Comparison of Alternative Hospital Supply Chain Systems using Simulation

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Siddharth Garg
Michael E. Kuhl
Industrial and Systems Engineering Department
Rochester Institute of Technology
Rochester, NY 14623 USA

Abstract

Hospital supply chain systems play an important role in the delivery of high quality patient care. Having the right products available at the point-of-use is important to the efficient and effective treatment of patients. Although there is a vast quantity of current supply chain research, much of the literature focuses on particular aspects of the supply chain. In this research, we study the hospital supply chain from manufacturers/distribution centers to the point-of-use within a hospital unit, taking into account the integration and implementation of the various echelons of the supply chain system. In particular, we design and compare alternative supply chain systems including a par level and Kanban systems. We utilize a simulation and optimization methodology to evaluate supply chain decision variables (order quantity, safety stock, etc.) and to compare alternative system configurations based on service level and operational costs, subject to variability in demand and lead-time, as well as perishable product and inventory space constraints.

Keywords: Healthcare, supply chain, inventory management, simulation, optimization

1. Introduction

In the United States, healthcare expenditures have grown to over $1 trillion [1], and continue to increase. Reports suggest that supply chain operations (i.e. medical supplies, handling and inventory) range from 25 – 40% of the hospital budget [2, 3]. Clearly, hospital inventory management is a significant aspect of hospital operations. Furthermore, there are at present 4862 community hospitals in United States [4], 2845 operate not-for-profit. According to Moody’s statement in 2015, the not-for-profit hospitals were running on a median operating margin of 3.4% [5]. Darling and Wise [3] state that inventory optimization can generate up to 10% savings. Thus, transferring inventory saving to value-added aspects healthcare delivery could have a positive impact on both the financial bottom line and the quality of care. However, since inventory management is not the primary purpose of a hospital, decisions and efforts regarding streamlining inventory and operations are seldom given the status of high priority. In this paper, inventory management systems are analyzed to draw conclusions about developing an effective supply chain methodology to deliver patient care.

A typical healthcare supply chain consists of suppliers, manufacturer, distributors, healthcare providers and the patients (end consumers). Figure 1(a) illustrates the system overview of a healthcare supply chain. The diagram represents the key stakeholders involved in a healthcare inventory system. Demand travels from right to left while supply of products travels from left to right. In this work, we focus on the latter portion of the supply chain -- from the distributors to the point-of-use. Figure 1(b) represents these system components under consideration in a typical hospital, the inventory may be received from distributors and stored at a central location from where products are supplied to the hospital units or there may be direct shipments from an external distributor to the respective units. Furthermore, each hospital unit typically stores point-of-use inventory to enable on-demand access for anticipated items needed in the provision care within the unit.
The goal of this paper is to develop a system design methodology to enable the efficient supply of materials from distributor to point-of-use under stochastic demand and lead times. We propose the use of a hybrid optimization/simulation methodology to compare alternative system configurations based on service level and system costs.

2. Related Work

A significant body of work has been developed in the areas of supply chains in healthcare. In particular there is an emphasis on healthcare inventory management and the potential to improve its effectiveness [6 - 8]. According to Mathew, John, and Kumar [9] healthcare supply chains are quite complex, and hospitals are struggling to deliver care to patients in a timely manner. In addition, hospital supply chains are often operating as separate isolated units rather than operating as a system. In recent years, some of the hospitals and healthcare systems have realized that there is a definite need to improve their inventory systems [10].

Landry and Beaulieu [11] classify hospital replenishment systems as: perpetual and periodic inventory. For perpetual inventory, records are known all the times. The information is tracked for each item consumed. Technologies such as bar code readers and biometric readers are used to capture data while RFID enabled cards are used to identify patients and employees. RFID can also be used to track movement of patient. For periodic inventory, supplies are ordered and delivered in batches from the central inventory. It may also be sent directly to the vendor in case of non-stock item. Contrary to perpetual inventory, there is no real time inventory status record. The periodic replenishment method can be classified into following four principal replenishment modes:

- **Requisition**: Nurse counts inventory and estimates consumption. Product low on inventory is requested from material management department through electronic or manual requisition.
- **Exchange cart**: Carts with medical supplies are placed at the point of use location and products are consumed from the cart. The cart is then exchanged with a fully stocked cart from central inventory when empty.
- **Par Level**: Each product has its fixed estimated ‘par level’ determined by the storekeeper. A store keeper takes inventory count of medical supplies in a ward. The count is entered in the electronic system which compares the count to the expected par level. Based on the difference a pick list is generated for central inventory. The picked or ordered products are delivered to the wards and put away by the store keeper.
- **Two bin Kanban**: Products are placed in two separate bins. When the first of the bins is empty, nurse removes the Kanban card or label with product information and places it in a box to signal the storekeeper for replenishment. The storekeeper is notified for replenishment. The medical supplies are replenished in the empty bins. During replenishment cycle, product demand is met by the second bin kept in the unit.

The sequence of replenishment modes follow chronological order. The exchange cart was introduced as a need to fulfill basic requirement. Later par level and two bin systems were introduced for faster and accurate replenishment process. The goal is to make replenishment process convenient, more accurate and more responsive to the rate of consumption.
Based on our review of the literature we observe that the overall design of systems is not being considered by many researchers. Although much work has been done to determine optimal order quantities and reorder points under various conditions, the design and analysis of systems that implement these inventory decisions within the dynamic hospital environment has not been thoroughly investigated. Therefore, we have chosen to make this the emphasis of our research.

3. System Design and Analysis Methodology
The methodology that we propose centers on the design of a hospital supply chain system from the distributor to the point-of-use. Here, we are interested in the overall system design including the order quantities and reorder points as well as the operational aspects of the supply chain system such as gathering unit demand, order picking, transporting of inventory to units within the hospital, receiving, etc. An overview of the methodology is shown in Figure 2.

The methodology takes as input parameters from the operational aspects of the supply chain including information such as the average and variation in demand for per item for each unit, average and variation of lead time, and inventory and supply chain related costs. In addition, the analyst provides a set system designs to be evaluated such as a par level system, a Kanban system, or other desired alternative. Taking these inputs, the analysis methodology is a two-stage, iterative process.

The first stage utilizes established optimization models to calculate order quantities, reorder points, and safety stocks for each item within each unit as well as for the hospital central inventory. The second stage utilizes the first stage values as an input to a simulation model that evaluates the dynamic behavior of the of the supply chain system to determine the optimal system configuration for ordering, picking, transporting, and replenishing inventory based on overall system costs and service levels. The results of this second stage could feed back into the first stage and the process could be iterated as needed.

3.1 Determining Hospital Unit Inventory Parameters
The first stage in the analysis methodology is to determine the optimal values to use for the hospital unit inventory parameters including the order quantity, reorder point, and safety stock. We propose using established methods that are applicable to the system under consideration. For systems involving uncertainty where the assumption of normality can be made, we can utilize \((Q,r)\) inventory models [2]. In systems involving additional constraints such as space or perishability limitations, linear programming optimization methods can be used.

3.2 System Simulation and Optimization
The second stage in the analysis methodology is the construction of a simulation model to evaluate alternative system configurations. Simulation allows for evaluating the dynamic system behavior. In particular, we seek to determine the type of inventory system that will perform best under the specific characteristics of the hospital. The
processes that are common to most of these two echelon systems are shown in Figures 3 and 4. These include the periodic review and replenishment process for each item within the hospital units and the hospital central inventory.

Figure 3: Hospital Unit - inventory replenishment process

Figure 4: Hospital Central Inventory - inventory replenishment process

The simulation model includes both the tracking of the inventory as well as the stochastic demand, travel time, processing times, and travel distances. Through the simulation, we can evaluate the trade-offs among system performance measures such as inventory holding costs, supply chain personnel costs, and service levels.

4. Example Comparison of a Par Level versus a Kanban Supply Chain System

To illustrate the methodology described in section 3, we have constructed an example involving the comparison of a par level versus a Kanban supply chain system. We consider data representative of a small hospital with a single primary distributor. In addition, we assume that the following are provided for each inventory item:

- Mean and variance of demand within each hospital unit;
- Mean and variance of lead time for each item;
- Ordering cost; and
- Holding cost.

For this example, we apply a \((Q,r)\) inventory methodology for stochastic demand to determine \(Q\), the order up to quantity, \(r\), the reorder point, and the safety stock (see, [12]). We implemented and solved for these values using MS Excel. These values are then utilized as input to the simulation model.

The simulation models of the alternative supply chain systems were constructed using Simio simulation software. For each alternative, the inventory replenishment process described in Figures 3 and 4 are implemented.

For the par level system, a daily period review process is assumed. If the inventory level of the item within the unit is below the reorder point, an order is placed to the central inventory for a quantity that is equal to the difference between the par level and the current inventory level.

For the Kanban alternative, we have assumed a three Kanban system. That is, the maximum inventory for each item in a unit is split equally between three Kanbans. When a Kanban is empty, it is sent to the central inventory for replenishment.

The simulation model records the total system cost including the inventory ordering and holding cost as well as the labor cost associated with performing the supply chain tasks of inventory review, order placement, order picking, replenishment, and other associated tasks. In addition, the point-of-use service level is assessed. That is, the model tracks the patient demand for each product within each unit and the proportion of time that the demand was satisfied.
For this example, we varied the safety stock level to show the trade-off between the annual cost of the system and the service level that was achieved. These results are shown in Figure 5.

![Average Service Level vs. Average Cost](image)

Figure 5: Supply chain cost versus average service level for the example Kanban and par level supply chain systems

### 5. Conclusion

This paper presents a simulation based methodology for the comparison between different configurations in a hospital supply chain. The models take into account the overall system’s consideration while distributing products from distributor to various care units within the hospital. The two stage analysis methodology allows for the evaluation of order quantities and reorder points for each product within each unit and in the central inventory in stage one, while in stage two, the simulation model is used to focus on the design and performance of the operational aspects of the hospital supply chain.

Future work will include the continued development and refinement of the two stage methodology including a formal experimental performance evaluation to determine the factors that have the greatest influence on the supply chain decisions.

### References


