5-2019

The analysis of Erlanger Hospital's suture inventory management operations

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The Analysis of Erlanger Hospital’s Suture Inventory Management Operations

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Departmental Honors Thesis

The University of Tennessee at Chattanooga

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Examination Date: April 5, 2019

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Acknowledgements

There have been many people who have helped, taught, and supported me through this process. I am so grateful for the time, attention, and encouragement you have all given me. Thank you to Shawn Lowe who has always made time to teach, explain, and show me his world. I understand your time is not a luxury, but every minute you gave me has not only been vital in creating this thesis, but it has also opened my eyes to a field that I have grown very eager to pursue. I am so grateful for my thesis director, Dr. Cecelia Wigal's, trust and patience through this process. Your guidance and how well you've handled the stress with me has been deeply appreciated. The hours I've poured into this would have exhausted me if it weren't for my family and my best friends. This opportunity has shaped my future career, taught me things I would have never had in the classroom, and shown me the importance of loving what your do.

1. Introduction

1.1. Overview of Study

This paper evaluates the impact of using mechanical engineering and operations management principles to an inventory management system in Erlanger Hospital. Erlanger Hospital is a local, nonprofit hospital system in Chattanooga. Erlanger serves as a tertiary referral hospital and a Level I Trauma Center in the region. Therefore, they are heavily depended on during times of crisis or emergency [2].

This study focuses specifically on reducing the loss and ultimate waste of sutures across Erlanger's surgery wing. A criteria for the appraisal of using mechanical and manufacturing engineering to improve the current system is established based on existing data regarding the stock of sutures in the surgery wing. The current system is analyzed and evaluated for potential opportunities to reduce the number sutures wasted, thus saving money and time for the hospital. The results of this study are summarized in a white paper for customer use.

1.2. Problem Definition

Erlanger Hospital's Surgery Wing maintains a stock of 244 unique types of sutures in one centralized suture room. This room provides sutures to the entire surgery wing. However, when sutures are taken from this room, they are not always used. Instead of returning sutures to the suture room, they are forgotten or placed wherever was most convenient for the user at the time. Because they are not returned, many sutures are left unused until they expire. In 2017, approximately $2,339.59 worth of sutures expired before use.

Starting in 2020, the expiration period of sutures will change from a semiannual basis (once in January and once in July) to random months and days depending on the batch of sutures that was delivered. This will make the expiration of sutures less predictable and thus tracking of suture expiration more difficult. Additionally, the manufacturers of the various suture types are also reorienting the box which the individual suture packs are kept. Instead of being stored vertically, they will be stored horizontally, causing the selection of individual suture packs to be more difficult.

Through this project, the current inventory management system used in Erlanger’s surgery wing is studied to identify any issues that could be resolved to reduce or prevent wastage and the loss of money in lieu of these changes.

1.3. Purpose of Study

The purpose of this study is to determine if engineering principles, when applied to a hospital’s inventory management system, can help reduce waste and save money. Due to the nature of the healthcare industry, a fully automated inventory management system, commonly seen in large manufacturing plants, is not possible. In hospitals, items and processes interact with and often rely on the action of people. Therefore, a fully automated inventory management system is not the goal. Instead, this project will explore how manufacturing, engineering, and/or operational principles can improve Erlanger’s Surgery Wing inventory management system.

1.4. Project Goal

The primary goal of this project is to understand inventory control methods used in manufacturing environments to help analyze Erlanger’s surgery wing’s suture inventory control system and address wastage due to expiration. The specific objectives of this project are listed below.

- To define the weaknesses of the current inventory control system.
- To address how inventory management systems can account for human variables/ human nature.
- To determine how effective engineering / manufacturing principles can be when applied to the hospital industry.

1.5. Definition of Terms

Below are a list of terms heavily used throughout this report.

- <u>Suture</u> – A suture is a tool that holds a wound together. They commonly take the form of a stich or glue. Within the scope of this study, suture more broadly refers to a pack that contains sterilized equipment (most often a needle and thread) that is taken into a surgery room before the procedure begins. A suture is considered used once the packaging is opened. Figure 1 is an example of a suture box in two orientations. This box carries multiple suture packs.

***Figure 1**: Suture box horizontal (left) and vertical (right) orientation*

- <u>Surgery Wing</u> – Erlanger Hospital is a Level I Trauma Center. Within the hospital is a dedicated wing for various surgeries that allow the hospital to function as a major asset to the regional public and many others in the general region. This wing consists of several individual surgery rooms, two dedicated trauma rooms for more intensive surgeries, and many offices for the doctors and nurses of each specialty.
- <u>Tree</u> – Due to the size of the surgery wing and number of operating rooms, one suture room can become a nuisance for nurses and doctors to visit before every procedure. To remedy this, Erlanger introduced “trees”, or movable storage units. These trees, shown in Figure 2, are mounted on wheels and can hold up to 72 sutures. Each specialty has at least one tree dedicated to transporting a limited

***Figure 2**: Service/ specialty tree*

stock of sutures from the suture room to their designated area of the wing.

- Trauma Cart – Major trauma surgeries can be unpredictable and demanding. Therefore, large trauma carts holding up to 122 different sutures are kept in the trauma operating room for the doctors and nurses to have a variety of different sutures readily available to use when needed. Figure 3 is a photo of a trauma cart.
- Service / Specialty – There are eight services or specialties offered in the Surgery Wing. Each of these specialties have their own dedicated suture stocks and assigned suture tree.
- Suture Room – This is one centralized location that nurses or medical technicians can go to for sutures. This room stocks the trees and trauma carts and serves as an open stock for sutures to be taken as is needed.
- Secondary Supply Rooms – Each specialty and service require unique tools and equipment, therefore, there are various secondary supply rooms across the Surgery Wing to store the unique equipment. Sutures can also be stored there.

1.6. Research Methodology

Working closely with Surgery Supply Chain Supervisor, Shawn Lowe, I had access to various data through Erlanger's Oracle PeopleSoft system. This data includes records from 2017 to 2018 of suture types, quantities, PAR levels and the cost of each suture type. Oracle was able to directly provide me tracking data for unique suture types as well. Additionally, I was escorted through the Erlanger's Surgery wing to gather physical and qualitative data to better understand the nature of the system and the people operating it. I toured the surgery wing and shadowed Lowe and his team through each process the suture inventory goes through from delivery to disposal. I interviewed the supply chain management team to the nurses and medical technicians to get a full and rounded understanding of the system.

The only way to verify sutures are used is to see that they have been billed to the patient post-operation. EPIC System Corporation, a privately held healthcare software company, keeps these financial records [2]. I was not be able to get direct access to this specific data due to patient privacy laws, however, I was able to get a vague understanding of the data regarding suture usage.

2. Literature Review

Before collecting data and analyzing Erlanger's system, it is key to form an academic understanding of inventory management and various inventory control methods used across all industries. In this section, inventory types, costs, improvement methods, and the effect of human nature are discussed. Additionally, case studies discussing inventory management in the hospital industry are reviewed. By building a general knowledge of the elements that contribute to an inventory management system, it is easier to clearly define and evaluate the current system.

2.1. Definition of Inventory Management

Inventory management is a key aspect of business logistics that can directly affect a company's cash flow and it ability to meet customer needs. The purpose of an inventory management system is to "hold inventories at the lowest possible cost," while having enough to meet operational need [3]. The processes of receiving, holding, and replenishing inventories and the costs associated are the driving forces of choosing and designing an inventory management system. Inventory management can benefit profit and non-profit companies or organization across all industries as they all hold the common priority of delivering and meeting the customer demand.

2.2. Brief History of Inventory Management

Inventory management has evolved from merchant's notebooks recording the number of goods left at the end of the day to huge databases remotely monitored to radio-frequency identification, or RFID, tags that automatically track and store the locations and processes items go through. In the modern age, businesses have inventory management as a balance between inventory and management, treating them as two separate entities. This balance, however, is extremely hard to achieve as technology allows more goods to be produced faster with greater design variations. The evolution of technology demands an evolution in inventory management [4].

In the early 20th century, manufacturing companies were achieving an unprecedented level of efficiency by implementing inventory management, production planning, and scheduling. Henry Ford, the founder of the Ford Motor Company, capitalized on inventory management and high-volume production techniques to become a titan and role model in the manufacturing industry. Through implementing principles like "Just-In-Time" or JIT, Ford was able to reduce overhead costs and increase inventory turnover. The results from developing and implementing these principles not only resulted in money saved, but also brought attention to the lucrative benefits to implementing inventory management principles into the manufacturing industry [4, 5].

Companies around the world across all industries implemented Ford's principles. Inventory management systems moved beyond organizational and operational techniques to the integration of software to monitor the inventory and automate the reordering of goods. Today, there are companies exclusively devoted to managing inventory systems, offering programs with artificial intelligence to help predict variable demand [6]. Software-based inventory management systems work particularly well in highly automated, mass production industries where few things are human dependent. However, removing the human variable in most industries is near impossible and often not desired. Therefore, marrying together inventory software packages with hardware tools like radio-frequency identification chips, barcode scanners, or vending-style machines offer a multitude of unique forms of inventory management to fit nearly any industry. Inventory is defined as a stock or store of goods.

2.3. Types of Inventories

Below are the An inventory can fall six unique categories into [7]. Below is a breakdown of each of the inventory stock that commonly appears in the manufacturing industry [1].

2.3.1. Cycle Stock

Cycle stock is a result from the replenishment process. The replenishment time, or lead time, of this stock is known. Using these times, stock replenishment cycles can be scheduled to meet customer demands, assuming that is also known. This type of stock requires a predictable system with known complexities and variances.

2.3.2. In-transit Inventories

In-transit inventories refer to inventories that are being transported from one location to another. This type of stock is very similar to cycle stock, as they often occur on a schedule. However, they are not considered available for sale until it reaches its destination.

2.3.3. Safety of Buffer Stock

This stock is held in excess to cycle stock of offset any unexpected demands or lead time delays. Average inventory at a stock-keeping location that experiences demand or lead time variability is equal to half the order quantity plus the safety stock.

2.3.4. Speculation Stock

This stock is held for reasons outside of satisfying current demand like delivery delays due to strikes, natural disasters, or unknown ordering system error.

2.3.5. Seasonal Stock

This is a form of speculation stock that is kept specifically during high demand seasons. This stock ensures that a company can meet the customer demand with less risk of running out of goods.

2.3.6. Dead Stock

This is the type of stock that should be avoided. Dead stock is unwanted and not needed immediately. This type of stock can be caused by a sudden technology change, or because the cost of disposal is higher than the cost to simply keep it.

2.4. Inventory Costs

There are three types of cost that should be considered in setting inventory levels [8]:

2.4.1. Holding or Carrying Costs

These are the expenses associated with storage, handling, insurance, taxes, and interest on the funds financing the items. These charges typically increase as inventory levels rise and economic inflation occurs. To minimize this cost, a company could make more frequent orders of smaller quantities of the needed goods. This type of cost is commonly calculated as a percentage of unit value.

2.4.2. Ordering Costs

These costs are associated with placing an order. This includes the expenses from interacting with a purchasing department, communications, and handling of related paperwork. To reduce this cost, a company should place fewer orders of a greater quantity of goods. This cost is commonly expressed as a monetary value per order.

2.4.3. Stock-Out Costs

This includes lost long-term and short-term sales due to insufficient inventory. These charges are generally hard to compute, although it is valuable data for a company to have as it represents the customers' incurred expenses when inventory policies fail. By monitoring and understanding this cost, inventory levels can be maintained to justify the customer requirements.

2.5. Inventory Control Systems

There must be enough inventory to satisfy demands in terms of quantity, quality, time, place and cost. Therefore, inventory control must address all of these aspects [9]. There are several types of inventory control systems. Below are the inventory control systems studied to later relate to this project.

2.5.1. Fixed Order Quantities (FOQ)

The basic characteristic of this system is that a fixed quantity is ordered, or the economic order quantity, is placed when stocks are replenished. Figure illustrates how control systems recognize fixed order quantities. By defining a number of set parameters based on a predictable pattern, the inventory model can be conveniently illustrated by a graph. Inventory is set at a maximum level and is depleted over a period of time up to the lead time T_L. If the re-order level (R_L) is reached but the

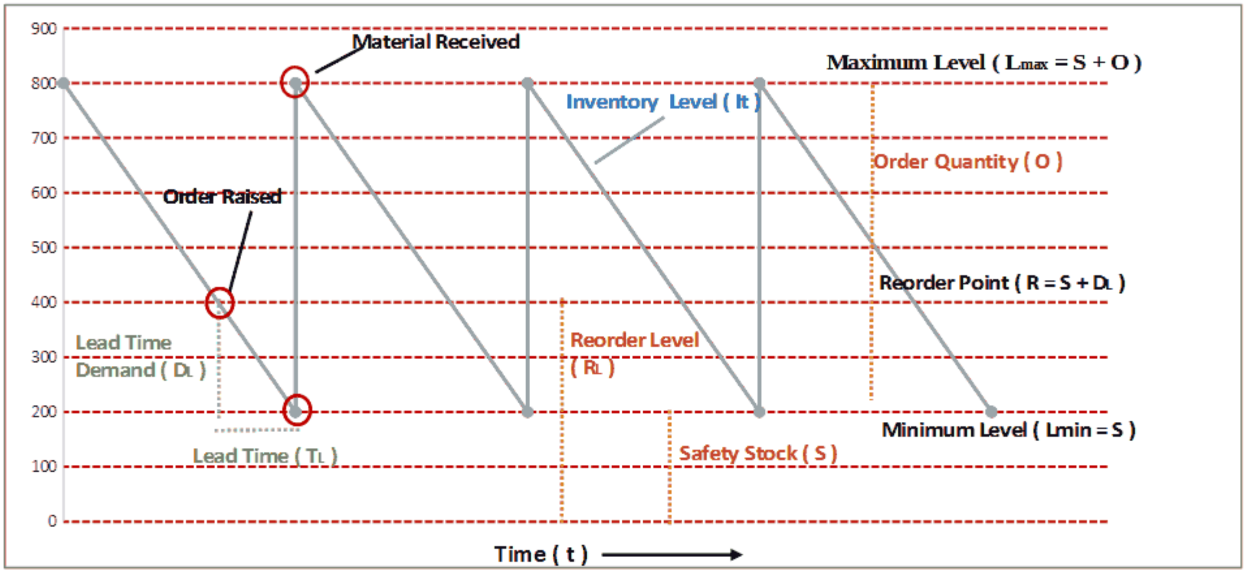


***Figure 4**: Fixed Order Quantity Inventory Model [9]*

inventory is further depleting, the safety stock level (S) gives the company extra time to replenish their inventory. If no safety stock is needed because the ordered fixed quantity is received on time, the inventory is replenished to level the maximum level. The process repeats itself and a fixed quantity is ordered whenever the reordering level is reached [9].

2.5.2. Periodic Automatic Replacement Level System (PAR)

The Periodic Automatic Replacement Level system defines a minimum level of inventory required to meet the demand. This point is called the PAR level. Once the inventory drops below the PAR level, it is automatically replenished, similar to how the fixed order quantities system operates. The critical difference between the fixed order quantities system and the PAR system are the number of known parameters and values required. The PAR system eliminates the need to define a maximum inventory level. Each inventory item is given a PAR level, or the ideal quantity number. This PAR level replaces the maximum level in the FOQ model and sets the minimum level to zero. Instead of having a fixed reorder quantity, the PAR level system orders up to the PAR level. This ensures that there is never an excess amount of inventory [10]. This system can be graphically shown similarly to the FOQ system, however, it is more common to have a table of items with their respective PAR levels that could be managed manually through counting or through an inventory management software, like Oracle. PAR levels can be calculated using many different techniques. Most calculations, however, consider delivery schedules, demand, and average inventory levels are known. The actual calculation is based upon the average, minimum, and maximum usage rates as well as the variability in usage. Safety stock is also taken into account as this model is often applied to industries that may have a less predictable demand cycle. The most common equation for determining PAR levels is stated below.

$$\text{PAR} = (\text{Max Usage Rate} + 1) + Safety\ Stock \qquad (2.5.2.1)$$

The maximum usage rate is often determined by the user(s), a tracking software, or the intuition of the supply chain manager. This value is often expressed as items per day [16].

2.5.3. Kanban System

The Kanban system is a visual signaling system that can be used for work flows, process progress, or inventory levels. This system helps to schedule the stock so that it is only available when needed. This allows inventory levels to remain as low as possible to meet demand needs [8].

The procedure of signaling stock replenishment differentiates this inventory control method from the rest. The Kanban system can take many different forms. Erlanger Hospital use buckets to signal when a repurchase is necessary. For example, two buckets full of inventory items are held at Erlanger’s docking area and held until the inventory is requested to be delivered elsewhere. One bucket is slowly emptied as items are used. This empty bucket is traded for the second full bucket, but the empty bucket signals the supply chain management team to restock the empty bucket. This cycle continues as long as the inventory items continue being used [1].

This system allows customer demand to determine the need for materials. However, the supply chain management team must determine the optimum initial inventory level that is needed on hand to prevent stock outs. The team must also closely monitor the docking area for signals to replenish the inventory [8].

2.5.4. Just In Time (JIT)

JIT systems focus on reducing inefficiency and optimizing the production process with the ultimate goal to continuously improve the process and quality of the final product. This system, also referred to as lean production, relies on employee reliability and maintaining the minimum amount of stock to satisfy the production's demand. Originally conceived by Henry Ford in 1923, this model has often been used in industries outside of engineering to maximize efficiency by minimizing waste. This is often done by eliminating non-value added activities, thus improving overall productivity [11]. JIT systems can be implemented using various techniques. Below is a list of methods that can be implemented to reduce waste and improve manufacturing efficiency in accordance to JIT principles [18].

- Setup Time Reduction - Setup time is the time taken to adjust the machine to produce another type of product. It is the time between runs when the machine does not produce anything. Reducing setup time will increase machine productivity, decrease batch sizes, decrease lead times, decrease inventory levels, and increase the flexibility of the system.
- Uniform Plant Load – It is a goal to balance and coordinate the product flow where production rate is equivalent to the demand rate for the product. However, the production rate cannot be equal to the ability to produce. The production the finished product should be in time with the final demand rate and constrained only by bottlenecks within the process.
- Group Technology – In JIT systems, manufacturing facilities are laid out in work cells where it is organized by product instead of function. This allows for products to flow one at a time from machine to machine compared to the more traditional set up of batches moving from one operation to the next.

- Total Preventative Maintenance – Problems arise and shut downs will sometimes occur in manufacturing plants. When machines break or something goes awry, money and time is inevitably lost. The only way to mitigate these negative effects is to either predict or prevent failures. A total preventative maintenance (TPM) program of systematic inspection, detection, and prevention of failure in production and support equipment would help reduce the number of production delays or help predict and plan operating schedules and costs.
- Total Quality Control - The JIT prioritizes the elimination defects. Total quality control allows for existing defects to be removed while also preventing defects before they occur. In just-in-time systems, a manufacturer will not carry excess inventory to reduce the consequences of defective parts. This forces the manufacturer to solve quality problems before the process can continue.
- Employee Involvement – Without employee involvement, improving the system would be hindered. Employees, the ones experiencing the process first hand, are a vital source of ideas and suggestions of improvement throughout the company. Their input and compliance is critical in terms of quality, productivity, and design. Employee involvement is what can make or break a JIT system.

This principle, when applied to any system or industry, can help reduce cost and improve quality of whatever product is produced or service provided [11].

2.6. Inventory Management Improvement

There are six necessary elements to improve inventory management. Each of these elements are discussed below in a business context [12].

2.6.1. Top management commitment ensures that all lower levels of inventory management are working together to meet customer needs and company standards. Senior leadership has the oversight and ability to maintain the necessary inventory needed or invoke change if necessary.

2.6.2. *Performing an ABC analysis of all inventory items* allows the overall inventory to be managed more effectively and allow any leadership to stay more aware of the inventory on hand. ABC analysis is a form of categorizing the inventory based on demand. The A classification means that the item should be virtually 100% available at all times. These items often generate the highest profit or are deemed essential by the company and its customers. The B classification means it should be available most of the time for the customer, although it is not required at all times. C classification means it is a low demand item that doesn't need to be constantly stocked or kept on hand at all.

2.6.3. *Improved performance of other logistical activities* adds up and make a large overall impact. By performing reviews on transportation, order processing, warehouse functions, and other logistical steps, each can be analyzed and optimized individually. Then managers can focus on improving specific activities that could lower the need for inventory.

2.6.4. *Improved demand forecasting* allows inventory to be less variable in terms of expected versus actual sales. By predicting what inventory needs to be on hand helps to ensure inventory is used and is not over or understocked.

2.6.5. *Using an inventory management software* allows managers to track the inventory sales, costs, sitting time and analyze to offer points of improvement. In business or warehouse settings, inventory management software are often structured around some form of material requirement planning (MRP) or distribution requirement planning (DRP). MRP manages material and in-process inventory for production while DRP deals with finished product inventory. Together, these planning methods provide a precise control over material flow through the logistics systems.

2.6.6. *Postponement* involves modifying or customizing items after the manufacturing process is complete. Final configuration of products can be delayed as far as necessary.

2.7. The Human Element in Operations Management

Though technology is growing sophisticated enough for machines and robots to handle many operational and logistical processes, the human element of operations management cannot be ignored. When inventory management principles are taken from a highly automated process, like widget manufacturing, and adapted to a service industry, the most apparent difference is how involved humans are. An inventory management system can account for human nature so that it can function optimally. Key aspects of human nature and their impact on inventory management are described below [8].

2.7.1. People act according to their self-interest, therefore, people often need incentives to perform actions. Understanding and creating incentives that induce behavior that is overall productive could positively impact the inventory management system.

2.7.2. People differ. With different talents, interests, and motivations, different systems can be more or less successful with different workforces. Hiring the right team can directly affect how optimal an inventory management system is. With a good balance of backgrounds and aptitudes, a balanced team with a healthy dynamic is more likely to focus and reach their goal without burdening one individual or becoming distracted by tertiary issues.

2.7.3. Champions can have powerful positive and/or negative influences. Although leaders and experts are necessary and important, they hold the power to change systems for better and sometimes for worse. To control this, improvement initiatives should be reviewed and implemented pragmatically and incrementally. This allows the change to be monitored and analyzed to ensure it is as effective in the field as it was on paper.

2.7.4. There is a difference between planning and motivating. Using data regarding capacity, yield, or reliability for motivational purposes can be very effective in keeping the employees aware of their impact. However, it can be destructive if used to quantify burdens and stress. When data and statistics are used in excess, it can distract from the ultimate goal and turn ones focus toward reaching a number.

2.7.5. Responsibility must be proportionate with authority. As rapid, low work-in-progress manufacturing styles grow more popular, it becomes more important to provide managers with a level of authority that reflects their operational responsibility.

2.8. Inventory Management in the Hospital Industry

Healthcare providers do not have the same inventory management techniques as most other industries. As a service industry, hospitals can maintain a similar distribution chain as manufacturing companies, however, they require a much more complex inventory system. Demand forecasting for hospitals is extremely difficult to do with too much certainty as accidents and injuries do not occur in any stable pattern. Though there are known seasons that the medical community are aware of (trauma season, vacation/no-school season), things like weather is more difficult to predict long term and thus prepare for. Additionally, hospitals often carry a large variety of items that have a finite shelf life. To maintain health code standards, American hospitals must respect expiration dates and often have a specific disposal process for their inventory items [1]. The variability that comes with service industries and hospitals specifically means that the inventory management system must be unique to each application. Below are two examples of hospital inventory systems that used or a likened to manufacturing inventory principles.

2.8.1. USAF Eglin Hospital

The Air Command and Staff College at the Air University conducted a study of the impact of automated medical supply chain management system to save money in the Military Health System (MHS), specifically at Eglin Hospital. Originally Eglin

Hospital almost explicitly used a manual inventory management system that was based on a visual method. No algorithms, or mathematical processes were used. Instead, items were restocked when it was indicated on a community white board. For an item to be restocked, the unit's equipment custodian must see the whiteboard update and place the order. The unit equipment custodian is technically not responsible to be educated on supply chain or inventory management systems. Therefore responsible people are "oblivious to the underlying condition of their inventory management practices; and it is not a problem because there have been no adverse events pinpointed to lack of supplies" [13]. This study researched the impact of applying a more automated supply chain management system onto Eglin Hospital. Pyxis supply technology were the primary tool studied. The implementation of Pyxis technologies in 2012 Munroe Regional Hospital resulted in "$2.7 million in the first nine months" of its implementation [13]. Additional cases of Pyxis technology positively impacting hospital inventory management systems were presented to form an argument as to why it would positively impact Eglin. Pyxis is a "configurable supply technology consisting of programmed cabinetry and shelving units that enable perpetual inventory management and easy access to supplies" [13]. In other words, it is a machine that enforces the check-in/check-out system for specific inventory items, similar to a vending machine where unused items could be replaced back. This system tracks who is using the item, what items are being used, and the inventory level at all times. This helps to hold the users accountable if they need to replace an item and track who is using the most of what item. Pyxis units have been recorded to "reduced supply stock-outs, increased staff satisfaction that in turn decreased a number of calls unit managers were receiving due to supply stock-outs and enabled clinicians to focus more on patient care, and increased work/charge capture" [13]. Therefore, it appeared to be a very good solution to the inventory/ supply chain management system problems seen in Eglin. This paper proposes that by implementing the Pyxis system would help improve the system and provide reliable and efficient inventory asset-tracking.

2.8.2. *Institute for Healthcare Improvement*

The Institute for Healthcare Improvement has worked with more than 60 hospitals in the United States and the United Kingdom to implement JIT principles to improve the timely flow of patients through each hospital department [14]. Hospital performance is measured across a variety of dimensions: clinical, financial, operational, psychological (patient satisfaction) and societal. A hospital's clinical performance is often regarded as the most important to improve. However, for a hospital to function, a series of processes and operations much successfully occur. Tools must be readily available during a surgery, a doctor must be on time for a patient's appointment, and other processes must successfully take place for the system to operate smoothly. This operational performance can be practically measured and improved to positively affect a hospital overall. The manufacturing industry has optimized their operational performance through engineering process flows and devising solutions to delays and bottle-neck points. If one can understand that hospital services can be equated to manufacturing as they both "employ processes that add value to the basic inputs used to create [a] final product," then it becomes clear to implement engineering/manufacturing principles to improve a hospital's operational performance [5]. Table 1 equates manufacturing operations with hospital operations. This provides specific criteria where an engineer would play a critical role in designing and improving both manufacturing and healthcare systems.

Table 1: Comparison between manufacturing and healthcare production system [12]

Criteria	Manufacturing	Healthcare operations
Problems	Poor layout, size of factory. Long product cycle time. Excess inventories. Material handling. Eliminate/expose problems covered by inventory. Reduce inventory.	Poor layout, size of factory. Long service time. Excess inventories. Material handling. Eliminate/expose problems covered by inventory. Reduce inventory.
Objectives	Establish long-term supplier relationships. Involve workers in the quality cycle. Improved material handling. Reduced product cycle time.	Establish long-term supplier relationships. Involve workers in the quality cycle. Improved material handling. Reduced service time.
Quality	Involve workers in the quality cycle. Improved material handling. Reduced product cycle time.	Involve workers in the quality cycle. Improved material handling. Reduced service time.
output	Quality finished product.	Quality health service generated
JIT functional	All functional personnel(engineering, quality, purchasing, suppliers, workers	All functional personnel(medical, quality, purchasing, suppliers, workers)
storeroom	Incoming stores parts, components, subassemblies etc.	Incoming medicines, equipment's etc.
Type of purchase	Majority of purchases: repetitive, rebuys or modified rebuys.	Majority of purchases: repetitive, rebuys, or modified rebuys.

Any attempt to apply JIT to health production systems must also look at unique characteristics of health care production system.

3. Research Findings

Qualitative data regarding the system are discussed in the following sections. The current inventory management system used is broken down into its major processes: delivery, sorting and distribution, usage, tracking, and replenishment. Additionally, the inventory control system used for the suture inventory, PAR, is explained. Finally, the known problems with the system are defined. These issues are based upon interviews and personal observations taken while shadowing the supply chain management team.

3.1. Understanding the Current System

A team of four, headed by Shawn Lowe, manages the inventory system used in the Surgery Wing of Erlanger Hospital. Lowe is the Surgery Supply Chain Supervisor. This team is responsible for counting the current inventory and ensuring that the necessary items are replenished on time and are available for use.

Figure 5 below describes the current inventory process of sutures through the surgery wing. The black "X" shows the central delivery point in the Surgery Wing. From here, the inventory gets sorted and distributed to the suture room (blue box), and each of the specialties' individual inventories (green pentagon). The sutures in the suture room are available for nurses, medical technicians, and doctors to take as needed. These sutures are also used to stock the trees and carts (yellow circles). These trees and carts serve as movable stocks and are assigned to specific specialties. The specialties are responsible for the inventory usage on each of their trees, however, it is common for nurses to grab the tree that is nearest to them. Both the trees and carts are stocked when most convenient for the nurse or technicians. There are 30 trees that float across the surgery wing and 2 carts which are devoted for trauma and emergency surgeries. The capacities of the trees and carts can be found in Appendix.

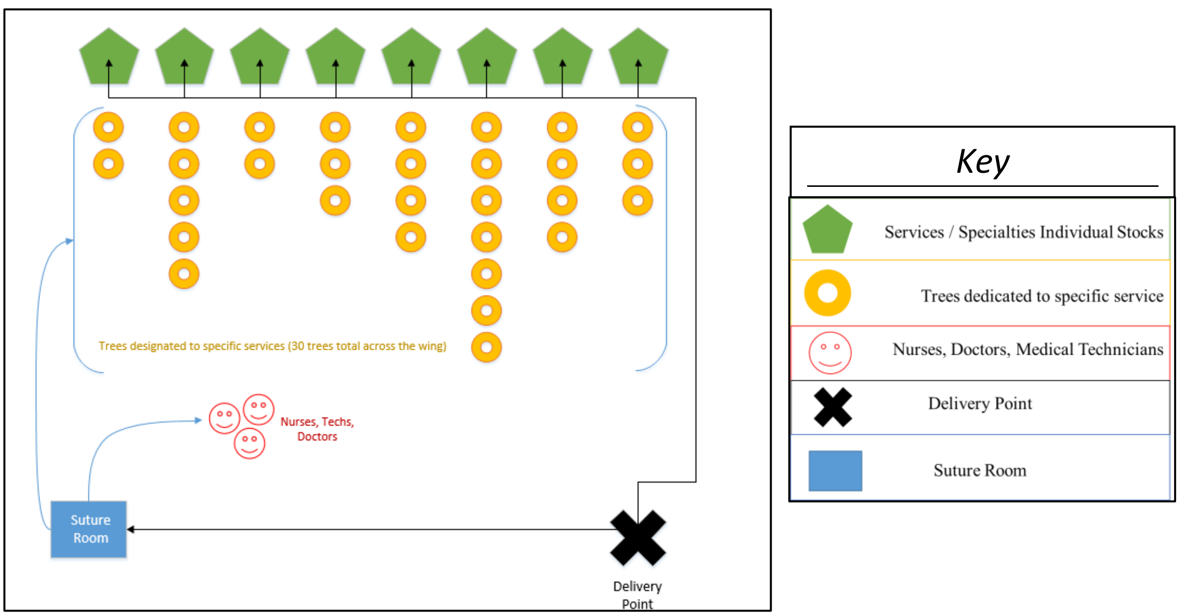


***Figure 5**: Flow of sutures across Surgery Wing*

3.1.1. Delivery

Sutures, and most inventory items, are initially delivered to a central location within Erlanger hospital: the dock. The dock consists of an unpacking area, holding area, and a discard/trash area. The unpacking area is where the goods initially arrive either from a warehouse in Knoxville or directly from the manufacturer. From here, the items are unpacked and placed into their designated place within the warehouse holding area. A Kanban inventory system is used with barcodes and manual monitoring to meet supply demands across the surgery wing and other areas of the hospital. Unfortunately, some items in the dock never get used. When this happens, there are two designated disposal areas: one for biological hazards and one for hardware. This separation ensures every item is either disposed of or donated appropriately. Tools like clamps, gloves, and sutures are donated to a local animal shelter, McKamey Animal Center. Erlanger does not receive any tax benefits for doing this.

3.1.2. Sorting and Distribution

Inventory items are delivered to a designated area for Lowe and his team to distribute through the surgery wing. First, Lowe and his team assign barcodes of varying colors for each of the items. The barcode color indicates whether the items were sourced from the warehouse or from a secondary manufacturer. This barcode, shown in Figure 6 below, is made and logged into the hospital system using Wasp © barcode software.

Figure 6 shows the general set up for inventory items across the surgery ring. Here, the inventory item is placed parallel to its barcode. When Lowe and his teams receives order requests from the nurses, the color of the barcodes help make communication more clear. By relaying the suture type and the color of the corresponding barcode, Lowe can quickly recognize where the item is sourced and can place an order without having to identify many other details.

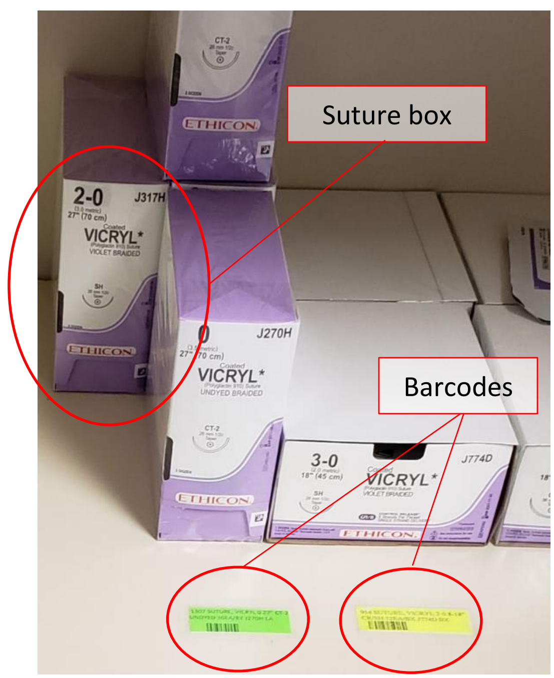


Figure 6: General inventory barcode system set up

A grand majority of the sutures delivered to the surgery wing are sorted into one central location: the suture room. Figure 7 shows the suture room where over 200 unique types of sutures are organized on shelves.

Although there are small stocks of sutures for each of the services across the surgery wing, this room is the largest and most popular stock of sutures. The trauma cart, a high capacity (<122 sutures boxes per cart) movable stock exclusively for the trauma emergency room, and trees, moveable stock (<72 suture boxes per tree) that are assigned to each service, get a majority of their items from the suture room. These trees and carts are manually stocked by nurses and assistants during off-peak hours of the day or between procedures.

Figure 7*: Suture room with various suture types organized on shelves.*

3.1.3. Usage

Sutures and most inventory items are considered used at the point of use. It is after this that these items can be billed to the patient and recorded by Erlanger's preferred healthcare software company, EPIC Systems Corporation. After the item is used, it can either be disposed, or sent to be autoclaved/sterilized. Most sutures, once used, are disposed.

3.1.4. Tracking

Once the inventory items are in their designated areas, Lowe and his team manually track the usage of each item using Oracle's PAR Location Management Software, a database management system. The Oracle's PAR Location Management Software is a part of the Oracle Inventory Management Cloud. This system uses cloud technology with a handheld scanner to manage the inventory and place orders when stock is running low. Lowe and his team go through the entire surgery wing to manually count the on-hand inventory twice a week. The handheld scanner utilizes a separate system called @PAR. This system allows the user to enter in an inventory count and associate it with a barcode. This barcode is unique to both the item and its location. The @PAR system records the inventory count and creates individual files for the Oracle software to create forms. The Oracle system tracks inventory use and sends out an order signal whenever the inventory drops below PAR. The Oracle software prevents over ordering by always ordering up to the PAR level. Therefore, in a perfect system, the minimum amount of inventory required, or the defined PAR level for that item, should never exceeded. The software also prevents duplicate orders.

3.1.5. Replenishment

Once the suture or inventory item is tracked to be below the PAR level by the Oracle software, the item is automatically ordered. Once the item order is placed, the Oracle system prevents any duplicate order requests until the shipment is received. Inventory items can be sourced from two major points: the warehouse or directly from the manufacturer. The lead time from the warehouse is 2-3 days while the lead time from the manufacturer varies. If warehouse items are ordered from the warehouse before 1 P.M., then they can arrive as early as the next day. The PAR level for each item accounts for their unique lead time to ensure that the inventory item arrives in time to meet the demand. The replenishment process is managed by Oracle as well.

3.2. Current Inventory Control System

The Periodic Automatic Replacement method of inventory control is designed to be used in small scale applications. Its implementation into Erlanger's inventory management system has be split between a manual counting system and a digital tracking system. Shawn and his team monitor the available inventory by manually counting them twice a week. This is performed at this specific rate due to the @PAR software. This software is programmed into a handheld scanner. A barcode corresponding with the inventory item is scanned and the number of available units (normally in terms of boxes or cases) is counted and entered into the scanner. The scanner takes this data and sends it to Oracle's People Soft PAR Location Management and Replenishment software. The Oracle software is loaded on Lowe and his team's desktop computer. This software tracks what is needed and places orders. To prevent duplicate orders, the Oracle system only accepts replenishment requests once, and does not allow another request until the order has arrived and re-logged in the system.

The PAR levels for each inventory item were originally estimated using equation in Section 2.5.1, but were ultimately set by doctors and nurses who most often used the items. Over the years, the PAR levels have been adjusted as the surgery wing dynamic naturally evolved and doctors come and go (doctors often have a preference for tools and items that they are more comfortable with, their personal preference heavily effects the rate of use for an item).

3.3. Known Problems with System

The primary issue of the current inventory system regarding sutures is that the items are expiring before used. Therefore, the hospital is investing money in these sutures to never gain a profit from them. The known causes of this issue are described below.

3.3.1. Human Nature

Lowe and his team understands that most of the expired sutures on the surgery wing are most likely caused by the forgetfulness and indolence of the hospital staff. As discussed in the literature review, it is human nature for people act according to their self-interest [8]. Regarding sutures, a very common item to use in the surgery wing, and how large the surgery wing is, it appears that nurses and doctors are more likely to leave any sutures not used during a procedure on the most convenient surface than to replace it from where it was taken. This leads to sutures being left in places they don’t belong, like inside drawers, on desks, and inside random cabinets. These are all areas where nurses and doctors are not likely to return to when they are in need of more sutures. When sutures are not replaced in their designated area, it is more likely for it to be forgotten. When they are forgotten, it is very likely that they are not touched again until they have expired.

In order to respect the unpredictability of surgical procedures, sutures must be constantly available and it is expected for the medical professionals to take an excess number of sutures to ensure they are well prepared. However, in in 2018, the surgery wing was responsible for $3,437.09 worth of unopened/ unused sutures.

3.3.2. Manual Tracking

As previously discussed, the current inventory management system is done by manually counting and using a software to regulate replenishment. This method is extremely laborious on Lowe and his team and it has lead much of the inventory management system to rely on their instincts. This has created a system that is extremely reliant on a limited number of individuals. These individuals, Lowe and his team, are all nurses by training who had adopted a role in supply chain management later in their career. Although they are the experts for the surgery wing inventory management, their roles have been based on extremely valuable experience. Therefore, it is very difficult for this team to grow or evolve, as they have defined their jobs and adapted to the peculiarities or Erlanger's surgery wing. Unfortunately, instinct and experience is difficult to quantify enough to clearly define points that could be improved. Also, having a manual tracking system that relies so heavily on humans can often lead to mistakes and miscommunications. This issue, however, has been partially addressed by the Oracle Software, as it prevents duplicate replenishment requests.

3.3.3. Product Evolution

In the near future, the suture manufactures will be changing the box orientation and the batch expiration patterns. As shown in Figure 3, suture boxes can be stored in a vertical or horizontal position. Instead of the orientation varying from type to type, most suture types will be manufactured to sit horizontally. This orientation inherently takes up more surface area, limiting the number that can fit on shelves, trees, and carts. Another issue this poses is the accessibility to individual suture packs, as the packs are not encouraged by gravity to the box opening, and the horizontal box requires more touches from the user, as they have a lid that must be lifted to access the packs.

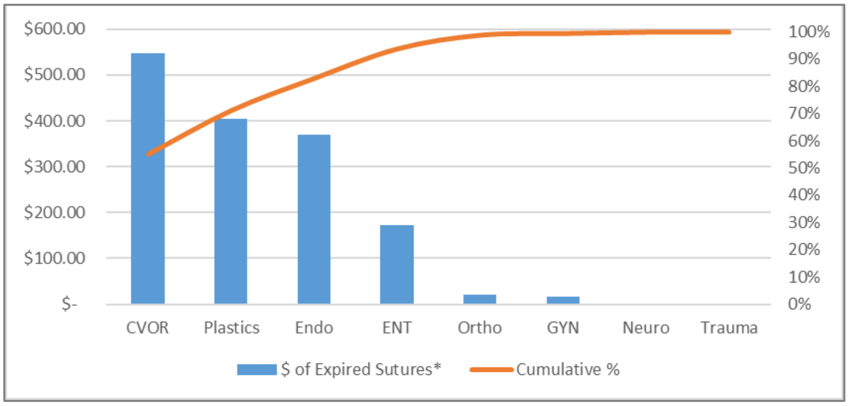
Up until this point, sutures had a 6 month lifespan. Most sutures either expired in early July or late January. This predictable pattern helped the surgery wing supply chain team plan and time major restocks and disposals. This pattern will become less predictable as the suture manufactures are moving to producing smaller batches that could expire at any time of the year. Without a predictable expiration pattern, it adds a complexity to the supply chain team's responsibilities as they need to ensure no expired sutures are available to be used.

4. Results and Discussion

Quantitative data and its significance is described below. The financial statistics of suture wastage due to expiration, the indicators to measure the health of the inventory management system are discussed. Finally, inventory usage was graphed over a three month span to show replenishment points. This data forms a clear image of the biggest contributors to suture wastage due to expiration.

4.1. Money Lost Due to Suture Expiration per Specialty / Service

Studying specifically the process flow of sutures across the surgery wing, it became clear that there is no way to quantifiably understand the physical movement of the item from delivery to disposal. However, the points within the process that can be tracked are delivery, items on-hand, and when an item is used. Also, due to the expiration cycle of the sutures, Lowe and his team goes through the surgery wing and records the expired items found. This information is recorded per specialty/service and brought together to determine the financial impact of the expired sutures. Figure 8 is a Pareto chart that describes the money lost in 2018 due to expired sutures per specialty. The data used to build this chart was taken manually and it was calculated that $3437.09 was lost. This figure shows that Cardiovascular Operating Room (CVOR) contributes the most at $548.34 lost. Plastic surgery contributes the second most with $401.28, and Endoscopy (Endo) procedures following at $370.06 lost. The Ear, Nose, and Throat (ENT), Orthopedic (Ortho), and Gynecology (GYN) surgical services also lost money due to expired sutures, however, their contribution can be neglected seeing their impact is not near as large in magnitude as the preceding services. The Neurology and Trauma services had no expired sutures found. This is most likely because they use many sutures through each procedure, causing a high turnover rate for their inventory.



Key	
CVOR	Cardiovascular Operating Room
Plastics	Plastics
Endo	Endoscopy
ENT	Ears, Nose & Throat
Ortho	Orthopedic
GYN	Gynecology
Neuro	Neurology
Trauma	Trauma

Figure 8*: Money lost due to expired sutures per service*

It should be noted that this data does not account for CVOR and Plastics being the two largest specialties in the surgery wing. This data can be scaled to how many procedures are done, however, it is considered sensitive information by Erlanger and cannot be distributed. It can be stated that the scaled data follows a very similar trend shown in Figure 8, therefore, it is clear that CVOR and Plastics are the biggest contributors to wasted sutures due to expiration [1].

4.2. Defining and Assessing the Key Performance Indicators for the System

Erlanger Hospital, among many other businesses, use Key Performance Indicators (KPIs) to easily and quickly monitor and track specific statistics that can impact the hospital as a whole. Table 2 shows the KPIs used by the head supply chain manager for inventory management and the state of the supply chain as of December 2018. Each of the indicators are classified as operational, and have a baseline value and target value generated by an in-house software and management team. The baseline values are the minimum value that is required to maintain hospital operations. The target values are the point in which the system is optimally operating. Target values present a goal for management to reach. Table 2 has specific KPIs for the warehouse, an off-site inventory storage unit, and surgical services, which pertains mainly to the Surgery Wing although this also supplies other area of the hospital.

The status for each of these indicators are represented by color. Green/Good means that the performance of that indicator is good, or within acceptable bounds. Yellow/Okay means that the performance of the indicator is either in or trending out of acceptable bounds. Direct action is not required, but the data for that specific indicator may become a problem in the near future. Red/Bad means that the performance is unacceptable or potentially damaging the system. This table shows that the inventory management is overall doing fairly well, however, the Days on-hand (Warehouse), Discrepancy % of Throughput, and Point of Use Compliance % are all in the red or yellow status. To remain within the scope of this study, the Discrepancy % of Throughput, and Point of Use Compliance % are the two indicators of interest.

***Table 2**: Erlanger Hospital Supply Chain Management Key Performance Indicators December 2018 [17]*

Inventory Managament		Indicator Type	Baseline	Actual	Target	Status
Inventory Turns (Warehouse Only)		Operational	17.63	26.63	>14	Good
Inventory Turns (Surgical Services Only)		Operational	4.5	15.73	>12	Good
Days on-hand (Warehouse Only)		Operational	21.2	13.71	20-25	Bad
Days on-hand (Surgical Services Only)		Operational	N/A	23.2	20-25	Good
Discrepancy % of Throughput		Operational	7%	51%	<1%	Bad
Point of Use Compliance %* (Null Transactions)		Operational	13%	87%	>95%	Okay
**Assemsment Baseline identified technilogy errors wich were consequently repaired.*						

Discrepancy % of Throughput indicates how much of the inventory was recorded as used and how much of the inventory was actually used. This data is exclusively recorded for the hospital's inventory dispensary system. The system is similar to the Pyxis system discussed in section 2.8.1 of the Literature Review except it has a door that can be opened or closed by the user. According to the Table, 51% of the inventory that is dispensed by the system is not recorded to have exited the system at. This discrepancy most likely exists due to the user taking more than what they entered. For example, a nurse or medical technician may enter in that they need one needle, which will unlock the door. However, when the door is opened, the person takes multiple needles and closes the door. There is no internal tracking system within the dispensary machine. It completely relies on the user's honesty. Erlanger's inventory dispensary machine normally does not hold sutures, however, it holds similar commonly used items. This KPI indirectly measures the merit of human nature, therefore, it provides insight to how the hospital employees regard inventory items. It also shows how it is common to not know how many inventory items are needed during a procedure. It is much more logical to take more than what is needed to be well prepared.

Point of use Compliance % is the measurement of how many people return the items they checked out compared to the number of items actually checked out of the dispensary system. Table 2 shows that this KPI is under the yellow/Okay status, therefore, it is trending negatively. At 87%, this metric is still close enough to the target value of >95%. However, this metric shows that there is an issue of medical employees replacing the items taken from the dispensary. Physical observation of this system and interviews regarding the system revealed that it is very common for nurses, medical technicians, and doctors to bring the items back to the machine, but fail to return the item to the machine after use. This is most likely because it takes time to enter in the required information to replace an item. As discussed in the literature review, it is human nature to act in personal interest. Time is not often a commodity on the surgery wing, therefore, it is rather inconvenient and a sacrifice for medical professionals to give their time to a machine that doesn’t directly impact them.

4.3. Analysis of Suture Usage Trends

Usage data that is manually entered into the @PAR system and recorded in the Oracle PAR Location Management and Replenishment Software is normally not available to the supply chain management team for the surgery wing. Due to the turbulent nature inventory demand and the great variety of inventory in a hospital, it is often not useful to model inventory usage. In addition to the complexity of inventory usage for hospital inventory items, there are 264 unique suture types used in the surgery wing alone. This would result in 264 unique inventory usage models which could be further broken into more if the storage location of the sutures were taken into account. Figure 9 and 10 are graphs of the inventory usage trends over a three month period. This suture, Vicryl 2-0 8-18” UNDYED (JD39D), is stored in the suture room and is kept at a PAR level of 5 boxes. Each of these boxes hold 17 sutures packets. Therefore, when the inventory is at PAR, there are a total of 85 suture packets on hand. The blue, or bottom line in both Figures show the inventory level, in boxes. This line peaks at 5, since that is the PAR level. In The orange/upper line in Figure 9 is the shows for the number of items left in the opened boxes. This data is what Lowe and his team manually tracked to determine how soon a replenishment order many need to come. In Figure 10, the green/upper line is the trend line for the total number of suture packets on hand. The vertical, dotted, purple lines are the points where a replenishment order was placed.

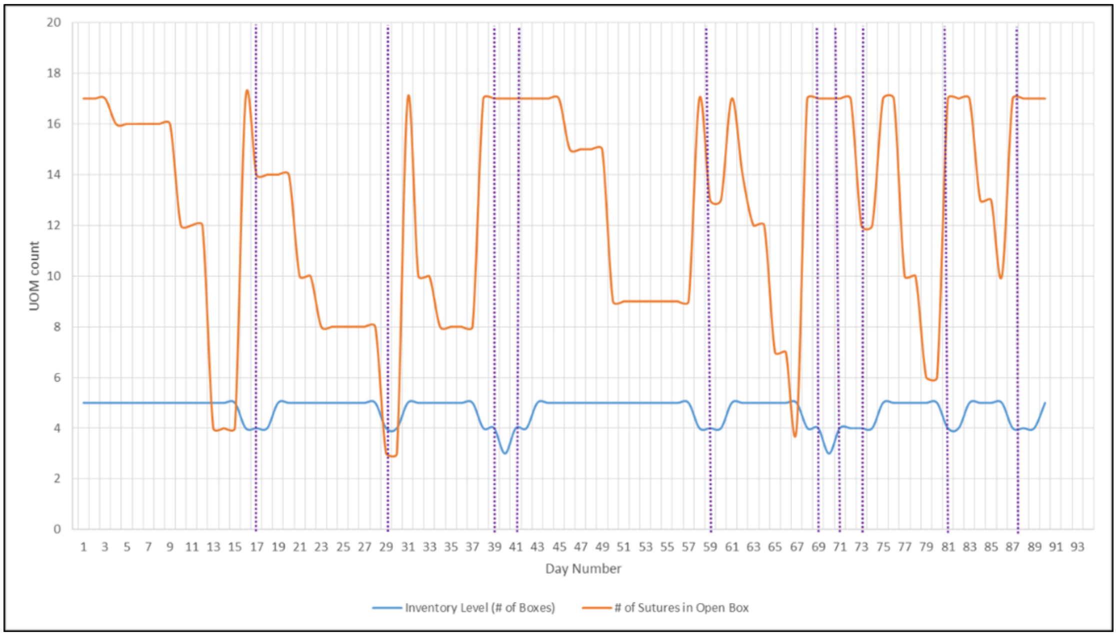


Figure 9: *Inventory Usage Graph, Available Inventory and Inventory Level*

The trends shown in Figure 9 appear to be rather insignificant. The count of sutures available in an open box is does not directly correlate with the inventory level or the replenishment points. Figure 10 shows a direct correlation between inventory level and total number of suture packs. Figure 10 shows a direct correlation between inventory level and total number of suture packs. For both of these figures, each data point was taken or based upon Lowe's and his team's manual count every two to three days. As the graph reflects, the suture usage is unpredictable and can drastically change within a very short time frame. Therefore, the tracking rate that is maintained on the surgery wing is justified and necessary to ensure there are no stock outs.

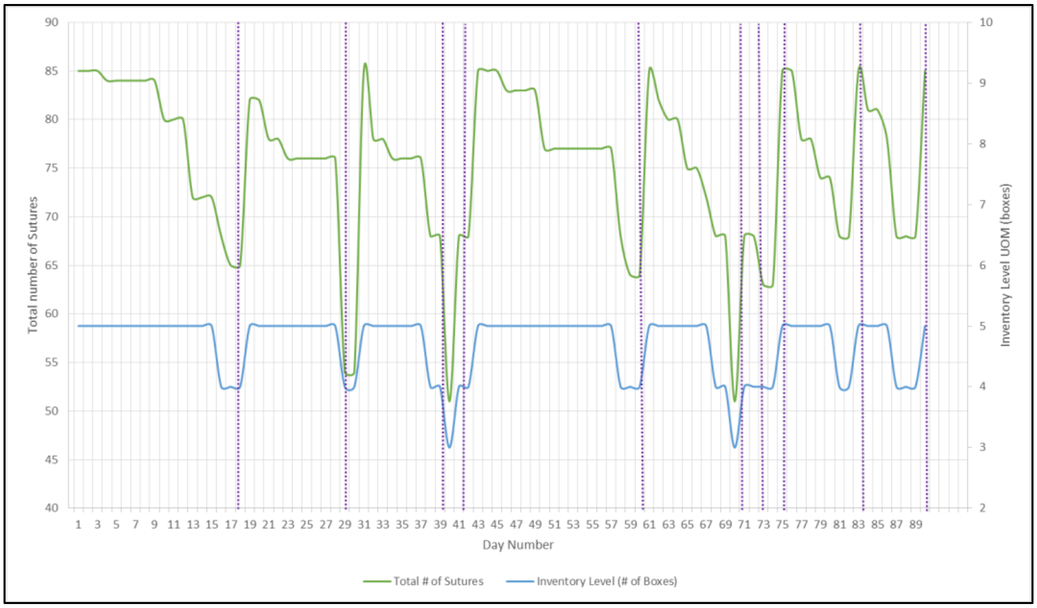


Figure 10: *Inventory Usage Graph, Total Number of Sutures, Inventory Level*

When an order is placed, the Oracle Inventory Management System is programmed to only order up to the PAR level, nothing more. Both Figures show from Day 68 to Day 72, three orders were placed but the inventory did not reach PAR until Day 76. Within these 3 consecutive orders, only 2 of the orders went through. This is because the Oracle Inventory Management System prevents duplicate replenishment requests until the order is registered to have arrived at the surgery wing. This data shows that the suture type never exceeds the PAR level and technically never could with the Oracle System. However, from interviews, on-site observations, and the data shown in the Figures, it is clear that this is not the case.

5. Recommendations

Four primary points that could help reduce the amount of money lost due to suture expirations are discussed below. These points address (1) tracking the expiration dates of each batch of sutures, (2) more effectively accounting for human nature in the inventory management system, (3) designing ways to make the current tracking system more efficient, and (4) forecasting demand more effectively.

5.1. Tracking Expiration Dates

Tracking the expiration date itself using an alternate inventory management software or technique. For example, expiration dates could be tracked manually. Adding an additional process of recording the expiration date once a batch of sutures arrive at the surgery wing may be useful if entered into a database that could signal Lowe and his team when a specific suture expires. Another option is to use the current inventory management software, Oracle's PeopleSoft Inventory software package. This software package has many functions to track inventory, one including lot management. A lot is "a quantity of inventory items produced as a group or otherwise collected into an identifiable unit" [15]. This is commonly used in manufacturing industries where items have a limited window of use, where the availability date and expiration date is defined. The lot management software tracks the life cycle of the lot, from arrival time to use or expiration. It also tracks when the item reaches various checkpoints [15]. This software function requires the manual entry of expiration dates and other information for each suture type. In the surgery wing, the availability date of the item would be the day it arrives on the surgery wing and the manufacturer would give the expiration date. Once the software is set up, the software system would warn the user when the item is nearing or past its expiration date. This system would not lessen the burden of Lowe and his team, as they will still have to manually track the inventory. It will simply provide a system to alert when items are going to expire. However, it is unclear how compatible the Oracle lot management software function is with the existing Oracle PAR Location Management and Replenishment System.

Additional control systems, like Arbimed Medical inventory management software package, could replace the Oracle software package. This system similarly operates using the PAR inventory control system and a handheld barcode scanner. It also specifically tracks expiration dates [10]. This software package, however, operates by tracking transactions. All transactions are recorded by EPIC, a privately held healthcare data management system. This information is considered sensitive as Erlanger directly ties procedure information with the patient is was performed on. Investing the Arbimed system to track sensitive information that is already managed by an external company is not easily justified. Implementing this system will have a high upfront cost and training requirements. There is also a high likelihood of integration issues as Erlanger currently uses multiple inventory management software packages that perform similar functions as the Arbimed system. Understanding this, Erlanger could not logically implement the Arbimed system without having a well-developed plan and confidence that the benefits are worth the overall invenstment.

5.2. Accounting for Human Nature

Another point that could be approved is addressing and accounting for human nature regarding inventory use. One of the biggest contributors to suture wastage due to expiration is the suture not returning to its designated spot after it is removed. This issue can be contributed to human nature, as it is the nurse's or medical technician's responsibility to return unused sutures back to its designated stocking area. The process or returning a suture to its stocking area is often not convenient. A physical or mechanical system can be implemented to make this process simpler for hospital professionals. Although Erlanger currently uses a dispensing device, as discussed in Section 4.2 in the Results and Discussion, there are issues with the system accounting for or addressing the fact that nurses and technicians take more than they indicate and often do not replace the items they do not end up using. The human dynamic varies from hospital to hospital, so a commercial device, like the Pyxis system described in the Literature Review, may not be the best fix for Erlanger. However, it could be beneficial if the inventory management system could be altered to more effectively count the number of items on hand or track the individuals who have checked an item out. For example, a check-in/out machine or device could have an internal counting system using light sensors to detect distance. The distance from the sensor to the item would either increase or decrease when an item is removed or replaced. Another way of detecting this within the system is by using scales and the known weight of the items. When the weight fluctuates, the system is signaled that an item is removed or replaced. Depending on the sensors sensitivity, both the light and weight sensor could measure changes so accurately it can correlate to the exact number of items taken or replaced. Using a check-in/out system like Pyxis, however, would require a high up-front cost.

Another potential solution for holding the user more accountable for the items they take is to monitor the suture room. The suture room sees a lot of traffic of medical professionals going in and out. By adding a locked door requiring an access code or card would help monitor who is entering the suture room without obligating the user to do anything out of the ordinary. This system could additionally track what items are being taken by placing a unique identifier on each suture type for the user to key in, or scan upon exiting the room. However, this additional process may be very effective in tracking the sutures and who is using them, Lowe and his team to modify their current distribution process to include the creation and placement of a barcode or ID code on each suture type to be scanned or keyed in. The manufacturer's barcode could be used to track; however, it is unlikely the barcoding system used can recognize codes from external companies. Therefore, it will require more time and effort from Lowe and his team.

Counting the items on hand more effectively would reduce the Discrepancy % Throughput KPI value to a more acceptable level. Also, in tracking those who check the item out, the user will be held more accountable. A dispensary device would be useful for many inventory items, but for sutures, a high volume and commonly used tool, it would me more logical to implement a tool to track which specialty uses the most sutures per inventory location. This information could be used to shift certain inventory levels to be higher or lower depending on how commonly they are used. Knowing where the most and least sutures are taken could reduce the number of sutures left unused until expiration and possibly address areas that have shortages in their suture inventory.

5.3. Designing more Efficient Tracking Process

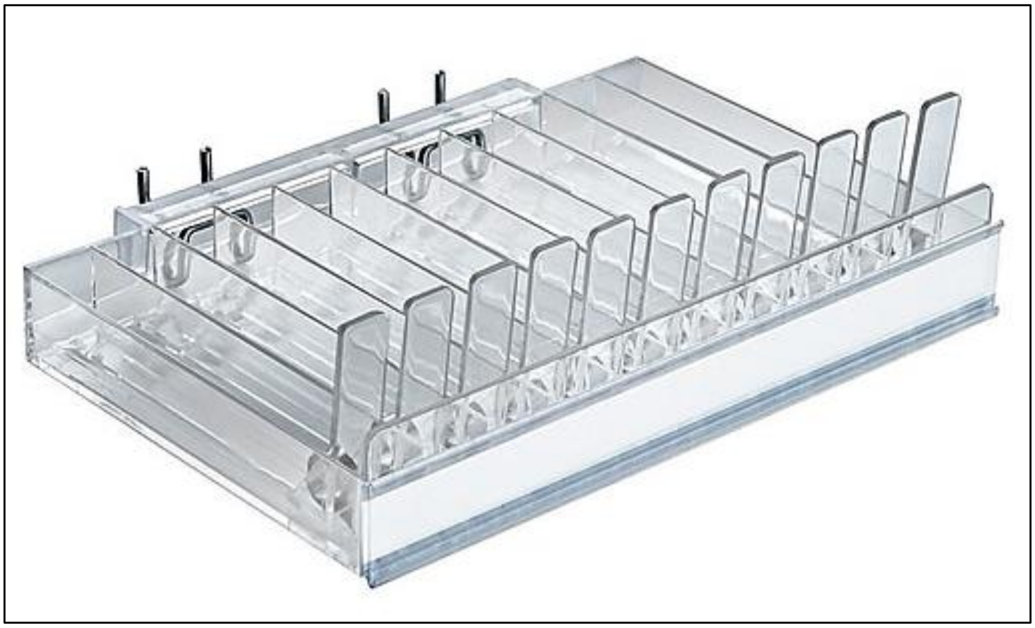


Figure 11*: Auto-feeder Pusher System [19]*

It is recommended to simplify the manual tracking process across the surgery wing's inventory. It is difficult to fully eliminate as it is how the inventory management system of the surgery wing has operated for years. An issue with this system is that it is heavily influenced by experience and instinct. It would be very difficult for anyone but the surgery wing's supply chain management team to monitor and track the on-hand inventory. To simplify this process, a future design team could create a device to conveniently display the on hand inventory count. For example, an auto-feed pusher system, shown in Figure 11, is often used in grocery stores to prevent items being stuck in the back of the shelf. Applying this system to suture inventory, a set number of boxes that fit in the pusher system. Ideally, this number will be the PAR level. Once the boxes are placed in the pusher system, the number of boxes per column can be set on an analog counter. As items are used, and a suture box is eventually removed, the device pushes the next box forward. This movement could be tied to a counter, thus updates the count of inventory. Inventory space in the surgery wing is limited. Therefore, this system must be modular to fit on various shelf sizes and take up little additional space.

With a counter displaying the inventory level for each suture type, Lowe and his team would be able to track the on-hand inventory by a quick glance. This would make the counting process quicker. This device could also be adapted to fit on the trees and carts to better track the inventory kept on the trees and carts.

5.4. Forecasting Inventory Demands

Finally, if one were to conduct more research over a much longer span of time, a model to help forecast inventory demands could be developed. In Section 2.8, the difficulties of using predictive modeling in the hospital industry was discussed. However, there are advantages to identify and quantify the trends known across the medical community like trauma season, and academic break cycles. Understanding these trends could aid in more accurately ordering inventory during this time and timing inventory replenishments with more accuracy to ensure there is no overstocking.

6. Conclusion and Future Work

It is recorded in many cases that engineering and manufacturing principles can improve a non-engineering/manufacturing process. Some inventory control systems they fail to adequately address the human element of inventory management and other issues prevalent in the hospital industry. As discussed in the literature review, inventory control systems like FOQ require a level of predictability and mostly known variables. JIT would be best applied across the supply chain management system to control the process from supplier to use. Applying JIT principles specifically to the suture inventory could be more difficult due to how unpredictable the usage trends of the various suture types as shown in Section 4.3, Figures 9 and 10. The Kanban inventory control system applied to the suture inventory could be successful in clearly signaling Lowe and his team when inventory is low or out, however, it may not directly address suture wastage due to expiration. The Kanban system aids in tracking the on hand inventory more efficiently, but not more accurately. As previously discussed in in Section 3.3.2 and 5.3, more efficiently tracking sutures simplifies Lowe’s and his team’s job of manually tracking the on-hand inventory in the hospital. However, without accurate data, it is difficult to clearly identify points in the inventory management system that can be improved. Monitoring and tracking inventory levels closely allow for Lowe and his team to modify inventory levels as the demands change and surgery wing staff evolve.

However, the signaling element of the Kanban system could be very useful if applied to an inventory item approaching their expiration. The PAR inventory control system, which is currently used for suture inventory on the surgery wing, appears to be the best way to manage the suture inventory. PAR is a flexible inventory control system that requires constant tracking. However, this tracking ensures that information is kept up to date and accurately reflects the inventory usage, regardless of how turbulent it may become. Also, the PAR system is easily applied to inventory items that vary and are kept in large quantities since PAR levels are often assigned to an individual inventory type. Addressing the wastage of sutures due to expiration would be most easily done through the PAR inventory control system, however, elements of JIT and the Kanban system could also help. Engineering and manufacturing principles are very effective in improving processes within the hospital inventory. It is key, however, that these principles are adapted accordingly to the service industry to account for unpredictable schedules, human interaction, and inventory diversity.

Perfect machines, control systems, and processes can be designed and created, however, the user will always be a primary source of error and fault. The current inventory control system in the surgery wing heavily relies on the assumption that their system is ideal and the users will comply with the tools and machines already implemented. Although the reality of the system and its faults are known, they are not addressed or accounted for in the current system. Instead the system's nuisances are almost exclusively known by the supply chain management team. Therefore, the system is extremely dependent on the team's intuition and understanding of the surgery wing's activity. To address this, the system may not need to be drastically changed, but instead streamlined in accordance to the six elements recommended to improve inventory management as discussed in Section 2.6 of the Literature Review. Erlanger already implements many of these elements, but there are opportunities to focus and streamline the system they already have. For example, it may be worthwhile to educate the main supply chain management staff, and the majority of the medical professionals who work in the surgery wing about the supply chain and inventory management systems used at Erlanger, specifically in the surgery wing. Ensuring that the surgery wing population are aware of the inventory management issues and the initiatives focused on improving the system, the community could be more inclined on furthering and encouraging these efforts, especially if there is an incentive for them. The education of the leaders in each specialty and earning their commitment to improvement would also help make the system better.

In the future, the recommendations made in Section 5 would need further research and development. A design team could develop prototypes of the mentioned devices and propose them to Erlanger's supply chain management team. The software packages recommended would also have to be further researched. It would be most beneficial to directly contact the software providers to determine the capabilities and adaptability for hospital operations. From this point, a cost-benefit analysis is needed to determine the positive effect the devices or software packages may have. Later, the device or software could be tested for a discrete amount of time to clearly define whether or not a large scale implementation would reduce the number of sutures wasted due to expiration.

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Appendix

Table 3: General information regarding surgery wing services / specialties

Specialties/ Services	# OF ROOMS
ENDO	2
UROLOGY	1
GYN	3
NEURO	2
ORTHO	2
ENT/PLASTIC	4
GV	2
CHILDRENS	4
CENTRAL	1
Total # of Rooms:	*21*
Total Number of Services:	9

Specialties/ Services	# OF TREES
ENT	2
Plastics	5
CVOR	1
GYN	3
Ortho	4
GV	7
Neuro	4
Endo	4
# Trees per Service	*30*

Table 4: General suture and stock room information

SUTURE STOCK ROOM		
# of suture types:	244	
Size of room:	5x12'	
GENERAL STOCK ROOMS		
# of rooms:	18	
TREES (movable stock sources)		
# of trees:	30	
# of boxes per tree:	72	maximum
TRAUMA CART (movable stock sources)		
# of carts:	2	
# of boxes per cart:	112	maximum
Size of suture box:	5.5 x 6.5"	

Table 5: Suture Data per Specialty / Service

	Trauma Cart	ENT 1	ENT 2	Plastics (Breast)	Plastics (Hand)	Plastics (Breast Wound)	Plastics (Craniofacial)
# of Unique Types of Suture:	123	57	62	59	37	58	49
Total # of Sutures:	2013	1468	1495	1198	709	1166	1088
Financial Worth:	$ 7,274.81	$ 5,181.78	$ 5,035.30	$ -	$ 5,559.53	$ -	3955.28
$ of Expired Sutures (2018):	$ -	605.27					

	CVOR	Robot GYN Urology	GYN 1	Ortho 1	Ortho 2	Ortho 3	Ortho 4
# of Unique Types of Suture:	31	58	55	33	31	32	32
Total # of Sutures:	533	875	842	662	477	634	567
Financial Worth:	$ 1,327.64	$ -	$ -	$ -	$ -	$ -	$ -
$ of Expired Sutures (2018):	$ 548.34	$ 16.85		$ 21.00			

	Room 21	Neuro 1	Neuro 2	Neuro 3	Neuro 4	Endo 1	Endo Vascular
# of Unique Types of Suture:	71	37	38	27	25	45	46
Total # of Sutures:	868	534	391	378	364	1223	1175
Financial Worth:	0	0	0	0	0	0	0
$ of Expired Sutures (2018):	?	$ -				$ 370.06	

	GV	GV 1	GV 2	GV 3	GV 4	GV 5
# of Unique Types of Suture:	59	48	53	51	53	46
Total # of Sutures:	817	723	668	650	662	697
Financial Worth:	0	0	0	0	0	0
$ of Expired Sutures (2018):	$ 1,875.57					

Total $ Expired : $ 3,437.09