they are needed by the hospital. Sometimes items are also ordered directly from suppliers. Figure 2 shows this model.
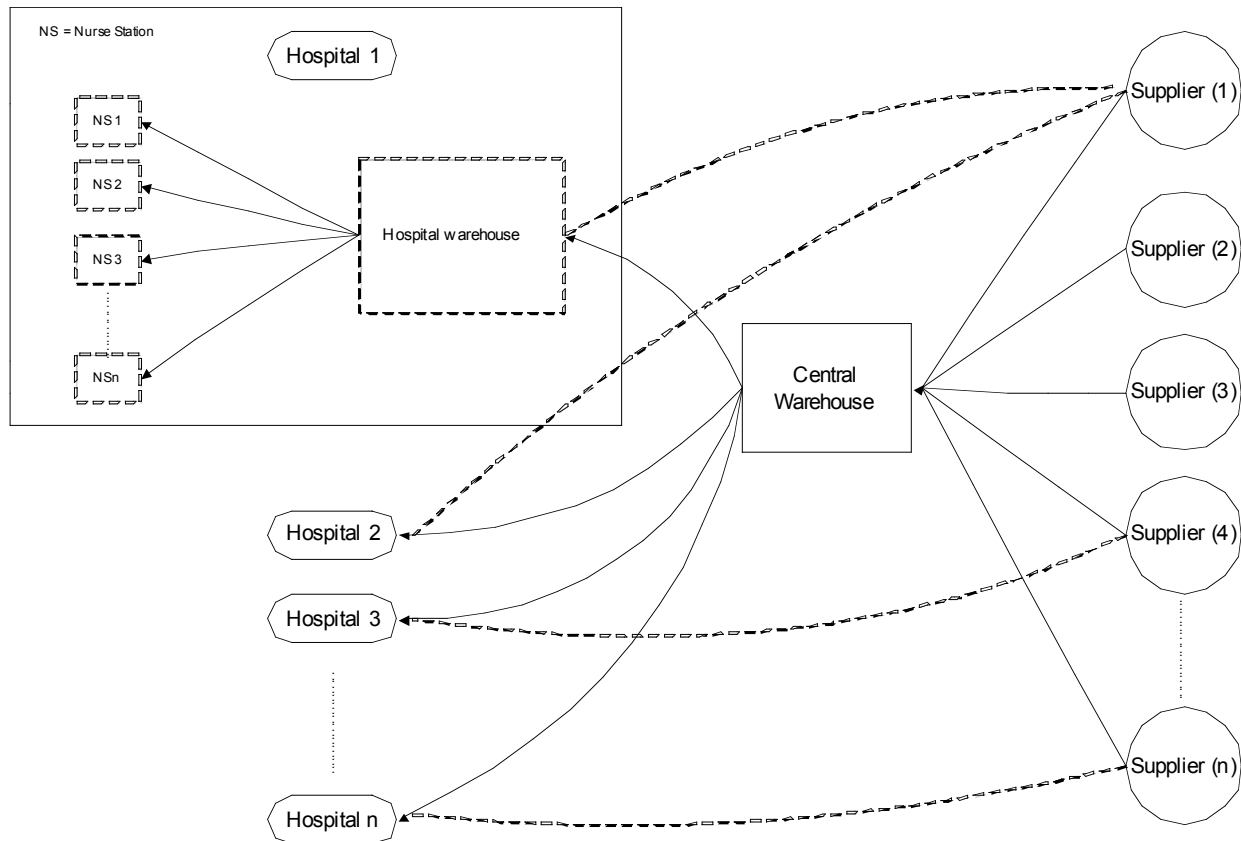
Figure 2 – Traditional Supply Chain

In this traditional model, there is a large amount of inventory in the system. This keeps the number of deliveries relatively low which keeps transportation and ordering costs low. But there is a high cost in both holding inventory and the significant amount of material handling required.

In the newer model used by Mercy, a centralized warehouse system replaces the distributor and the need for a hospital warehouse is eliminated. In this model, the suppliers ship directly to the central warehouse called the central service center (CSC), which for Mercy is located in Springfield, MS. The CSC breaks down the shipments into smaller units and repackages them for use in the hospitals. The materials are then shipped directly to the hospitals, called strategic service units (SSU). The Mercy network consists of approximately ten hospitals across four states. If the hospitals are not close enough to the CSC the materials are cross-docked in an intermediate location. Figure 3 shows this model.
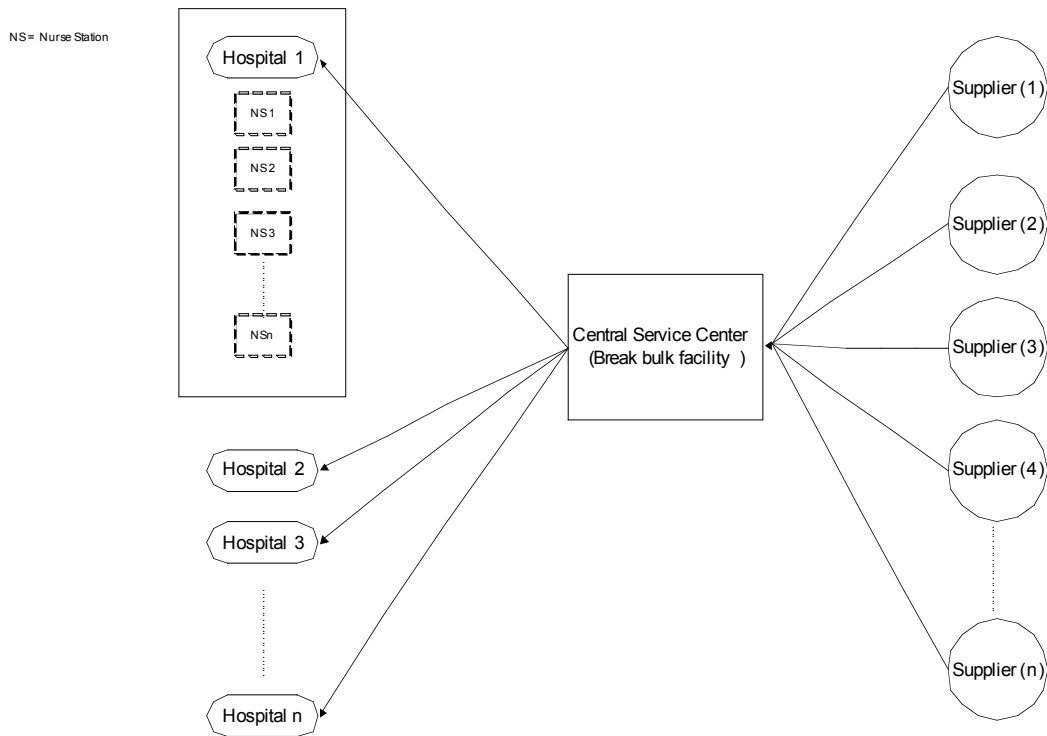
NS= Nurse Station

Figure 3 – Newer model used by Mercy

In this newer model, the CSC takes full responsibility of material handling and inventory management. The CSC at Springfield, MS receives shipments from the suppliers and which are then broken down, repackaged, bar coded and stored. The CSC receives the orders for the next day's demand through the central server every evening. These orders show up on the pick list and are picked, sorted, packed based on their destination, and shipped early in the morning. The trucks return back to the CSC at the end of the day.

In the Mercy model, there are many improvements over the traditional model. No third parties between the suppliers and hospitals are used, increasing efficiency and eliminating third-party mark-up fees. Mercy even owns its own trucking fleet in order to further reduce cost. Inventory holding costs and material handling costs, which make up a large portion of total costs, are greatly reduced over a traditional system. The CSC's large warehouse, which stores products for all its hospitals, allows for bulk purchasing discounts to further reduce costs. In this new system, 3,000 nursing level stock outs per week were eliminated over Mercy's old system and next day, first time fill rates improved from 85-90% to 99% (Moore, 2006). Since the CSC uses automatic repackaging equipment to repackage products into smaller, bar coded containers, the inventory management system is also greatly improved. The improved inventory management

system included medicine cabinets, which automatically pick the medicines for the nurses, and a bed-side scanning system which verifies the medication by scanning the nurse's badge, the patient's arm band, and the medication. This annually eliminated more than 178,000 medication errors such as giving medication to the wrong patient or giving the patient the wrong dosage. In addition, the CSC polls all the medicine cabinets each night and automatically downloads replenishment orders for needed medicines.

Another model that does not make use of the traditional system of GPO's and distributors is the one used by the Nebraska Medical Center (NMC). In the Nebraska model, the entire supply chain of the NMC is outsourced to a single company, Cardinal Health Inc. Cardinal has a warehouse in the same city, Omaha NE, and sends shipments to the hospital four times per week. The NMC pays Cardinal a single flat fee to manage the hospital's inventory. Unlike Mercy, the NMC is a single location hospital which is unable to leverage economies of scale to create a more efficient supply chain system. Also, by outsourcing its inventory management system, the NMC is able to use the comparatively small amount of capital it has to focus on patient care. Not only does the NMC not need to worry about transportation costs, material handling costs, etc., but since Cardinal owns all of the NMC inventory, the NMC does not need to tie up its capital on holding inventory either.

Like Mercy, the NMC does not rely on the complicated network of GPO's and distributors to meet its inventory needs. Neither system relies on the use of a warehouse at the hospital, and both minimize material handling at the hospital. Also, like Mercy, the NMC has frequent shipments to minimize the inventory needed at the hospital while keeping stock outs low and fill rates high. Both the Mercy system and the NMC system represent two ends of the outsourcing spectrum for the healthcare value chain as illustrated in Figure 4.
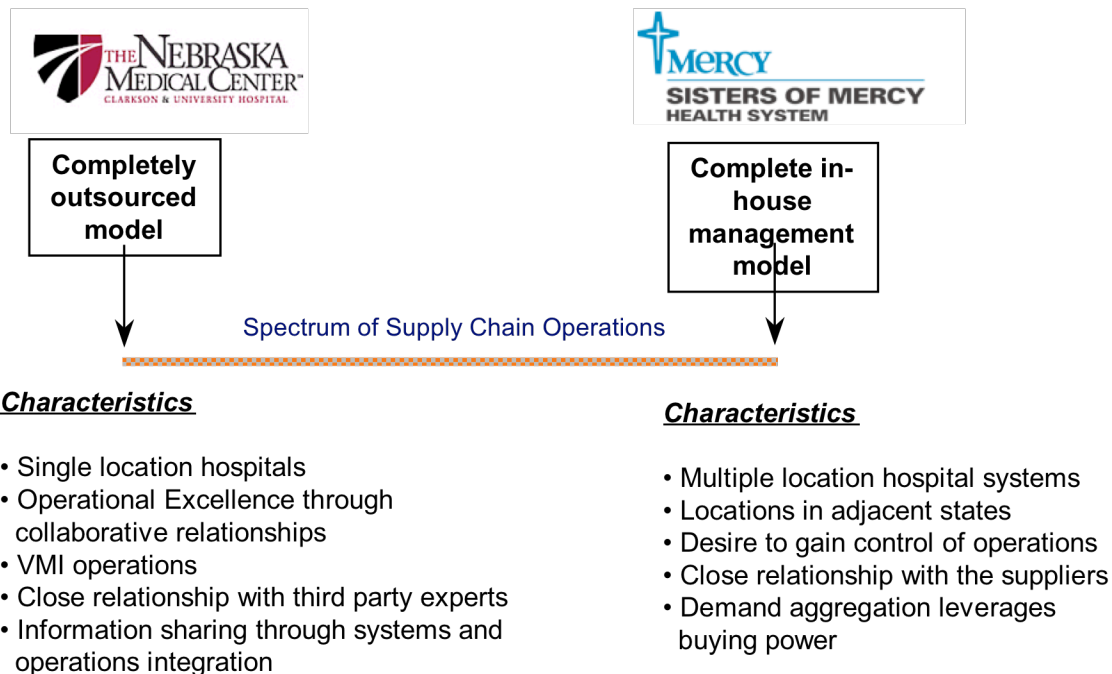
Completely outsourced model

Complete in-house management model

Spectrum of Supply Chain Operations

Characteristics

• Single location hospitals
• Operational Excellence through collaborative relationships
• VMI operations
• Close relationship with third party experts
• Information sharing through systems and operations integration

Characteristics

• Multiple location hospital systems
• Locations in adjacent states
• Desire to gain control of operations
• Close relationship with the suppliers
• Demand aggregation leverages buying power

Figure 4 – Spectrum of Supply Chain Operations

Within the health care supply chain, material and supply costs are rising at significant rates and may even outpace labor costs in the near future. This motivates the need for focused research on reducing inventory and supply costs within the health care value chain through better inventory management.

Inventory Management Research in Health Care

Inventory management research in health care has been a topic of extensive research. This section highlights and summarizes some of the published research in this area.

The main goal of inventory management and supply chain research is to reduce the cost of healthcare without sacrificing service typically by improving the efficiency or productivity of the system. Many of the papers in this section discuss general techniques for reducing cost, while others go more into depth by discussing one or two specific techniques. The main techniques discussed in this section include implementing a just-in-time or stockless inventory system, outsourcing the inventory management system, using new models to improve scheduling decisions, using simulation for various purposes, using the multi-objective methods to measure the performance of hospitals or parts of hospitals, and creating better demand forecasts.

A roundtable discussion at the MIT Center for Transportation and Logistics (Meyer and Meyer, 2006) highlighted some of the important issues in healthcare, particularly in supply chains. Some of the problems and constraints discussed included the high cost of healthcare, wasteful behaviors, and complex requirements and regulations. The solutions focused on making supply chains more demand driven, increasing collaboration between the various parties involved, increasing visibility of practices and inventories, and implementing more and better standards. In a survey released by HFMA (Anonymous, 2002, "Resource…"), executives and supply chain leaders of healthcare organizations identified ways to improve care and reduce cost. These included standardizing supplies, central purchasing, reducing inventory, improving demand forecasts, reducing labor costs through automation, improved collaboration with vendors, online purchasing, and more. In an HFMA white paper about operating room efficiency (Anonymous, 2002, "Achieving…"), the author discusses the need to increase the efficiencies of operating rooms. Some of the ideas include better integrating data, making better scheduling decisions, reducing paperwork through electronic data systems and automated documentation, and standardizing products.

Burns and Pauly (2002) discuss their skepticism of the trend in healthcare toward increasing consolidation, such as having primary care physicians or HMOs in the same organization as hospitals. They assert that the horizontal and vertical integration that healthcare organizations are trying to achieve are often counterproductive, and that the economies of scale of a larger organization fail to compensate for the increased bureaucracy and typically poor restructuring. Instead, they suggest using more practical ways of reducing cost, such as improving the information technology (IT) systems and the better handling of the treatment of chronic diseases, which often have high costs.

Chandra and Kachhal (2004) talk about the issues, trends, and solutions currently in the healthcare industry. The main issues and trends involved distribution networks, vendor relations, and Internet purchasing. The solutions presented involved using modeling to make better decisions in supply chain management. Williams (2004) discusses emergency departments and the task of keeping these departments stocked and running while still keeping costs low and not overstocking. He suggests the use of techniques such as using preventative maintenance, anticipating demand variation, using automated supply delivery, restocking every shift, and tracking products with bar codes or RFID tags.

Process Improvement and Costs

Colletti (1994) describes in his article about health care reform that hospitals will be differentiated in the marketplace by how well they manage the costs of services. He identifies that the key opportunities will be in changing processes to eliminate non-value added administrative, supply chain, and process activities and their costs. He describes various factors that affect costs and how the total delivered cost of materials can be reduced strategically. He also describes the importance of information sharing in achieving these goals.

Connor (1998) talks about the process of re-engineering the health care material management system. He points out that a re-engineering methodology seeks to optimize the combination of work processes, organizational structure, systems, technology and incentives that maximize value provided to the customer and minimize associated costs. The basic process is considered a project and the project path is defined as: evaluation, envisioning, empowerment and excel. The author illustrates the use of this methodology via a case study with the Midwestern Integrated Health System as the entity under study. It was concluded that there was an opportunity to achieve economies of scale for the health system through spreading fixed costs by sharing management and other overhead activities.

Norris (1988) investigates reducing costs for hospitals by considering the total delivered cost of a product rather than just the unit cost. This involves quantifying in dollars every cost associated with a product, such as the unit cost, the costs involved in ordering, the cost to hold in inventory, the cost to distribute the item, costs involved in preparing and using the item, and the cost to handle the paperwork. Harding (1998) describes a method of calculating the total unit cost of a product in order to choose a supplier for the product. Her method includes typical factors such as quoted price, transportation costs, and quality of the product; good service factors such as on-time delivery, lead time, point-of-use delivery, and consolidated billing; and social factors such as the use of products made from recycled material and the charitable activities of the supplier.

Reiner and Bremer (2005) describe various means for reducing the supply chain and IT costs of a hospital. They recommended improvements such as using a point-of-use tracking system with barcodes or RFID, better coordinating information and materials across the hospital's departments, standardizing the products used, and reducing the number of suppliers. In a paper released by CGI (Anonymous, 2004), the author stresses the importance of IT in a

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hospital. The author recommends using electronic medical records and physician order entry to save time, reduce cost, reduce medical errors, and make it easier to share information across departments. Since many hospital IT departments may not be able to effectively overhaul and manage a new IT system such as this, the author recommends outsourcing the IT department to a qualified business.

Just-in-Time and Stockless Systems

Kim *et al.* (1993) compare the conventional, just-in-time, and stockless material management systems in the health care industry. The authors sent survey questionnaires to randomly selected health care institutions from the database of the Healthcare Material Management Society and collected data from the 66 responses. The authors then used statistical methods to compare conventional, just-in-time (JIT), and stockless systems based on the 32 problem variables given in the questionnaire. The results of a stockless system compared to a conventional system included both psychological benefits, such as reduced employee resistance to major changes and management more willing to delegate tasks, and inventory related benefits such as fewer problems managing large inventories and better responsiveness to demand fluctuations. The study also found that there was not a significant difference between JIT and stockless systems, and that implementing either a JIT or a stockless system in a hospital that currently operates a conventional material management system would significantly improve the effectiveness of the operation.

Rivard-Royer *et al.* (2002) discuss the adoption of a hybrid version of the stockless replenishment system, combining the stockless method with the conventional approach to patient care unit replenishment. The medical supply distributor supplied high-volume products for the patient care unit in case quantities, leaving the central stores to break down bulk purchases of low volume products into point-of-use format. The study revealed marginal benefits from the hybrid method for both the institution and the distributor. The experiment conducted at a healthcare institution in the province of Quebec (Canada), focused on a single patient care unit. The result indicated that the total cost of replenishment was reduced by a negligible amount. Although the results for this form of hybrid stockless system have not been conclusive, other alternatives may be examined. The study opens the door for wider discussions and experiments in the future for reducing total costs via examination of stocking policy and inventory location.

Egbelu *et al.* proposed a cost model for different hospital material management systems and compared the costs via a case study using data from a hospital that operates currently under the conventional mode of material management with large bulk deliveries. An analysis was performed to determine if it would be profitable for the hospital to operate under JIT or Stockless systems. Three scenarios were analyzed in the study. First, the hospital operates in the JIT mode with less inventory at the central stores and frequent bulk deliveries. Second, the hospital operates in the stockless mode where the distributor delivers items in units or "eaches" to the receiving dock and the hospital does its own internal material transfer from the receiving dock to nurses' stations. Third, the distributor delivers in eaches directly to the nurses' stations under the stockless mode. The authors concluded that there are various factors that need to be taken into account before deciding on the system. Parameters such as the inventory levels at the nurses' stations and central stores, the number of full time equivalent workers, the amount of warehouse space, and the potential service charges from distributors that affect the total annual cost. This model is a good starting point for analyzing and comparing various material management systems in the health care industry based on total annual cost. A simulation study of various systems, concentrating on the inventory analysis and distribution, with the use of the cost model would give better insight into the implications of changing a hospital's material management system.

Analysis of Outsourcing

Kamani (2004) talks about the issues involved in upgrading the inventory management system of a hospital in the context of outsourcing it to a third party. Some the important points the author makes include eliminating poor quality data about products and vendors, analyzing spending patterns of the hospital, using a good classification system of the medical supplies, and enhancing product entries with relevant data, such as whether or not gloves are latex or latex-free. Rosser (2006) describes the improvements to cost savings and patient care in hospitals in London, Ontario brought about by the 1997 creation of the Healthcare Materials Management Services (HMMS). The HMMS consolidated a number of different departments of the area hospitals and standardized the supplies, procedures, and policies of those hospitals.

Nicholson *et al.* (2004) developed analytical models to study and analyze the impact of outsourcing of inventory management decisions to third party provider that offers inventory

management in health care. They compare the inventory costs and service levels of non-critical inventory items of an in-house three-echelon distribution network to an outsourced two-echelon distribution network. They try to evaluate the cost savings associated with switching from an in-house network to the outsourced network. In addition, they compare the service levels for each department within the hospital under the two scenarios. They studied a hospital network in Florida with seven hospitals and approximately 20 patient departments within each hospital. They conclude that the outsourced network dominates the in-house network in terms of total cost. The service levels of both the systems were comparable.

Lapierre *et al.* (2007) present an approach for improving hospital logistics by focusing on scheduling decisions and a supply chain approach rather than the more common multi-echelon inventory management. In an inventory management model, products for a care unit are ordered from central storage based on a certain minimum stock level known as the reorder point. The central storage also makes orders from suppliers based on reorder points. However, this model does not take into account the reality that orders for items are placed together at set times. Secondly, this model may not take into account the time-expensive "hot-picks," or unscheduled picks from stock outs at care units, which may occur as a result of this model. And thirdly, this model may not take into account the limited amount of storage capacity in both the care units and the central storage.

In a supply chain approach, all the operations involving a significant amount of labor associated with ordering are taken into account, such as the replenishment decisions, order picking, delivery of products, purchasing activities, and handling of supplies at the reception docks. Additionally, in this approach some items may be delivered directly to care units instead of the central storage. The authors use the supply chain approach in their two models, both of which focus on making decisions for the optimal time to buy and deliver products to each care unit and also decisions for employee management such as work shift and task assignments. The first model seeks primarily to minimize inventory costs, and the second model seeks primarily to balance workload among the days of the week. Since both models were complex, heuristic methods were used to solve the models. Eventually, a version of the second model was used and applied to the satisfaction of a hospital in Montreal, Canada.

The drawbacks of this approach concern the fact that models used in this paper are much more complex than traditional inventory models. Furthermore, optimal solutions could not be

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found due to the use of heuristics. However, given the improvements in cost, labor, organization, and stock control, this type of research, which focuses on scheduling, may warrant further study.

The previously discussed research forms the building block for future research in the area of health care supply chain management. The shortcomings of analytical models have motivated other researchers to develop simulation models that effectively replicate the real world scenarios and thus give a better understanding of the performance of the supply chain.

Applications of Simulation

One use of simulation is in the field of modeling inventory systems. Duclos (1993) developed a simulation model to determine the relative significance of several common inventory system variations on a hospital's ability to operate successfully under normal demand and emergency demand conditions. Two models were developed to test three common inventory system parameters on the hospital's ability to operate successfully under both of the demand conditions. These parameters include: inventory review frequency policies at central stores and point-of-use locations, location of safety stocks within the hospital, and product volume variations between point-of-use locations. Results of the simulation reveal that the review frequency plays a major role in the success of operations under emergency demand conditions.

Pasin *et al.* (2002) used a simulation model to study the impact of equipment pooling among the health clinics, called local community service centers (CLSC), in Montreal, Canada. The equipment was for the home use of patients and included items such as wheelchairs, electric beds, and therapeutic mattresses. Before equipment pooling, the Island of Montreal had 29 CLSCs that each managed their own supply of equipment. Whenever any CLSC was short of equipment, that equipment had to be rented at additional cost. To reduce the cost of renting, a plan was made which would allow CLSCs to share risk and pool resources by letting CLSCs borrow equipment from one another whenever they were short. However, these plans met resistance from CLSCs who had a number of concerns about the cost of the plan for each CLSC and the effect on patient care. Therefore, a simulation model was developed to estimate the effect of the plan and its cost.

For the simulation, the authors thoroughly analyzed the costs of lending and borrowing equipment, including the administrative cost and the wear and tear cost. The simulation was run for different demand levels, as well as with different restrictions on the amount of equipment a

CLSC could lend or borrow. The simulation found that the option with the least restrictions produced the least overall cost for the CLSCs, but any option with equipment pooling was better than the previous system without equipment pooling. Furthermore, the benefit of equipment pooling increased for increased demand levels. The simulation also found that the CLSCs which had an overabundance of equipment received the least benefit from equipment pooling, but additional methods could be applied to more evenly distribute the cost.

Simulation has also been used in the healthcare industry for material distribution management. Rossetti *et al.* (2000) used simulation modeling to analyze the costs, benefits, and performance tradeoffs related to the installation and use of a fleet of mobile robots (Automatic Guided Vehicles) within mid-size hospital facilities. Specifically, they examined how a fleet of mobile robots can meet the performance requirements of the system while maintaining cost efficiency. Four simulation models were developed to understand the trade-off between cost and system performance, including utilization of vehicles, amount of work in progress, system throughput, delivery turnaround time, and delivery variability. The models were then tested for clinical laboratory and pharmacy deliveries. The results of this project indicated that mobile robots are highly suitable for automating the delivery mechanism in mid-size hospitals. Rossetti *et al.,* (1999) looked at the efficient allocation and utilization of staff resource issues facing the emergency department administrators. They used simulation models to test alternative emergency department attending physicians staffing schedules and analyzed the corresponding impacts on patient throughput and resource utilization. The use of simulation was the key to success in obtaining results that were of practical value to the medical professionals involved in both of these research projects.

Applications of Multi-Objective Techniques

Rossetti and Selandari (2001) extended the work presented by Rossetti *et al.* (2000) and explored the effect of mobile robots on the elevator response, reliability of both elevators and robots, and a multi-criteria formulation of the automation introduction decision problem. The problem was characterized by very different and conflicting performance measures, which were observed to be qualitative and quantitative in nature. The Analytic Hierarchy Process (AHP) was used to address these trade-offs, which are often very significant within a health-care setting. AHP is based on the analysis of a hierarchy structure. This hierarchy structure has two basic purposes: it

naturally leads to a decomposition of the problem into objectives and sub-objectives and it enables a better and more systematic approach to problem solving. AHP is composed of four steps: decomposition, prioritization, synthesis, and sensitivity analysis. AHP can be extended to group decision-making problems similar to the one discussed above and can be applied to address problems that have multiple conflicting performance measures. Rossetti and Selandari (2001) successfully used AHP in the multi-objective analysis of hospital delivery systems to decompose the problem into sub-objectives and then used absolute mode for final comparison between the alternatives.

Such a multi-objective and group decision making approach can also be used in formulating quantitative solutions to measure the effect of different supply chain configurations. The healthcare value chain configurations are characterized by multiple objectives such as competing product classifications and performance criteria. In addition, non-quantitative factors, such as relationship history, etc. will be critical parts of the decision making process. This multi-objective approach has also been applied successfully when looking at hospital performance.

In Hariharan *et al*. (2004), AHP is used to measure the performance of hospitals. In this instance, AHP works by breaking down the performance of the hospital by its different "success factors" and sub-factors, which are the essentially different departments of the hospital, and categorizing those departments according to the type of work they do. The intensive care units, for example, would be categorized as acute care (as opposed to chronic care) in the patient care category. The radiology lab would be classified under establishment. Each category and department is given a weight based on how important it is to the functioning of the hospital. For instance, patient care is considered more important than administration, and is given a higher weight. Departments are also given weights based on how well they perform. Different criteria of performance are used for different categories. For instance, an establishment department such as the radiology lab determines performance based on how state-of-the-art its technology is, and patient care departments such as the intensive care units (ICUs) determine performance based on patient care, patient turnover, and adverse patient occurrences. The weights given for the importance of a department, the weights given for how well a department performed, and the criteria for performance were all determined after extensive interviews with hospital staff and analysis of the hospitals studied in this paper.

As a result of this method of performance analysis, the authors were able to gain a much clearer understanding of the quality of care given by the hospitals studied in this paper. Also, the AHP method gives a very thorough analysis of the performance of a hospital and allows a hospital to determine the specific areas it needs to improve. The thorough analysis used by this method may also be viewed as a disadvantage since the amount of work required to obtain the necessary information is much greater than other performance measures such as the mortality rate of a hospital.

Wu *et al*. (2007) also used AHP in a very similar manner to Hariharan *et al*. (2004). Wu *et al*. used AHP to evaluate the performance of hospitals in Taiwan. Performance measures may be a good topic for future investigation because they can help determine which hospitals or parts of those hospitals need the most improvement so efforts to improve healthcare can be concentrated in those areas.

Research has also been done in the use of benchmarking as a tool for the improvement of health services supply department. Dacosta-Claro *et al*. (2003) carried out a benchmarking study on the supply departments of Quebec's health services. They begin by defining a methodology to collect the information needed. This preliminary analysis allowed the classification of each hospital's performance and explained the operational approaches used. They observed that considerable amount of money could be saved by exercising economies of scale by regrouping supply activities. Their study showed that the best performance of central store services was achieved by receiving packages as small as possible. As a result of the strategies, they determined that the possible economies range from 20 to 30 percent of the actual supply-chain management cost.

Demand Management

O'Neill *et al*. (2001) examines the effect of implementing a Materials Requirement Planning (MRP) system in a health care setting. A two-part study was conducted at The University of Iowa Hospitals and Clinics (UIHC) concerning the inventory of green linens. Green linens are linens used for surgery, which for each use require laundering, material processing, and, for many items, sterilization. In the old system, more than ten thousand pounds of laundry were processed during five and a half days per week. A number of factors made managing this system difficult. Very high service levels were required, and shortages caused

delays, extra cost, and unnecessary stress. Surgical schedules for the next day were not posted until 6 pm, meaning short lead times. Most green linens had to be sterilized using a 12-hour process, and sterilized items had a shelf life of only 14 days. Some items were issued both separately in pre-made packs of several items. Demand was cyclical, i.e. different for each day, and small variations for each day caused large variations for laundry, material processing, and sterilization. Finally, the system was overly complicated and resulted in some days of overflowing inventory and other days of no inventory at all.

In the first part of the study, the hospital's green linen use was monitored over an 8 week period, which was then used to estimate demand. As expected, average demand for each day was different. The study proposed two alternatives to fix the system. The first alternative proposed processing only the amount of green linens needed for the day, resulting in a variable amount of labor for each day. The second alternative proposed processing a constant amount of green linens, holding stock for the days when demand was less than that amount, and using up stock when demand was greater than that amount. Both alternatives included safety stock. Ultimately, the second alternative was chosen due to lower cost of holding stock compared to paying workers overtime in every department along the supply chain.

For the new production schedule to work, the hospital needed the cycle time and total inventory of green linens. Total inventory was especially difficult to find due to losses from pilferage and the discarding of worn out linens. In the second part of the study, 49 green linen pillowcases were dyed blue and affixed with a bar code. They pillowcases were tracked as they left laundry and material processing. Average cycle time was found, and total inventory and seepage levels were estimated using statistical methods. As a result of this study, many improvements were made. An analysis of the system revealed redundant folding and inspections across several departments. A streamlined system resulted in 5 hours per day of saved labor. Safety stock was reduced by 20%, inventory within packs were reduced by 40%, and 5 different pack types were eliminated. Additionally, an improved system resulted in fewer incidents of stock outs and better communication among the departments.

Callahan *et al.* (2004) discusses demand forecasting, including the issues involved in making good demand forecasts and the benefits of good demand forecasts for health care. The ideal health care supply chain, according to the authors, is one that automatically performs a number of operations after a medical procedure has been scheduled. These include choosing

standardized products for the patient, assessing the need for backup supplies, picking necessary supplies, grouping supplies that need to be together, verifying the latest price of items based on the latest contract price, determining if any products need replenishment, placing orders for those products, and recording data for predicting future demand.

An effective demand forecast, according to the authors, first requires accurate means of tracking items, such point-of-entry data entry and RFID tags. Next, demand can be forecasted based on hospital scheduling, seasonal variation, and the preferences of the physicians. The demand forecast can then be further refined with data about the patients, such as age, weight, gender, medical conditions, and allergies. Any effective demand forecast should include all the phases of patient care, including pre-op, procedural, and recovery phases.

There are many benefits of an improved demand forecasts and a supply chain, which is responsive to these forecasts. These include lower costs for case preparation, improved fill rates and service levels, and reduced inventory. Since many products have a high risk of obsolescence, expiration, damage, or recall, keeping low inventory levels can greatly reduce cost. Additionally, good demand forecasts also help the manufacturers and distributors of the hospital or clinic in supplying the necessary products.

Topics for Future Investigation

In the report by Meyer and Meyer (2006), a number of problems and potential solutions within the healthcare supply chain are articulated. Three of the future research areas for the health care supply chain suggested by the report were:

- Increasing the role of the supply chain in new product development
- Forecasting and demand management
- Inventory management practices within the walls of a hospital

The emphasis on these areas is motivated largely because of the rising costs within the health care supply chain. According to Haavik (2000), in some instances supply chain costs may amount to as much as 40% of the cost of providing care and that if demand and inventory are better managed a savings of 4.5% can be achieved. Chandra and Kachhal (2004) suggest, based on a study by Pricewaterhouse Coopers, that the cost savings could range from 6 to 13.5%.

Some of this cost is due to the expanded used of new products and technologies. For example, a recent study by Blue Cross Blue Shield Association (Lovern, 2001) indicated that

19% of health care cost can be directly traced to the use and deployment of medical technology and that new medical technology is a key reason for double-digit health care costs. Thus, there is an increasing need to understand the role of the supply chain in new product development and adoption.

The introduction of new technology (e.g. equipment and related supplies) for patient care introduces a number of logistic management and control issues within a health care supply chain. The first decision faced by hospital systems is to evaluate whether or not a new technology and its related supplies should be adopted. This traditionally involves a cost analysis as well as an evaluation of the medical effectiveness of the technology that may or may not take into account logistic issues. After adoption, new equipment and related supplies are sometimes placed within an expense category rather than an asset category because initial treatment plans are not standardized for the use of the new technology. In addition, the potential demand for the new equipment or technology is difficult to project.

Unfortunately, as the use of the new technology matures, the items often remain an expense longer than they should rather than being moved into an inventory management category where their use can be better optimized within the health care supply chain. In addition, for many new technologies the method of marketing through personal interaction between the supplier and the doctor is well entrenched. This personal marketing can bypass the traditional controls that are in place within the managed inventory items.

To address this need, a methodology for evaluating the trade-offs between the cost and the effectiveness of the new supplies/equipment needs to be developed. Such a methodology should capture the cost of the supplies/equipment in terms of inventory asset value but also the cost of managing the inventory within the supply system. This should involve the transportation, holding, and ordering costs. A unique aspect of this inventory modeling will be in characterizing (or forecasting) the demand for new items as well as the effect of technological change on the price/value of the items over time. For example, the introduction of new technology may cause the price/value of items already in inventory to change. Planning for this change over time can be an important factor in evaluating current technology versus new technology and any discounts offered by manufacturers. In addition, where to stock the items will be important because inventory pooling may be a very effective strategy for high cost, low demand items. Traditional

inventory models typically assume stationary demand and static item costs over an infinite planning horizon. This will clearly provide less than ideal planning for these types of items.

An ideal methodology should also evaluate the logistical performance (e.g. fill-rate) for various levels of cost. The development of such a methodology should also take into account the best practices currently being used to manage new technology as well as how to take advantage of recent advances in information technology.

As indicated in the previous discussion, even for new technology, inventory management is a critical issue. To improve inventory management, the best place to start is at the beginning of the supply chain. That is, understanding and characterizing supply chain demand is critical because so much planning depends on the form of the demand. It could not be articulated any better than in the Center for Global Development's report on improving global health through better demand forecasts:

> *"One of the weakest links—and one of the most vital for achieving both short- and long-term gains in global health—is the forecasting of demand for critical medical technologies, including vaccines, medicines and diagnostic products. Demand forecasting, which may seem at first glance to be a small piece of the very large puzzle of access to medical products, is of central importance."*- CGD (2007)

Some have advocated that retail-forecasting practices be adopted within the health care supply chain; however, it is not clear how these practices should be adapted to the unique aspects of the health care supply chain. One thing that is clear is that better demand management practices are imperative for achieving the potential savings that have been suggested. Callahan *et al.* (2004) indicate that the time may now be right for making this adaptation:

> *"Having incorporated these lessons into the lore of supply chain management, we contend that our industry is now ready to develop its own set of principles that draws upon the concepts of retail demand forecasting models, but which fully accounts for the unique nature of health care – in which a failure to meet the demands of consumers (patients and clinicians) can have dire consequences."*

They indicate that projecting demand is the key. That is, utilizing all automated systems to "create realistic bill of materials for procedures from the preparation phase through recovery and follow up" (Callahan *et al.*, 2004). See also the discussion on treatment pathway profiling in Meyer and Meyer (2006). This is a key insight to replace uncertainty with information and get closer to derived demand.

Derived demand is demand that can be computed deterministically based on the requirements from other items (e.g. end items). Typical end item demand forecasting relies on historical records to model future demand, largely treating the demand as independent. Whenever possible, it is advisable to substitute derived demand in place of typical forecasted demand. Within manufacturing settings (e.g. make to assembly, make-to-order) end-item demand is forecasted and the component demand is derived via the product structure (bill of materials). Because of advances in information technology, hospitals now have large quantities of data available concerning patients and their use of supplies. These systems track diagnosis, medical events, patient satisfaction, purchasing, accounts payable, reimbursements, surgical team preferences, dispensing of pharmaceutical, etc. With this sort of information, it may now be feasible to create a probabilistic "Bill of Materials" for categories of patient types and/or disease management regiments. From such a bill of materials, it may be possible to derive demand requirements for materials according to hospital scheduling, patient demographics, admission records, and seasonal demands.

For example, consider hip-replacement surgery. These types of procedures are often scheduled weeks if not months in advance. For each procedure, there are three sets of materials 1) those that are always used, 2) those that might be used, and 3) those materials that could not have been anticipated. The analysis of information on past patients should allow some analysis of sets 1 and 2. Then, a bill of material could be determined for those materials that are always used. This could allow pre-packaged kits to be developed; however, since many procedures may have common items, it is the schedule information along with the lead-time to order the item, which could allow for better just-in-time management of the items. This would allow the postponement of the kit building process to the last possible moment. Thus, given a procedure schedule, the ordering, stocking, and delivering of significant amounts of material can be pre-planned. In addition, there is the possibility of creating a probabilistic bill of materials for the items that will probably be needed. Finally, with appropriate data, those materials that are being

used but could not be anticipated could be forecasted and treated as independent demand items. This process could allow for significantly reduced levels of inventory, while still meeting delivery service requirements.

In some sense, the delivery of health services (in the form of procedures) to patients can be conceptually similar to something like aircraft maintenance. In order to optimize aircraft maintenance, one looks at scheduled maintenance and unscheduled maintenance. The scheduled maintenance allows derived demand to substitute for uncertainty. Then, the supply system can handle the inventory requirements for unscheduled repairs. While the analogy is not perfect, it should be apparent that some of the techniques applied to analysis and control of spare part supply networks should be applicable to the health-care supply chain.

In order to examine these ideas within the health care supply chain, there is a need to examine and document current (best) practices in regards to demand management. Then, the information requirements for analyzing and building bill of material candidates would need to be specified. Finally, the ideas would need to be modeled and compared to current methods. This would allow for a better understanding of how much benefit could be gained before committing larger resources to demand management techniques.

Summary

This report discusses the supply chains and inventory systems of health care facilities such as hospitals. In particular, this report discusses the areas that show great opportunity for reducing cost and improving service and the techniques that could help to achieve these goals.

First, this report gives an overview of the health care industry and the reforms that have been made in the last two decades. The adoption of the reforms of the 1990s served as the basis for the traditional distribution model. In this model, hospitals made use of group purchasing organizations (GPOs) and distributors to supply them with all the products the hospitals needed. However, this model had inefficiencies and flaws that unnecessarily drove up the costs involved.

In the first alternative model, exemplified by the Sisters of Mercy Health System, a branch of the organization, called the Resource Optimization and Innovation (ROi) division, acts as the purchaser and distributor for nearly all the hospitals in the Mercy system. The ROi operates by keeping a single central warehouse and sending daily shipments from that warehouse

to all its hospitals. This is opposed to the traditional system, where each hospital had its own warehouse or storeroom, in addition to all the warehouses of the hospital's distributors. The reduction in the number of warehouses and businesses involved in handling and distributing the product to the hospitals led to increased efficiency and reduced cost. In addition, since Mercy had direct control over its distribution system, it was able to implement new procedures that improved service for both the hospitals and its patients.

In the second alternative model, exemplified by the Nebraska Medical Center (NMC), all of the distribution of products is outsourced to a single provider. The NMCs provider, Cardinal Health Inc, sends deliveries to the hospital four times per week from its warehouse in the same city and was able to increase the efficiency of the distribution system in a manner similar to Mercy's ROi. However, since the NMCs entire product distribution system was outsourced, it did not need to invest any capital in inventory and was able to spend that money elsewhere.

In the second section of the paper, literature concerning health care supply chains and inventory management is reviewed. First, literature concerning general health care practices and cost reduction is reviewed. Next, literature concerning IT in a hospital is reviewed, and several importance topics such as the use of bar codes and RFID are discussed. Literature concerning Just-in-time and stockless inventory systems is reviewed next, and the literature showed that there is a considerable cost savings potential in implementing one of those systems. The review also contains literature describing the outsourcing of a hospital's inventory management system as well as literature detailing new analytical models or simulation models. In general, the use of new models or simulation showed great potential in increasing the efficiency of a hospital. Next, the literature review discusses the use of performance measures, which showed potential in identifying the hospitals and parts of hospitals that could use the most improvement. Lastly, literature concerning demand forecasts is reviewed. The literature showed that better demand forecasts were also a good method of helping alleviate many inventory and supply chain problems.

In the third section of this paper, there are several areas of healthcare in which there is great potential for improvement but little research, and thus there is a need for future research in these areas. The first proposed topic of future research concerns the adoption of new products into the hospital, especially if the new product relates to a new technology or if the new product significantly affects the rest of the supply chain. A new methodology needs to be developed

which takes into account all the relevant factors, including not only the holding, ordering, and transportation costs of the new item, but also the effect the new product will have on the quality of service and the prices and value of other products. The second proposed topic concerns the use of better demand forecasts to improve service while reducing inventory. Because of scheduled surgeries and other known events, a large portion of future demand can be determined exactly. Therefore, inventory management techniques that take advantage of derived demand should be investigated for application within the health care value chain. Both of these topics should facilitate improvements in inventory management for the health care value chain.

Acknowledgments

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