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Inventory Optimization: A Case Study at the Emergency Department in a Lebanese Academic Medical Center

By

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Dedication

This thesis work is dedicated to my husband, Jalal, and my children, Sofia and Catherine. I give my deepest expression of love and appreciation for the encouragement that you gave and the sacrifices you made during this graduate program. I am truly thankful for having you in my life.
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Inventory Optimization: A Case Study at the Emergency Department in a Lebanese Academic Medical Center

Karina Indus

ABSTRACT

This research examines the various problems in consumable inventory management within an Emergency Department (ED) of the Lebanese Academic Medical Center (LAMC). Specifically, this research supports understanding how the implementation of lean tools and quantity models can change daily operations in the inventory management of an ED. This case study has two general objectives 1) to clean and redesign the stock room and 2) develop a proper order policy. Relatedly, the ABC and 5S methods were used to meet the first objective and the quantity models, EOQ and (R, s, S), were used for the second objective. Specifically within the ABC analysis, two categorization variables (value and use) were used. In developing the order quantity policy, four models were examined and a full cost analysis was performed for each. In the end, the periodic review policy with fixed reorder period was selected and tested in the field. The chosen policy proved to be efficient relative to the ED situation prior to the implementation of the selected policy. The efficiency was measured via survey with all relevant ED employees.

Keywords: Inventory, Policy Creation, ABC Categorization, EOQ, Periodic Review Reorder Policy, 5S tools.
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Chapter One

Introduction

Health care costs have increased over the years. A significant part of these costs is the inventory component. Improving healthcare inventory management is crucial not only because of the financial scale but also because the availability of the supplies are critical to patient care (Evans, 2017). The key issues for the material managers in the hospital setting is the identification of effective strategies to improve inventory availability, while decreasing the costs. Previous studies done in Emergency Departments (ED) demonstrate efficiency gains associated with inventory optimization techniques. However, the majority of recent research done in the healthcare sector was based on pharmaceutical products rather than on consumables.

In the literature, the document Optimizing Healthcare Supply Management (2012) describes a typical problem in the ED: a patient admitted to the ED needs immediate care, but the clinical staff cannot find the items in their places or the items are out of stock. In response to this event, the staff members, in order to avoid future shortages, replenish the items in high quantities and stock it in cupboards, supply closets, and storage carts without informing others on the team. Ultimately, the piles of supplies are “hidden” and inventory costs increase.

This research is a study in the optimization of consumable inventory within an ED of a Lebanese Academic Medical Center (LAMC). The ED is a facility that specializes in emergency medical services. It deals with acute care patients who come to the hospital without prior appointment by their own means or by an ambulance. The inventory under study is located in the stock room of the ED. When the ED stock room was initially approached for the study, managers of the hospital had established fixed reorder policies. Therefore, this study is concentrated on optimizing the stockroom layout and order quantity, highlighting further operational improvements as part of a consumable inventory management framework.
The thesis is organized as follows: A comprehensive literature review is presented in Chapter Two that focuses on lean tools, ABC analysis, and inventory ordering policies as applied in the given case study. The detailed study methodology is presented in Chapter Three, and an optimal reorder policy is designed in Chapter Four along with explanations for all of the possible inventory models. Chapter Five focusses on the results of the case study. Chapter Six contains the conclusion of the study and recommendations for future research. Figure 1 contains an overview of the study. The numbers represent the sections of the thesis in which the related information is presented. Finally, the left column specifies the methodological tools used, and the right column specifies the outcome of those tools.

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Figure 1: Overview of the study
Chapter Two

Literature Review

This chapter provides background on the application of inventory optimization methods within the healthcare industry. The literature review starts with an overview of standard organizational structures within a hospital and the role of the ED in a hospital is explained. The subsequent section details the functions of inventory in operations and provides an overview of inventory flow in a hospital. A follow-on section covers a literature review on the ABC categorization method, the 5S workplace organization tool, and order quantity methods. In conclusion, the review moves from theories of stockroom layout to a review of inventory control tools with a focus on order quantity models.

2.1 Overview of the organizational structure of a hospital

The organizational structure of hospitals varies in size and complexity. Figure 2 represents a traditional organizational chart of a hospital by services and departments. Hospital administration oversees the departments within the hospital, budgeting and finance, and establishes policies and procedures. Informational services are responsible for documents and process information. This administrative unit checks in patients to the hospital, bills patients for services, and is responsible for recruiting and hiring employees. The departments listed under therapeutic services are responsible for the treatment of patients. The hospital receives support services from central supply, biomedical technology, housekeeping, maintenance, and transportation departments. The central supply department includes material management and pharmacy sub-departments. Diagnostic services are provided by a medical laboratory, imaging, emergency medicine, cardiology, and neurology departments (Garber, 1995).
"The ED serves as a hub for prehospital emergency medical systems, an acute diagnostic and treatment center, a primary safety net, and for 24/7 quick patient admission" (Schuur & Venkatesh, 2012, p 391). According to Tang, Stein, Hsia, Maselli, and Gonzales (2010), the admission of the patients to US hospitals through the ED increased by 50.4% for the period from 1997 to 2007. Another study performed by Storrow et al. (2014) showed that overall 83.7% from the average of 958,167 visitors in the United States were admitted to the hospital through the ED for the period from 2006 to 2010. Schuur and Venkatesh (2012) explained that the reason for the increase of admitting patients with all conditions is that the emergency doctors are more likely to admit patients with controversial diagnoses, and they are unwilling to discharge patients when they cannot follow up on the patient. In the majority of cases, this is a life-saving experience. Also, a large US national survey found that it is problematic for patients to arrange a timely sick visit with family doctors or specialists because their schedules are often full (Schuur & Venkatesh, 2012).

The variable nature of patient flow to the ED makes inventory management difficult. Furthermore, the time required to properly manage inventories in the ED can be an obstacle in delivering high quality healthcare services.
2.2 Inventory in a hospital

Inventory is the most significant and expensive asset in many companies. Sometimes, it represents a great portion of a company’s assets (Ravinder & Misra, 2014). About 30% of the annual hospital budget is spent on buying supplies and materials, including pharmaceuticals (Anand, Ingle, Kishore, & Kumar, 2013). Well-established inventory management reduces the costs related to inventory ordering and holding. One way to save on costs is to decrease available inventory levels in stock. However, by minimizing inventory on hand, hospitals might face stock-outs that lead to customer dissatisfaction. To avoid customer dissatisfaction, medical centers have to work on creating a strong supply chain and ordering policy (Kros & Brown, 2013). Moreover, hospitals can manipulate the cost by receiving quantity discounts. Whenever healthcare units order a stockpile of a particular material, it benefit not only from quantity discounts but also protect itself from uncertainty in the supply chain that can create stock-outs (Nahmias & Cheng, 2009). In other words, the aim of inventory management is to have sufficient inventory while minimizing the costs associated with purchasing and holding inventory.

Maintaining a clear and efficient inventory flow in the hospital is critical. At each stage of the inventory flow, active managers implement inventory control methods to decrease associated costs. As depicted in Figure 3, the inventory flow starts from a vendor. The hospital deals with a variety of suppliers to secure sufficient inventory. A central supply department receives supply and distributes materials to material management and pharmacy sub-departments. The emergency department sends a replenishment order to the sub-departments. When the inventory is received, the material is stored in the ED stock points. A portion of the inventory is stocked at points of use such as patients’ rooms where the end user (patient) receives emergency care services.

The emergency department has two types of inventory: pharmaceuticals and consumables. The inventory in the ED plays a major role in the primary diagnosis, trauma care, and initial treatment. Having sufficient and complete stock guarantees timely treatment and correct diagnosis.
2.3 Stockroom layout

To create an efficient layout of a storeroom, managers must be confident that the amount of inventory is accurate. As the accurate amount of the inventory is known, the distribution of the stock is planned to meet the capacity of the storeroom. Fixing the items within the location leads to the efficient layout. Then, if they can validate the accuracy of the stock, costs are reduced. Since the costs created in the ED consist not only of the cost of supplies but also from time wasted looking for products, duplication of procedures, and others. Therefore, by validating the accuracy of stock, the waste is minimized. In next part of the literature review, the ABC categorization method and 5S workplace organization tool are discussed. The ABC method facilitates adequate storage of materials in the stock point. Moreover, for accommodation in inventory flows and design of the stockroom layout, the ABC method can be used separately or combined with a lean tool such as 5S. Both of these methods were applied in the following case study on the optimization of consumable inventory within the ED of LAMC. Thus, a detailed explanation of these tools with examples of applications in healthcare follows.

2.3.1 ABC analysis

ABC analysis requires dividing the stock keeping units into A, B, and C categories. Dependent on the categorization, different stock placements and policies are established. The A group inventory is considered the most critical and valuable to the
functions of the organization. The A group items represent a significant amount of money, 70-75% of the dollar value of total inventory and about 20% of items in inventory. Therefore, these inventories must be carefully monitored. Then, the B group is important but not critical for the company operations. In turn, the B items are 20% of dollar value and 20-30% of total inventory. Thus, not all items in the group must be closely monitored. The last C group represents the least valuable inventory. Generally, items in the C group denote only about 10% of the monetary value of the business but may constitute 70% of items in inventory. As well, the categorization can be made accordingly to the revenue contribution of the items (Dhoka & Lokeswara Choudary, 2013; Kros & Brown, 2013; Ravinder & Misra, 2014).

ABC analysis is a widely used technique. From a theoretical point of view, this classification is based on the Pareto principle. That is a simple technique for prioritizing problem-solving work. The Pareto principle states that 80% of problems may be caused by as few as 20% of cases (Syntetos, Keyes, & Babi, 2009). For the last 30 years, there has been an accumulation of research questioning the use of the single criteria, which is dollar value, for making the categorization of products. The researchers Flores and Whybark (1987) proposed to take into consideration more than one criteria in ABC analysis. Among these are price, value, substitutability, criticality, the number of suppliers, availability, the likelihood of spoilage or obsolescence, predictability, and weight (Ravinder & Misra, 2014). According to the study of Dhoka and Lokeswara Choudary (2013), the analysis of different time periods results in different items in each category. The researchers highlighted that before ABC analysis is done, the need for the analysis has to be studied. If forecasting and planning of ABC analysis were not done properly, it may lead to serious inventory shortages or excess of available inventory that results in loss of revenue (Kros & Brown, 2013).

Inventory has quantitative and qualitative characteristics. Therefore, some weighing must be done before performing the analysis. Many researchers use subjective weighting and rating. In the Analytic Hierarchy Process (AHP), the weighted score is calculated by comparison of the criteria to the overall objective (Flores, Olsen, & Dorai, 1992; Kabir, Hasin, & Khondokar, 2011).
In addition, researchers used linear optimization analysis to determine the weights of the inventory for ABC analysis (Zhou & Fan, 2007). The researchers offered different methods of the linear optimizer. At the end of the process, each item was given a score that can be used in ABC analysis. Moreover, with the growth of new technologies, clustering, genetic algorithms, and neural networks became available for ABC analysis. These methods rely on artificial intelligence and data mining techniques (Ravinder & Misra, 2014).

Usually, these methods start with a training model that was developed by managers familiar with an ABC criteria. The benefit of artificial intelligence is that it simultaneously takes into consideration multiple criteria (Ravinder & Misra, 2014).

For instance, Partovi and Anandarajan (2002) used the four criterion of unit price, ordering cost, demand range, and lead time to perform a categorization. Researchers, Kabir, Hasin, and Khondokar (2011), went further and used “fuzzy” clusters to analyze the inventory. Fuzzy clustering allows some inventory to belong to more than one cluster. After analysis, three clusters are identified. The next step is to label each cluster on the basis of the average criterion value within a cluster. The cluster with highest average criterion value is marked “A”, the next highest as “B”, and the last one as “C”. Ladhari, Babai, and Lajili (2015) proposed a new hybrid weighted linear optimization model. This model was built by merging Ng’s (2007) weighted linear program with Zhou and Fan’s (2007) composite index concept. The researchers were able to manage misclassified items and also treat the conflict cases between the two considered models.

In practice, researchers use different combinations of inventory control methods in healthcare. Ballentine, Ravin, and Gilbert (1976) tested the effect of the ABC inventory analysis and the Economic Order Quantity (EOQ) on the ordering system in a hospital. They found out that with the proposed ABC-EOQ system the hospital would save on the cost of B and C category items which had lower cost and were purchased too often.

In other studies, Thawani, Turankan, Sontakke, Pimpalkhute, and Dakhale (2004) and Devnani, Gupta and Nigar (2010) applied a combination of ABC analysis and the VED matrix (V –vital, E- essential, D- desirable) categories on a hospitals’ pharmacy store. They were able to identify the group of drugs that required greater monitoring since
these drugs were consuming most of the funds. This method helped to find drugs that must be monitored for optimal use of finances and elimination of stock-outs in the pharmacy. Clevert, Stickel, Jung, Reiser, and Rupp (2007) joined ABC analysis with frequency of use XYZ analysis. They divided the inventory into 9 categories, classified by predicted value and frequency of ordering. As a result, the total value of frequently used items with a high value reduced from €175,000 to €52,000 across overall stock levels.

Kastanioti, Mavridoglu, Haralampos, and Polyzos (2016) recently conducted a study at 19 public hospitals using ABC classification and a descending principle of Pareto. They concluded that inventory control is an effective measure to control drug expenses by identifying the items requiring stringent control allowing for the rational use of funds in public hospitals.

Accordingly, in the study, the ABC categorization method was applied on unit-base and dollar-value categories. The results were compared and evaluated in Chapter Three, section 3.3.5.

While ABC categorization reveals categories of inventory that must be monitored more closely than others and points out places for saving costs, lean management tools deal with a physical layout of the storage room. These tools facilitate decisions on shelving models, implementation of advanced information technologies in inventory monitoring and purchasing. Lean tools take into consideration the results of the ABC classification in terms of decisions on where to store A, B, and C type inventory.

2.3.2 Lean management

Lean is an improvement approach that aims to eliminate waste. The lean principles were developed more than 100 years ago. The intellectual leader Frederick Winslow Taylor published a book “The Principles of Scientific Management” in 1911 where he summed up his efficiency techniques. He focused on studying existing workflow processes and experimenting with alternative processes that remove unnecessary or inefficient activities. These inefficiencies are termed waste and can generally be classified into eight different types, as specified in Table 1.
The key concept in lean thinking is value (refer to Table 2). Value is a specific activity that a customer wants and is willing to pay for with minimal time between order and delivery of the service or product. By understanding what the customer wants, the activities can be divided into value adding and non-value adding. In healthcare, customers can be patients, families, physicians, nurses, and other hospitals (Graban & Prachand, 2010). Value added activities directly contribute to the service or product that the customer wants, such as less time spent on discharging patients, centralized, well-organized items, and less time spent on searching for items. Therefore, all activities that do not add value are called waste. The waste needs to be removed or avoided (Joosten, Bongers, & Janssen, 2009).

Table 1: The eight types of waste

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Brief description</th>
<th>Hospital examples</th>
</tr>
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<tbody>
<tr>
<td>Defects</td>
<td>Time spent doing something incorrectly, inspecting for errors, or fixing errors</td>
<td>Surgical case cart missing an item; wrong medication or wrong dose administered to patient</td>
</tr>
<tr>
<td>Overproduction</td>
<td>Doing more than what is needed by the customer or doing it sooner than needed</td>
<td>Doing unnecessary diagnostic procedures</td>
</tr>
<tr>
<td>Transportation</td>
<td>Unnecessary movement of the product in a system (patients, specimens, materials)</td>
<td>Poor layout, such as the cath lab being located a long distance from the ED</td>
</tr>
<tr>
<td>Waiting</td>
<td>Waiting for the next event to occur or next work activity</td>
<td>Employees waiting because workloads are not level; patients waiting for an appointment</td>
</tr>
<tr>
<td>Inventory</td>
<td>Excess inventory cost through financial costs, storage and movement costs, spoilage, wastage</td>
<td>Expired supplies that must be disposed of, such as out-of-date medications</td>
</tr>
<tr>
<td>Motion</td>
<td>Unnecessary movement by employees in the system</td>
<td>Lab employees walking miles per day due to poor layout</td>
</tr>
<tr>
<td>Overprocessing</td>
<td>Doing work that is not valued by the customer, or caused by definitions of quality that are not aligned with patient needs</td>
<td>Time/date stamps put on forms, but the data are never used</td>
</tr>
<tr>
<td>Human potential</td>
<td>Waste and loss due to not engaging employees, listening to their ideas, or supporting their careers.</td>
<td>Employees get burned out and quit giving suggestions for improvement</td>
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Although the lean concepts were initially developed to improve car production, subsequent studies have shown that the lean concepts can be applied to any manufacturing system (Womack & Jones, 1996). Today, lean principles are very well known and successfully used for the production of goods and services including healthcare delivery (Ng, Vail, Thomas, & Schmidt, 2010; Souza, 2009). For instance, Henry Ford wrote about efforts to apply his production methods to a hospital in Dearborn, Michigan. Ford said:

“It is not at all certain whether hospitals as they are now managed, exist for patients or for doctors … It has been an aim of our hospital to cut away from all of these practices and to put the interest of the patient first … In the ordinary hospital the nurses must make useless steps. More of their time is spent in walking than in caring for the patient. This hospital is designed to save steps. Each floor is complete in itself, and just as in the factories we have tried to eliminate the necessity for waste motion, so we have tried to eliminate waste motion in the hospital” (as cited in, Ford & Crowther, 1922, ch. 15).
While the literature does not reveal the exact date of the first application of lean management in a healthcare sector, time has shown its value. Heinbuch (1995) offered an initial idea about the use of just-in-time (JIT) lean method in a hospital to minimize physical inventory. He was able to get good results in cost reduction (Manos, Sattler, & Alukal, 2006; Souza, 2009). Ng, Vail, Thomas, and Schmidt (2010) conducted a study on the effect of JIT on waiting time in the ED and patient satisfaction. According to their study, waiting time was decreased leading to a reduction in the number of patients left without seeing a doctor. Using bottleneck analysis, the clinical staff did an exercise on the department reconfiguration. All available inventories were relocated and sorted according to need. The outcome was increased efficiency, shorter waiting time, and increased patient satisfaction.

Pokinska, Fialkowska-Filipek, and Engström (2016) worked on 23 emergency care centers. The aim was to find out if the mixed-lean method in the ED creates more patient satisfaction or not. Researchers compared the results of the levels of patient satisfaction from centers with lean management and without. They came up with the conclusion that patients of care centers with lean are not more satisfied than patients of centers not applying lean techniques. Manos et al. (2006) applied one single lean tool, the 5S workplace organization method, in a storeroom used by the clinical labs. They achieved a 40% reduction in floor space use and a 17% increase in storage space. Sobek and Jimmerson (2003) applied JIT in a pharmacy department. Although not clarifying how the results were achieved, they claim a 40% decrease in missing medication. Jimmerson, Weber, and Sobek (2005) reported a reduction in backlog and inventory in the same pharmacy department. In another pharmacy case study, Esimai (2005) presented an over 50% reduction in medication errors, increased capacity, labor cost reduction, and emphasized on the increasing staff morale. Portioli-Staudacher (2008) confirmed the efficiency of lean methods in the pharmacy department. He reached an overall decline of 35% out of 6 million euros of initial inventory.

Despite these advances, there is still a lot of waste seen in the healthcare industry. As Cindy Jimmerson, the founder of “Lean Healthcare West” organization said:
“The national numbers for waste in healthcare are between 30% and 40%, but the reality of what we’ve observed doing minute-by-minute observation over the last three years is closer to 60%. It is everywhere: patient care and nonpatient care alike” (as cited in, Graban & Swarts, 2012, p 317).

In response to findings such as these, lean tools have become an integral part of healthcare management. Most of the studies were concentrated on patient satisfaction, pharmacy, and time management. Only a few were done on consumable inventory. In the literature, JIT and 5S were the most applied lean tools in medical care, separately or combined with inventory control techniques (Souza, 2009; Graban, 2009).

Table 3 describes the steps of the 5S process. The first 5S activity is to organize the department area, distinguishing between items that are necessary and those that are less essential, removing unnecessary items or tools from the workplace. The second step is to identify each item’s frequency of use and allocate a location where items best meet their functional purposes. There must be a sufficient space for each item. After removing unneeded items and determining the best storage location for those that remain, the 5S focus turns to cleanliness.

Table 3: 5S workplace organization tool

<table>
<thead>
<tr>
<th>5S</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sort</td>
<td>Sort out needed items, keep items based on frequency of use</td>
</tr>
<tr>
<td>Store</td>
<td>Organize for the reduction of waste</td>
</tr>
<tr>
<td>Shine</td>
<td>Keeping the workplace clean, daily</td>
</tr>
<tr>
<td>Standardize</td>
<td>Developing a consistently organized workplace</td>
</tr>
<tr>
<td>Sustain</td>
<td>A system for ongoing support of the first 4Ss</td>
</tr>
</tbody>
</table>
Hospital departments often rely on a centralized housekeeping department. In the 5S approach, people who work in the department take responsibility for their own light cleaning and the overall cleanliness of the department. Once sorting the items, defining the location for items, and cleaning the department are complete; it is time to ensure that items are always kept in the defined locations. Standardization is usually performed through visual methods such as labeling or shadow outlines of items. Moreover, to prevent 5S from becoming a one-time event, plans must be made for sustaining and continuously improving workplace organization (refer to Table 3). The department needs a formal plan, where supervisors and leaders can see if new standards are being followed. Visual methods make it possible for leaders to scan the department. They can easily see if something is misplaced or missing. If an item is misplaced, the leaders can question clinical staff. It might be that an employee found a better or more convenient location for the item. This is a way to maintain and continually improve 5S practices (Morrissette, 2009; Grunden & Hagood, 2012).

Using the aforementioned studies as a foundation, this study seeks to organize the inventory at LAMC via the ABC categorization method along with the 5S workplace organization tool. Beyond simply organizing the inventory, this study also seeks to develop an order quantity plan for the ED inventory at LAMC.

### 2.4 Order quantity

Inventory management models focus on the questions of how much to order and when to order. To answer these questions, management needs to have reasonable estimations of ordering, holding, shortage costs, and capacity levels. Inventory control models take demand and cost factors associated with ordering and holding inventory into consideration. The costs of ordering and keeping inventory are directly related to the quantity of inventory in stock. Accordingly, the managers must work towards balance in establishing inventory levels. The primary purpose of controlling inventory is to minimize total inventory costs (Muller, 2003; Dellaert & Van de Poel, 1996).
2.4.1 Inventory control policy

To choose an inventory control policy, an analysis of the number of orders per period, the investment level per order, and the stocking point space is needed. There are two standard models for inventory management, the reorder point model and the periodic review model. In the first model, at the moment when inventory reaches the quantity that is equal or less to the specific reorder point quantity, an economic order quantity is ordered to replenish inventory. The reorder point of each item must be monitored constantly. In the periodic review model, the reorder point is defined in advance, and its quantity equals the difference between existing stock and the stock needed. Periodic review control allows multiple items to be reviewed and ordered at the same time. As a result, the administrative costs and procurement costs are reduced when there are multiple stock keeping units in the inventory. Besides, quantity discounts can be received. The limitation of the last model is that the reorder point must be accurately defined to avoid stock-outs or excess stock in any one item (Frederick & Gerald, 2001). Reorder methods and the classification of inventory allow managers to perform control over inventory and take corrective actions.

2.4.2 Optimal order quantity

*EOQ*. F. W. Harris in 1915 developed the economic order quantity (EOQ) model that is aimed to find an optimal purchase quantity that will minimize total annual inventory costs. The optimized order quantity minimizes both holding and ordering costs. The EOQ method is relatively easy to use, but it has several assumptions, such as (1) demand for the item in question is independent, (2) demand is known and constant, (3) lead time is known and constant, (4) ordering costs are known and constant, (5) back orders, stock-outs, and quantity discounts are not allowed (McLaughlin & Olson, 2012). This model assumes that the inventory is ordered at exactly the moment when on hand stock has enough items to cover lead-time demand, and the ordered inventory is received at a point when the stock is completely depleted. Despite the limiting assumptions of the EOQ model, it is still applicable in real business situations and provides an understanding of cost relationships. The holding cost and optimal order quantity are indirectly related: as holding costs decrease, the optimal order quantity increases. Considering this relationship, managers believe that the holding cost is larger
than it was earlier supposed. As a result, companies work on decreasing order quantities and streamlining ordering processes. Consequently, to improve the efficiency of the inventory control system, managers follow up output periodically, match the actual output with planned output, and perform corrective actions (McLaughlin & Olson, 2012; Kros & Brown, 2013; Nahmias & Cheng, 2009).

The EOQ model helps us determine how much to order, but not when to order. The periodic review period model identifies the time to order when the stock level drops to a predetermined amount and what maximum stock level to keep.

**Periodic review period model.** In 1996, Dellaert and Van de Poel, developed a new model called \((R, s, c, S)\) on the basis of the EOQ, where \(R\) is the periodic review period, \(s\) is the minimum stock level, \(c\) is the can-order level, and \(S\) is the maximum stock level. The \((R, s, c, S)\) model was tested in the purchasing department at a university hospital in the Netherlands. The results were beneficial including reduced holding cost and total cost, increased service level, and a decrease in the total number of orders placed with suppliers.

Over the years, researchers have developed variations of the basic periodic review period model. Bijvank and Vis (2012) used the \((R, s, Q)\) and \((R, s, S)\) replenishment policies in their study. They stated that these policies are common in healthcare. In the \((R, s, Q)\) inventory model, every \(R\) time the inventory is evaluated to see if it has reached the minimum \(s\) quantity. Then the inventory is ordered the multiple of \(Q\) quantity that value is between \(s\) and \(s + Q\). In the \((R, s, S)\), the inventory is ordered up to the \(S\) level. The researchers asserted that the fixed order size policy \((R, s, Q)\) results in a more accurate replenishment process for hospitals with the use of bar codes. However, the \((R, s, S)\) policy, compared to \((R, s, Q)\), uses capacity more efficiently. Although, the researchers asserted that both policies perform equally well when the service level is relatively high.

After evaluating policies found in the literature, it was decided to use the \((R, s-1, S)\) policy since it takes into consideration the available capacity of the stockroom.

In this chapter, the methods described fit the LAMC Emergency Department setting, available data, and objectives. This study has two general objectives 1) to clean and
redesign the stock room and 2) develop a proper order policy. Relatedly, the ABC/5S methods were used for the first objective and the quantity models were used for the second objective. Specifically within the ABC analysis, two categorization variables (value and use) were used. In developing the order quantity policy, four models were examined and a full cost analysis was performed for each. In the end, one was selected and tested in the field.

The following chapter discusses the methodology of the thesis.
Chapter Three

Methodology

This chapter describes the development and administration of the intervention in inventory management at the Lebanese Academic Medical Center (LAMC). Specifically, a synopsis of the data collection protocols both before and after the intervention is provided. Also provided is a detailed description of the development of the order quantity policy that was implemented as part of the intervention.

3.1 Research context

The Emergency Department (ED) at the LAMC under study serves as the context for the present research. Figure 4 shows an overview of the inventory flow from vendor to patients through central supply and the ED stockroom. In the ED, there are two stockrooms; one room is for pharmaceutical products and another room for consumable inventory. The scope of this study is the optimization of inventory through improvements to the consumable stockroom layout and order quantity policy.

![Figure 4: Overview of inventory flow](image-url)
3.2 Research framework

This before and after case study began by identifying and developing the research objectives. This was done, as illustrated in Figure 5, via interviews with the head nurse at the ED of the LAMC. After collecting background information in the literature regarding possible inventory and organization methods to address the objectives of how much to order and how to control the stock. Once the inventory policy was established, it was implemented for five consecutive weeks. During this time, data was collected to ascertain the success of the selected policy. Given these results, the necessary changes were made with the aim of meeting the initial objectives.

<table>
<thead>
<tr>
<th>December, 2015</th>
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<tbody>
<tr>
<td>3.3.1 Informal interview</td>
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<td>Manager of Material Management Department</td>
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<table>
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<tr>
<th>March, 2016</th>
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<tr>
<td>3.3.1 Preliminary Interview</td>
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<td>Head Nurse of Emergency Department</td>
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<th>August, 2016</th>
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<tr>
<td>3.3.3 Consumables Usage Data Collection</td>
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<td>Manager of Material Management Department</td>
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<table>
<thead>
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<tr>
<td>3.3.4 Consumption and Stock Policies Survey (Appendix A)</td>
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<tr>
<td>Head Nurse of Emergency Department</td>
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</table>

<table>
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<tr>
<th>March 16, 2017 - April 20, 2017</th>
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<tbody>
<tr>
<td>3.4 Testing Inventory Policy</td>
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<tr>
<td>Testing stockroom layout</td>
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</table>

<table>
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<tr>
<th>April 20, 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3.2 Post-Test Survey (Appendix A)</td>
</tr>
<tr>
<td>Clinical staff - 9 surveys</td>
</tr>
</tbody>
</table>

Figure 5: Case Study

3.3 Inventory policy development

To develop an inventory policy, historical data was used. Here, the interviews with the material manager and the head nurse of the ED provided the historical data, as well as some estimated data. The surveys designed supported the policy development and pilot.
3.3.1 Preliminary interview

Initially, an informal interview held with the material manager, in December 2015, at the LAMC under study revealed a desire to focus on the consumable inventory in the Emergency Department. The head nurse of the ED was approached as a source of information on the existing inventory ordering pattern and problems in ED.

The head nurse directs nursing services and administrative activities in the emergency room, prepares and maintains patient clinical records, and reports of emergency room staff performance and services rendered. In addition, she maintains pre-set inventory standards for solutions, supplies, medicines, and equipment, and keeps track of narcotics, as well as ensures that department goals are met while adhering to approved budgets.

An interview with the head nurse was scheduled in March 2016 and the following questions were discussed:

1) Who does the ordering?
2) What is a typical order pattern?
3) How is the quantity order estimated?
4) How long is the lead time for the various products? Is it consistent for all products?
5) What items are stored in patient rooms?
6) What policies and rules exist related to inventory management in the ED?
7) Does the ED department experience any shortages?
8) If so, how often?
9) What are the reasons for these shortages?
10) What are expected results of the present case study?

This information was needed for understanding overall inventory management at the ED and the existing loop in the ordering and stocking processes.

According to the head nurse in the ED in an interview, LAMC managers have established fixed reorder policies for the ED stock. The ED places an order at the central supply to replenish the stock once per week, every Thursday in the morning and receives it the same day in the afternoon or the following day in the early morning. Since the lead-time is short, a maximum of 24 hours, the ED has never experienced any
shortages. Although the managers created a reorder policy, it does not include an order quantity policy nor does it specify an ordering pattern. Clinical staff estimate the size of the order. They rely entirely on their experience and a sense of need. Inventory is distributed from the ED stockroom to the eight patient rooms every morning.

From this interview, the objectives became apparent. As such, the remainder of the research focuses on the following goals:

1) Improve the layout of the stockroom
2) Develop an optimal order quantity policy

The next step was a development of the survey that would narrow and clarify existing problems in managing consumables.

3.3.2 Survey design and administration

After studying closely the 5S Facilitator’s Guide (2014), the article of Korkut, Cakicier, Erdinler, Ulay, Dogan (2009) on “5S activities application at a sample company”, and the “Inventory control for supplies in emergency department” study of Gabinski, Raghunandan, Kizhakethil, Lefteris, and Mazur (2012), two surveys were prepared: the Pre-test Survey and the Post-test Survey (Refer to Appendix A). The surveys were based on some of the supply-related problems found in the publications. The clinical staff involved in inventory management were asked to mark on a scale from 1 to 5, ranging from never experienced to experienced daily, the inventory issues they were facing while managing inventory in the ED. The problems addressed in the survey were related either to ordering and distribution, or visibility and tidiness of the inventory management.

The Pre-test Survey was conducted in March 2016. The purpose of the Initial survey was to find the existing problems in managing the consumable inventory and areas for improvement in the stockroom layout at the ED. The results of the survey were used in 5S activities. A total of nine surveys were distributed and collected from ED clinical staff including the head nurse.

The Post-test Survey was conducted in April 2017 during the testing period of the updated stockroom layout and ordering pattern. The purpose of this survey was to identify changes in the ED following the proposed intervention. Basically, the results
of the survey were used in the 5S and ABC activities that are layout design and distribution of the consumables within the ED. A total of nine surveys were distributed and collected from the ED clinical staff including the head nurse.

3.3.3 Consumables usage data collection

The next step in the research design was data collection on consumable inventory consumption and the existing policy for inventory management.

The material manager provided the weekly consumable inventory consumption as unit-based data without the dollar values for the period from January 1 to June 30, 2016, totaling 24 periods (Refer to Appendix A). The data on consumable inventory consumption was relative to the flow from the Central Supply Stockroom to the ED stockroom. The reconciliation between the Central Supply stock and ED stock is scheduled every December 31 and June 30, as a result we had reasonable assurance that the data was free from errors and reflected the goods in inventory.

The weekly consumption data is not homogeneous because patients admitted to the ED have a variety of diagnoses. Consequently, the clinical staff uses different items each week. Therefore, we assumed that out of the initially collected 24 period lists from the material manager, the longest list including 498 items represents the most comprehensive list of goods.

Before performing an analysis the data must be cleaned from any errors or inconsistent formatting. The following manipulations were performed:

1) As noted, the data was received in 24 separate excel tables. Therefore, we merged the 24 tables into one big table in order to simplify further analysis.
2) The longest list of 498 items was matched with available inventory in the ED stockroom. It resulted in 180 items match. Next, the data were cleaned from unused and obsolete stock keeping units that still appeared on the rosters, including zero accounts. Zero accounts included items that are used on regular bases in the ED but were not ordered during January 1 – June 30, 2016. After cleaning data from zero accounts, the final consumption database shrunk to 127 items in regular use.
3) Using a script in R, the prices per item were sourced online from the following online stores:
As the stores yielded a range in prices, the average price per item was found by averaging the lowest and highest prices reported.

The initial data on inventory flow of 498 stock keeping units between the Central Supply Stockroom and the Emergency Department Stockroom was provided by the material management department manager in August 2016.

3.3.4 Consumption and stock policies survey

The main purpose of the Consumption and Stock Policies Survey (CSPS) is to estimate what is the maximum level of inventory that is usually ordered. Plus, the information collected in the CSPS helped to understand the replenishment pattern used in the ED under study. The secondary purpose of the CSPS is to collect information about consumables stored in the patient rooms and the stock room. The head nurse was selected as a source of information since she is responsible for the order placement, distribution of items into patient rooms, and overall operations control.

The longest list of 498 items was taken as a base for the CSPS. The head nurse was asked using this list to match the existing items in the list with the items usually ordered and stored in ED stockroom, as well as determine what items in the list are obsolete and no longer used. This exercise revealed that some of the existing items that were ordered before January 1, 2016, were still available in the storeroom. After finalizing the list of consumables existing in the patient room and stockroom, the head nurse identified the maximum quantities that were usually ordered for each stock keeping unit.

In addition, the head nurse was asked to analyze the capacity and needs of the eight patient rooms for a 24h shift. Later, eight lists were prepared for each room with a specific location for each item.

The information collected in the CSPS was used in the ABC analysis, in the 5S workplace organization, in the optimal order quantity formulation, and in allocating stock into the patient rooms.
The CSPS was given to the head nurse in September 2016, and she submitted the completed survey in January 2017.

3.3.5 ABC categorization analysis

Two types of the ABC categorization analysis were performed. First, the analysis was conducted using the unit-based consumption of the 127 items identified in the section 3.3.3. Second, ABC analysis was performed using the average cost of the 127 items.

The unit-base data was not homogeneous. The units used were pieces and boxes. Therefore, in order to have consistent data in the ABC unit-based data analysis, the number of boxes consumed were multiplied by the number of pieces in each box.

The ABC analysis results were used to determine consumption distributions, the storeroom layout, and build an optimal ordering pattern. The following data manipulations were performed in Microsoft Excel for ABC categorization analysis on the unit-base consumption turnover and the cost-base:

1) Found total consumption for each item for 6 months.
2) Sorted data in descending order.
3) Found the percentage fraction for each item of the total consumption.
4) Summed up the percentage fractions one by one from 0 to 100%. Highlighted the range where the sum reaches 70% and labelled the products A category, up to 90% (another 20%) – were labelled B category, and up to 100% (additional 10%) were labelled C category.
5) Apply color code: A – products were highlighted in red; B in green; and C with no color
6) Merge results of the two ABC analyses (by consumption and cost) to compare items in each category.

The first ABC categorization, presented in Figure 6, attempt was made on the unit-base list of 127 items. The items in the A category were consumables with a high volume of consumption but with a low average price. As seen in Figure 6, the category A products
amounted to 10.24% of the items, the B category amounted to 9.45%, and the C category made up 80.31% of overall consumption.

The second round of ABC analysis was performed on the dollar value list of 127 stock keeping units. The result was slightly changed. As seen in Figure 7, the number of items contributing to A consumption increased up to 11.82%, the B items increased up to 12.60%, and the percentage of items in C category decreased to 75.58%.
However, when it came to the implementation step of the study, the clinical staff insisted on placing items according to the unit turnover or unit-base ABC analysis results. From the position of staff in ED, the costs are not important. The most important aspect in providing ED services is an availability of consumables that have high unit consumption.

To justify theoretically the clinical staff position, the two ABC analysis results were merged into one table. As shown in Table 4, in the dollar value A category there are 46.67% of unit-base C items and in the B category we find 50% of C consumables with a lower turnover. Moreover, in the C category we find 4.17% of the A and 5.21% of the B valued items. These items have high consumption. When the dollar value is discussed, the numbers are not significant. However, these items might be critical to patient life. Therefore, the unit-base ABC analysis result was implemented in stockroom layout.

Still, a few items were left in their original stockroom places ignoring the ABC categorization, due to the size and clinical staff habit.
3.3.6 Space allocation to items

To calculate the space allocated for each consumable item available in the stock, the following steps were performed:

1) Calculate the total available space in the stockroom in cm³ that includes six sets of shelves, one closet, and three sets of big floor drawers.

2) The capacity of small drawers, trays, boxes, and bins that are placed on the shelves were calculated, keeping in mind, that the space occupied is a part of the total available space.

3) The last step in the calculation of the space allocated was an estimation of the space of the items that were stored on the shelves, in the drawers, bins, and boxes. An approximate division of the available space among the items was performed, ignoring the actual capacity of the bins, trays, and boxes.

3.3.7 Usable space

The space allocated in the previous step was adjusted according to the actual space occupied by each item.
1) The space allocated for the items stored in the big and small drawers didn’t need any adjustments because space is limited by the size of drawer.

2) The space allocated for the items stored on open shelves, in bins, trays, and boxes was reduced to the holding capacity. The holding capacity is the actual usable space by items.

### 3.3.8 Optimal order quantity

The data collected in the Consumption and Stock Policies Survey (CSPS) was used in developing four order quantity policies: EOQ, Variable reorder periods, Fixed reorder period, and Mixed policies. The development of the policies is the dominant goal of this study and is the basis of Chapter 4.

### 3.4 Testing the inventory policy

While testing the inventory policy, a major reorganization step was applied. It included the implementation of the developed optimal order quantity reorder policy followed by the 5S method in order to have sufficient space for the distribution of inventory. In addition, the inventory items were labeled and placed according to the Set in Order (5S) step and ABC inventory categorization policy. It was decided to test the updated ordering policy for 5 weeks from March 16, 2017, until April 20, 2017, inclusive. It is important to highlight that the period from March 16 to April 20 is aligned with data collected in the 10th to 15th periods in 2016 (Refer to Appendix A). It was assumed that during the 5 week testing period the maximum number of consumables stored in the ED stockroom would be ordered, and there is a higher chance that the same item would be replenished several times. Accordingly, this would provide sufficient and adequate data to test.

Finally, the updated storeroom was piloted for 5 weeks while simultaneously collecting feedback from clinical staff. The Post-Test Survey was used to collect complaints and suggestions from clinical staff after implementing changes. This step aims to show how the 5S reorganization and ABC categorization changed daily operations and to what extent. According to the feedback, the items were moved up or down on the shelf or the
ordering units were increased or decreased. This was done to find out how the theoretical implications are used in a working environment.
Chapter Four

Optimal Order Quantity Policy Development and Selection

This chapter covers the development of four optimal order quantity policies along with the selection of the policy implemented. The formulas found in the literature on the economic order quantity (EOQ), periodic review period policy, and total costs were applied to determine optimal inventory quantities for the ED context. For the theories to be applicable in the working environment they needed several assumptions to simplify application of the models. Therefore, it was assumed that the average demand is the actual demand and that demand is constant.

4.1 The economic order quantity model (EOQ)

The main advantage of the EOQ is that it yields the most economical model of the number of units per order to minimize the ordering and carrying costs. Yet, it assumes that a new delivery occurs just when the inventory level drops to zero and hence no stock outs are encountered. The firm is able to satisfy demand when it occurs, and suppliers are able to deliver requested stock fully and without delays. In today’s business environment, this assumption is unrealistic (Aljian, 1958; Harris, 1915).

The economic order quantity $EOQ$ is given by the equation

$$EOQ = \sqrt{\frac{2CD}{H}}$$

where $C$ is the inventory reorder cost and $D$ is semiannual demand. The result is divided by $H$ that is semiannual inventory holding cost.

In order to illustrate calculations here and further, the randomly selected consumable “Clinic Paper Roll” is used.
The reorder cost $C$ includes labor, supplies used to place an order, and accounts payable procedures. In the ED under study, the head nurse places the online order once per week and spends 15 to 30 minutes on placing the order. So, the estimated reorder cost is $3.

The semiannual demand $D$ was developed from the Consumables Usage Data Collection results, as such: after reconciliation between the Central Supply and Emergency Department stockrooms, the consumption for 24 weeks reflects actual flows. Therefore, the sum of these flows is considered the actual demand for the ED.

The inventory holding cost $H$ is equal to 10% of the average price per item. In the Purchasing Handbook (1958), Aljian estimated holding cost from 12 to 34 percentage. The holding cost is a variable percentage that is based on a period of not less than one year. There are many factors considered in the calculation of a holding cost. Aljian includes in his calculations of the lowest level of holding cost by adding the following factors:

1) Interest cost
2) Taxes
3) Insurance
4) Obsolescence
5) Shrinkage
6) Storage costs
7) Scrap

Thereby, taking into consideration the nature of the inventory and the industry, the semiannual inventory holding cost is estimated to be 10%.
This equation was applied to the 127 stock keeping units one by one (refer to section 3.3).

The next step was to calculate the total semiannual policy cost under the EOQ model where $Q$ is the optimal quantity.

$$TC = \sum \left( \frac{Q}{2} H + \frac{D}{Q} C \right)$$

The total cost $TC$ is the sum of product’s average in-stock quantity $\frac{Q}{2}$ times the holding cost $H$ and number of reorders $\frac{D}{Q}$ times the reorder cost $C$. This total cost was calculated for each item and then summed across items in order to derive the total cost for the EOQ policy.

<table>
<thead>
<tr>
<th>EOQ – Semiannual Total Cost per item “Clinic Paper Roll”</th>
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<tbody>
<tr>
<td>$TC = \left( \frac{20}{2} \times 2.89 + \frac{186}{20} \times 3 \right) \approx $56.76$</td>
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</tbody>
</table>

4.2 The periodic review policy with variable reorder periods

In the periodic review policy $(R, s-I, S)$ with variable reorder periods, the stock level is kept under observation periodically at a specified time $R$. The items are ordered to the order-up-to-level inventory level $S$. Under this reorder policy, the inventory is ordered up to order-up-to-level quantities which simplifies the reorder process, but it keeps staff busy with frequent review of the inventory as each item may have a different $R$ that ranges from several times per month to once per several years. However, it does not require continuous monitoring of the inventory levels.

The reorder review period $R$ can be derived using procedures analogous to the EOQ model (Ghiani, Laporte, & Musmanno, 2004).
$R = \sqrt{\frac{2C}{HD}}$

where 2 is multiplied by the inventory reorder cost $C$ and divided by the product’s semiannual demand and inventory holding cost.

Reorder Review Period for “Clinic Paper Roll”

$$R = \sqrt{\frac{2 \times 3}{2.89 \times 186}} \approx 0.11 \text{ semiannual periods}$$

($\approx 0.66 \text{ months or } \approx 19.8 \text{ days review period}$)

The parameter $S$, the order-up-to-level, is determined in such a way that the probability that the inventory level becomes negative does not exceed a given value $(1-\alpha)$.

$$S = D (R + L) + z \sigma \sqrt{R + L}$$

where $D (R + L)$ and $z \sigma \sqrt{R + L}$ are the expected value and the standard deviation of the demand in risk interval $R + L$.

The lead time $L$ in the ED under study is equal to 1 day or $1/180$ of a semiannual period.

The Order-up-to-level “Clinic Paper Roll”

$$S = 186 \left(0.11 + \frac{1}{180}\right) + 1.96 \times 5.02 \sqrt{0.11 + \frac{1}{180}} \approx 24 \text{ units}$$

The associated safety stock level is determined by finding the difference between $S$, the order-up-to-level, and the standard deviation of the average demand,

$$s = z \sigma \sqrt{R + L}$$
The total semiannual cost of the periodic review policy is thus:

\[ TC = \sum \left( \frac{D}{2} H + \frac{D}{D} C + H \sigma \sqrt{R + L} \right) \]

where the average semiannual demand in the review period is \( D \); \( R \) is the review period and \( H \) is holding cost. The \( C \) is the reorder cost, with a product of the holding cost and the standard deviation of the demand in the review and lead time period with the level of service 97.5%, \( z = 1.96 \) (Ghiani, Laporte, & Musmanno, 2004).

4.3 The periodic review policy with fixed reorder period

The periodic review policy \((R, s-1, S)\) with fixed reorder period represents a “formalized” version of the current practice at the ED.

The periodic review policy with fixed reorder period is used when the item should be in stock and ready to use. In this case, rather than monitoring the inventory level and ordering when the level gets down to a critical quantity, the item is ordered at a certain
interval of time that is equal for all inventory. This is convenient when a group of items is ordered together, like in the ED under study.

The reorder review period \( R \) is 1 week or 0.25 month (Refer to Section 3.3 in which the Preliminary Interview is presented).

In developing a periodic review policy with fixed \( R \), the formulas of the periodic review policy with variable reorder period were applied for the order-up-to-level, the safety stock level, and the total cost. The total cost is calculated on a monthly and semiannual base for comparison purposes.

<table>
<thead>
<tr>
<th>The Order-up-to-level “Clinic Paper Roll”</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S = \frac{186}{6} \left( 0.25 + \frac{1}{30} \right) + 1.96 \times 5.02 \sqrt{0.25 + \frac{1}{30}} \approx 15 \text{ units} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Safety Stock Level “Clinic Paper Roll”</th>
</tr>
</thead>
<tbody>
<tr>
<td>( s = 1.96 \times 5.02 \sqrt{0.25 + \frac{1}{30}} \approx 6 \text{ units} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Monthly Total Cost per item “Clinic Paper Roll”</th>
</tr>
</thead>
<tbody>
<tr>
<td>( TC = \left( \frac{186}{6} \times \frac{0.25}{2} \times \frac{2.89}{6} + \frac{186}{6} \times \frac{0.25}{3} + \frac{186}{6} \times 1.96 \right) \times 5.02 \sqrt{0.25 + \frac{1}{30}} \approx 16.39 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Semiannual Total Cost per item “Clinic Paper Roll”</th>
</tr>
</thead>
<tbody>
<tr>
<td>( TC = 16.39 \times 6 = $96.33 )</td>
</tr>
</tbody>
</table>
4.4 Mixed policy

The mixed policy takes into consideration space constraints and the results of the dollar value ABC analysis. The selection of the policy applied the following rules:

- For the A and B categories of consumables, the main constraint is the usable space. In the case when several policies could be applied the policy with the shorter review period was favorable.
- For C category items, the usable space was critical, like for A and B. If more than one policy fit the capacity requirement, the policy with the lower Q was selected.
- If none of the policies satisfy the above conditions, the fixed review policy was selected for the A and B categories, and the policy with smallest review period \( R \) for C items.

The calculations were performed in Excel using the functions IF and OR. Then the appropriate total costs per item were found using HLOOKUP function. And the total cost was calculated by summing up all total costs per item.

4.5 Cost and composition analysis of the inventory ordering policy

Four policies were developed: the EOQ, Variable reorder policy, Fixed reorder period policy, and Mixed policy. The semiannual cost of each policy was calculated. The policies sorted according to the cost from lowest to highest can be seen in Table 5.

Table 5: Semiannual Costs

<table>
<thead>
<tr>
<th>Policy</th>
<th>Cost in $</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOQ</td>
<td>1039.00</td>
</tr>
<tr>
<td>Variable reorder periods policy</td>
<td>1272.02</td>
</tr>
<tr>
<td>Fixed reorder period policy</td>
<td>9426.66</td>
</tr>
<tr>
<td>Mixed policy</td>
<td>7294.62</td>
</tr>
</tbody>
</table>

The lowest cost is the EOQ. This is expected, as it provides the most economical model of number of units per order that minimize the order cost. The Variable reorder policy
is in second place. Here, the cost is minimized by defining different reorder periods to each stock keeping unit. The highest cost belongs to the existing policy at the ED the Fixed reorder period policy. It is the most expensive model because every week the stock must be replenished up to the maximum level. Even though some of the items were barely used and could last another week or two before approaching the safety stock level.

The Mixed reorder period policy, developed out of the EOQ, Variable, and Fixed reorder period policies, is cheaper than the existing policy, but it is seven and more than two times greater than the EOQ and Variable policies accordingly.

The composition of the Mixed policy is presented in Table 6. Almost 71% of the policy is the policy with a fixed period. This explains, why it is quite costly compared to the first two policies.

Table 6: Mixed reorder policy composition

<table>
<thead>
<tr>
<th>Policy</th>
<th>Stock keeping unit</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOQ</td>
<td>32</td>
<td>25.20%</td>
</tr>
<tr>
<td>Variable reorder periods policy</td>
<td>5</td>
<td>3.93%</td>
</tr>
<tr>
<td>Fixed reorder period policy</td>
<td>90</td>
<td>70.87%</td>
</tr>
<tr>
<td>Total</td>
<td>127</td>
<td>100%</td>
</tr>
</tbody>
</table>

The next step was to decide which policy to apply.

The EOQ was declined directly. The assumption of the EOQ model is extremely simplified. None of the existing companies would wait until the inventory level reaches a fixed and static reorder point and only then order piles of items that could expire or become obsolete given the dynamics of the ED inventory use. The model itself is the best introduction for more complicated inventory models. However, the full implementation of the business model in a modern business environment is doubtful. Nevertheless, the model was used partially in the mixed policy.

The variable reorder policy is applicable in the current business world. It sets the safety stock and maximum order up-to-level stock that is feasible among the variable review period. However, in the dynamic environment of the ED, the clinical staff cannot
contribute too much time to the constant review of the stock. The range of the review period was from twice per week to once per year. In order to simplify the reordering process, the items in the stockroom must be sorted and placed according to the replenishment period. Applying this type of policy for 127 stock keeping units in the small ED stockroom is technically complicated. First, the number of items to be sorted is small; in addition, the layout of the stockroom does not allow for a division into sections, as well the application of ABC categorization is complicated in this matter. This was the reason to decline the policy.

The Mixed reorder policy represents the merged version of all three policies. It consists of 25.20% EOQ policy, 3.93% Variable policy, and 70.87% of Fixed policy elements, refer to Table 6. In selecting the policy, the priority was the capacity of the stockroom, and then, the second choice was shorter review period. Again, in the Mixed policy, the review period is not fixed. As a result, it was declined for testing, like variable review policy.

The fixed reorder policy represents the mathematical simulation of the existing policy. The fixed reorder policy was considered to be the most “workable” inventory policy. The policy is consistent with the existing policy and doesn’t add additional workload to the clinical staff. In the case of the variable policy, the orders would be placed several times per week. But, it is time-consuming, and the ED will need to hire a person to take care of the stock which in turn would lead to an increase of reordering cost. Therefore, it was decided to pilot the fixed review period policy for 5 weeks.

The following chapter focusses on the analysis of the pilot.
Chapter Five

Analysis of Results

Within the testing period from March 16, 2017, until April 20, 2017, 86 out of 127 items were replenished. Furthermore, 63 titles match the replenishment list for the period from 10th to the 15th period in 2016 that was used in the methodology section as the semiannual demand function. This shows that the database used in this study is reflective of the pilot period conditions.

5.1 Before intervention findings

5S. In support of the 5S activities, the initial surveys revealed nine unanimous results indicating that the clinical staff, that deals with inventory management in the ED, experience the following problems 100% on a daily basis:

1. Missing labels on the bins/baskets/cups.
2. Unclear labels on the bins/baskets/cups.
3. Items in wrong bins/baskets/cups.
4. Insufficient items in the bins/baskets/cups.
5. Too many items in the bins/baskets/cups (e.g. overflowing items).
7. Inconsistent locations for items within the stock room.
8. Multiple open boxes of the same item.
9. Too much time spent trying to find an item.
10. Difficulty distinguishing similar items.
11. Consistent application of inventory rules.

And once per week:

1. Problem in placing an order.
2. Problem with restocking an item
The results of the Pre-test Survey confirmed the outcomes of the interview with the head nurse done in March 2016.

The ED under study had multiple locations with identical items that were open, overstocked, and stored without any system. The clinical staff, to avoid shortages, replenished items in high quantities and stocked them in multiple locations without informing others. This led to the piles of the excess “hidden” supplies that not only took space but expired or had to be recalled. This overstock of “invisible” inventory leads to unnecessary cost burden.

Another reason for the problems with replenishment and restocking was that the clinical staff didn’t have any reorder quantity policy. As the head nurse mentioned, the size of the order is estimated by the clinical staff who rely entirely on their experience and the sense of need. Indeed, the Optimizing Healthcare Supply Management organization (2012) reports, the cause of the errors in the order is that inventory is ordered by “best guess” or visual scans estimations. In addition, some experienced clinical staff members create their own “system” of avoiding shortages as a result of lack of tools and standard work processes.

One more problem that was highlighted during the surveys is the lack of computerization in the department. In addition to the report on Optimizing the Healthcare Supply Management organization (2012), Callender and Grasman (2010) reported that the manually driven process forces the clinical staff to dedicate too much time to managing inventory. The staff manually count the stock on-hand to generate orders. Moreover, 13.7% of the hospital staff reported that the lack of a consistent barcode system causes errors in billing and order placement (Callender and Grasman, 2010).

In this case study, the head nurse mentioned during the interview that the order quantity had errors, as a result, wrong items were delivered to the ED. The reason was the mistakes in the coding or in the title of the items. Moreover, the errors were frequently discovered only at the moment of reconciliation with the central stock, and only then losses and profits were adjusted.
5.2 Intervention experience

The initial changes in the layout of the ED started in March 2016, directly after the Preliminary Interview with the head nurse. The clinical staff started to collect and discover “hidden” consumables around the department. These were counted and placed in visible places. The major change in the layout of the ED took place in April 2016 when the department received and installed new shelving system at the stockroom.

The actions described in 5.2 Intervention Experience section were performed from March 2016 until March 2017.

5.2.1 5S

Taking into consideration all of the above-mentioned problems in Chapter Three, before working on the layout of the ED stockroom, the clinical staff had to clean, collect, and move all of the consumable inventory from the patient rooms to the stock room. After doing that, the existing stock was cleaned from the expired/obsolete items and counted. Some of the stock was reallocated in the patient rooms according to the lists with fixed locations and units. The locations were labeled according to general categorization used in the hospital.

The ED purchased a new shelving system, bins, trays, baskets, and small and large drawers. The functional stocking space was built. The inventory was distributed in the stockroom according to the capacity, accessibility, and need – as per the ABC analysis. Illustration 1 demonstrates the change in the inventory distribution, and Illustrations 1 & 2 visualize the change made in the layout of the stockroom.
Illustration 1: Before and after intervention (Refer to Appendix for the full size photos).

<table>
<thead>
<tr>
<th>Before</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Before Image 1" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="After Image 1" /></td>
</tr>
</tbody>
</table>
Illustration 2: Stockroom layout before intervention
Each stock keeping unit place was labeled and fixed to the location. The process of labeling and allocation of the items is described in the next section.

The head nurse and researcher explained to the clinical staff the new system of using, placing, and restocking the ED consumable inventory. As well, the weekly deep cleaning schedule was introduced.
The final list of items in the stockroom was developed and used for ordering stock (refer to the section 5.2.3)

5.2.2 Placement of the stock – ABC categorization

The head nurse assigned two staff members to assist in the reallocation of the stock. Most of the items were distributed according to the ABC unit-base analysis. However, as it is mentioned in the methodology Section 3.3.7, some of the items were placed according to the size or functionality ignoring any method. For instance, different size needles were stored in one location regardless of the ABC analysis, the same with bandages, syringes, and gloves. Medical pads for adults were placed on the top of the shelf set because of the package size. It could not fit on any shelf. When all items were fixed within the stockroom, they were labeled.

Another decision was made during the implementation process. As advised by 5S method, as well as by ABC analysis, a color code should be applied to facilitate follow up on inventory. However, the head nurse decided to ignore it. The reason is that in this study 53 out of 180 accounts (refer to section 3.3.4) were ignored because in the database collected these items had a zero consumption balance. The partial coding of 180 stock keeping units would consist of 127 items with the color code and 53 without color code. The head nurse was concerned that without prior training on the ABC method the clinical staff might misinterpret the color codes or ignore uncoded items. She explained that each individual will understand coding system up to their personal knowledge or expertise and concentrate on monitoring specific color. She pointed out that this would create new problems in managing stock.

5.2.3 Ordering of stock

The Fixed reorder policy was applied for 5 weeks. The selected policy represents the mathematical simulation of the existing policy. The head nurse used the replenishment form that was created in Section 5.2.1 where the order up-to-level and safety stock levels were stated (Refer to Appendix A).
5.3 After intervention findings

When the pilot test started on March 16, 2017, the ED had just replenished the stock up to the maximum capacity. The layout of the stock was completed a week before the testing period. In the pilot, the head nurse used the fixed review reorder policy for five consecutive weeks on the updated stockroom.

5.3.1 5S and ABC categorization.

The Post-test survey was distributed and collected after placing the fifth inventory order at the last day, April 20, 2017, of the testing period. The survey revealed that partial application of the 5S activities and ABC categorization had solved all previously recorded problems. The staff involved in inventory management claimed that starting from the day one of the pilot they have never experienced:

1. Problem in placing an order.
2. Problem with restocking an item.
4. Unclear labels on the bins/baskets/cups.
5. Items in wrong the bins/baskets/cups.
6. Insufficient items in the bins/baskets/cups.
7. Too many items in the bins/baskets/cups.
8. Inconsistent locations for items within the stockroom.
9. Multiple open boxes of the same item.
10. Too much time spent trying to find an item.
11. Difficulty distinguishing similar items.

Subsequently, the outcome of the survey showed that the following complications were still experienced once per month:

1. Dirty the bins/baskets/cups.
2. Consistent application of inventory rules.

Though these problems were encountered once in five weeks. The head nurse reported that problems experienced once during the second testing week due to the lack of
coordination between morning and night shifts. The problems were solved on the spot and constantly monitored.

Another point raised during testing period was how to allocate the part of the items (refer to the section 3.3.4) that were not involved in the analysis. Therefore, taking into consideration the feedback collected during the implementation of the ABC and 5S activities, it was decided to allocate them according to the need and expertise of the clinical staff (refer to the section 5.2.2). To point out, the expertise of the clinical staff met the 5S principles. As a result, the inventory was distributed according to the visibility, accessibility, and importance. Therefore the final layout of the stockroom was completed during the second week of the pilot test.

The clinical staff at the ED reported that the updated layout of the stockroom significantly decreased the time spent on inventory management activities, simplified ordering procedures, and improved visibility of the stock. The head nurse stated that the visibility of stock increased the efficiency and speed of providing services – a result that is critical in a dynamic environment of ED.

5.3.2 Ordering of stock

Feedback on the application of the Fixed reorder period policy was also collected. As it was mentioned in Chapter Three, the review period was already determined by the hospital management. The levels of the inventory order-up-to-level and safety level were estimated by the clinical staff upon their expertise. Therefore, the mathematical model was tested versus their expertise.

The replenishment results for five weeks were collected using the Replenishment Form (refer to Appendix A). The head nurse found it very helpful because even in her absence the clinical staff would order the necessary quantities without overstocking.

She used the form for five consecutive weeks. However, she ignored the columns “existing stock” and “received” in the replenishment form. So, it was impossible to follow up if the policy was fully implemented for the five weeks. Nevertheless, the researcher assisted the head nurse in counting stock and preparing the inventory request form for three weeks and observations revealed that the updated reorder policy was
successfully applied for 24 items. The estimated levels of inventory responded to the demand in the ED within the capacity of the stockroom.

In addition, the pilot test of 127 replenished titles of consumables revealed:

1) 41 listed consumables were not replenished during the 5 week pilot
2) 6 items were ordered once in the 5 week pilot
3) 72 items were replenished at a minimum of twice in the 5 week pilot
4) 12 consumables were replenished on a weekly basis
5) 5 items were not replenished
6) 49 items were replenished in order-up-to-level quantities
7) 39 items were replenished in larger quantity than the estimated order-up-to-level

- 6 out of 39 items that were replenished in a larger quantity than the estimated order-up-to-level were ordered once in 5 weeks
- 18 out of 39 items are ordered in boxes with fixed quantities that are higher than order-up-to-level. Therefore, it is feasible to continue ordering in higher quantities, ignoring order-up-to-level quantity
- the last 15 out of 39 items were replenished 2 to 3 times during the 5 week pilot period.

The items that were not replenished even once during the pilot test belong to category C and just one to category B (unit-base). The head nurse suggested that before 5S activities the C items were frequently ordered and stocked in multiple locations; therefore, it was “hidden” and that the ED is still consuming these “hidden” items.

The reordering pattern showed that 5 items reached the zero level. The reason might be that the clinical staff didn’t follow the recommendations on the safety stock levels, or an unpredictable high flow of the patients and highly occupied clinical staff that is not taken into consideration in deterministic reorder policy that was used in the this study.

Plus, some items were ordered in quantities greater than the recommended order-up-to-level. The head nurse explained that some order-up-to-level quantities are lower than the actual need. Consequently, the maximum level of orders were adjusted accordingly.
The following chapter presents the conclusion to this study along with the limitations of the study, recommendations for implementing inventory policies in EDs, and recommendations for further research.
Chapter Six

Conclusion

The aim of this study is to better understand various problems in consumable inventory management in an emergency department. This research supports an understanding of how an implementation of the 5S method, ABC categorization method, and optimal reorder quantity can change daily operations and to what extent. In addition, this research is an example of application in the change management in the ED working environment.

Consistent with Manos et al. (2006) and Esimai (2005), the application of the lean tool gave a positive result in the ED space management. The fact that all consumables that were found in the department were placed in one storeroom demonstrates that the lean organization increased the capacity of the storeroom. In addition, the number of errors in orders and in received items was eliminated. The updated storeroom facilitated and simplified the work of the clinical staff. The results of the Post-test survey showed that the consumables are easily accessible and visible.

The head nurse highlighted in her feedback that the time spent on managing inventory significantly decreased. She was surprised with some results of the ABC classification because it showed that some of the items which were closely monitored didn’t have high turnover, such as urine collectors. Instead, the item Clinics Paper Roll has high consumption and should be monitored frequently.

The periodic review period policy with a fix period was applied in this study. The Fixed period model was developed and compared with the EOQ, Variable review policy, and the Mixed policy. As the fixed period policy was tested, it gave beneficial results. The total cost was reduced. The head nurse mentioned that almost for a year some of the consumables were not reordered since they were “hidden” items with a long expiry date. The service level increased. The satisfaction of the clinical staff increased because
it was easy to use the stockroom. Plus, the newly hired clinical staff were capable of being efficient in using consumables from the day one.

Overall review of the positive and negative characteristics and recommendations of the methods developed and applied presented in Table 7.

Another positive result is that the head nurse spent less time preparing the replenishment order using the developed replenishment form; therefore, the reorder cost decreased. In addition, any clinical staff will be able to place an order without errors, in case the head nurse is absent.

Although the methodology entirely premised on assumed costs, the new policy worked well in ED under study.

For many reasons, the research process for this study was not ideal. However, this experience reflects many lessons learned. The major pitfall in implementing the proposed inventory system is human resources. Surprisingly, the studies found in the literature omit this problem. Some of the clinical staff members were avoiding the new system of stocking consumables. They continued placing orders according to their experience. It took a lot of commitment and dedication from the head nurse of the ED to influence her subordinates to make sure that everybody followed the developed rule.

In the ED dynamic environment it is very difficult to assign existing clinical staff who are multi-tasking to work on changes in the department. Every visit to the ED lasted from one hour to five hours. The head nurse could not assign staff to work on consumables during every visit.

Moreover, the internal approvals and procedures, in addition, to human factor, significantly slowed down the case study (Refer to Chapter 3, Figure 5).

1) Four months were spent on ordering the shelving system.
2) Two months were spent on purchasing bins, trays, and drawers.
3) Nine months were spent on waiting for data from the material manager
4) Six months were spent on receiving the completed CSPS.
<table>
<thead>
<tr>
<th>Method developed/applied</th>
<th>Positive</th>
<th>Negative</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. EOQ</td>
<td>1) lowest cost</td>
<td>1) placing order when inventory level drops to zero 2) assumes that inventory available upon the order 3) bulky occasional order</td>
<td>1) use it as a fundamental policy</td>
</tr>
<tr>
<td>2. Periodic review policy with variable reorder period</td>
<td>1) second lower cost 2) provides safety stock level 3) provides maximum order level</td>
<td>1) reorder period is different for each item in stock 2) stockroom capacity is not taken into consideration</td>
<td>1) pilot it on consumables in ED or another department</td>
</tr>
<tr>
<td>3. Periodic review policy with fixed reorder periods</td>
<td>1) meets ED reorder period 2) provides safety stock level 3) provides maximum order level 4) meets stockroom capacity</td>
<td>1) the highest cost</td>
<td>1) continue with further development using actual costs and different supply chain section (ED stock – end user)</td>
</tr>
<tr>
<td>4. Mixed policy</td>
<td>1) third cost 2) taking into consideration ABC categorization 3) partially taking into considerations capacity of the stockroom</td>
<td>1) complicated to apply in small storage 2) high cost</td>
<td>1) pilot it in another department</td>
</tr>
<tr>
<td>5. 5S</td>
<td>1) eliminates waste 2) fixes items within location 3) simplifies inventory management 4) simplifies reordering procedure 5) reveals human potentials</td>
<td>1) requires additional space 2) requires training 3) requires allocation of human resources to additional tasks</td>
<td>1) continue training clinical staff 2) implement in other supply chain storage locations</td>
</tr>
<tr>
<td>6. ABC categorization</td>
<td>1) categorizes inventory 2) highlights critical items 3) decreases cost 4) increases visibility and availability 5) simplifies reordering procedure</td>
<td>1) unit base vs dollar value categorization gives different results 2) needs additional training</td>
<td>1) train clinical staff 2) implement in ED stockroom 3) implement in other supply chain storages</td>
</tr>
</tbody>
</table>

Table 7: Overview of methods developed/applied.
Another problem with working in the ED is that the moving of items from room to room is done when the room is actually used by patients. Some of the patients were in severe conditions. During peak weeks and hours, the work on this study was “frozen”. The issue of ethical behavior is the main concern of the researcher. The researcher did respect the privacy of the patients, avoided making noise and remained professional.

Moreover, due to the format in which demand data was given, measuring daily, weekly, or monthly variability was impossible because the variability was not large. As a result, the average demand was treated deterministically. Thus none of the policies are really dynamic in the time-sense of the word.

This study has a broad field of further research. Due to limited data access, the research conducted has many estimations and assumptions. The analysis can be more accurate if data were collected from the supply chain section: the stock room to the end user. In addition, calculations can be more accurate using the actual average costs of the consumables provided by the Lebanese Academic Medical Center.

An interesting trajectory for future research includes post hoc going back to what actually happened in the field and developing a policy that reflects the two-step process undertaken by the nurses. The first step is the nurse counts items, and if the stock reached the safety level, then an order was placed. However, in case the stock is higher than the safety stock level, but lower than the order-up-to-level, the nurse decides to order or not to order based on min and max values. The research would question what are the optimal levels of min and max stock when the decision is to place an order or not.
Bibliography


Appendix A

Inventory Optimization: A Case Study at the Emergency Department in a Lebanese Academic Medical Center

Interview questions:

1. Who does the ordering?
2. What is a typical ordering pattern?
3. How is the quantity of order estimated?
4. How long is the lead-time for the various products? Is it consistent for all products?
5. What items are stored in patients’ rooms?
6. What policies and rules exist related to Inventory management in the ER?
7. Does the ER department experience any shortages?
8. If so, how often?
9. What are the reasons for these shortages?
Pre-Test Survey

Inventory Optimization: A Case Study at the Emergency Department in a Lebanese Academic Medical Center

Instructions: Please reflect on the most recent month you spent in the ED. In that month, please rate the frequency with which you encountered the following inventory issues.

1 - Never experienced, 2 - Experienced once in the month, 3 - Experienced once per week, 4 - Experienced more than once per week, 5 - Experience daily.

<table>
<thead>
<tr>
<th>#</th>
<th>Problem Description</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Problem in placing an order.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Problem with restocking an item.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Missing labels on the bins/baskets/cups.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Unclear labels on the bins/baskets/cups.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Items in wrong bins/baskets/cups.</td>
<td></td>
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</tr>
<tr>
<td>6</td>
<td>Insufficient items in the bins/baskets/cups.</td>
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<tr>
<td>7</td>
<td>Too many items in the bins/baskets/cups (e.g. overflowing items).</td>
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</tr>
<tr>
<td>8</td>
<td>Dirty bins/baskets/cups.</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>9</td>
<td>Inconsistent locations for items within the stock room.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Multiple open boxes of the same item.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Too much time spent trying to find an item.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Difficulty distinguishing similar items.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Consistent application of inventory rules.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Other:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Post-Test Survey

Inventory Optimization: A Case Study at the Emergency Department in a Lebanese Academic Medical Center

Instructions: Please reflect on the most recent month you spent in the ED. In that month, please rate the frequency with which you encountered the following inventory issues.

1 - Never experienced, 2 - Experienced once in the month, 3 - Experienced once per week, 4 - Experienced more than once per week, 5 - Experience daily.

<table>
<thead>
<tr>
<th>#</th>
<th>Problem Description</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Problem in placing an order.</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Problem with restocking an item.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Missing labels on the bins/baskets/cups.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Unclear labels on the bins/baskets/cups.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5</td>
<td>Items in wrong bins/baskets/cups.</td>
<td></td>
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<td></td>
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<tr>
<td>6</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Other:</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Consumption and Stock policies Survey

Inventory Optimization: A Case Study at the Emergency Department in a Lebanese Academic Medical Center

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Code</td>
<td>Description</td>
<td>Code</td>
<td>Description</td>
<td>Code</td>
<td>Description</td>
<td>Code</td>
<td>Description</td>
</tr>
<tr>
<td>2</td>
<td>#</td>
<td>Unit</td>
<td>Category</td>
<td>Q</td>
<td>Location</td>
<td>Q</td>
<td>Location</td>
<td>Q</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room III</td>
<td>Isolation Room IV</td>
<td>Location</td>
<td>Q</td>
<td>Location</td>
<td>Q</td>
</tr>
<tr>
<td>Room V</td>
<td>Trauma Room V</td>
<td>Location</td>
<td>Q</td>
<td>Location</td>
<td>Q</td>
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</table>
Weekly Replenishment Form

Inventory Optimization: A Case Study at the Emergency Department in a Lebanese Academic Medical Center

<table>
<thead>
<tr>
<th>Code</th>
<th>UNIT</th>
<th>ABC</th>
<th>minimum - maximum</th>
<th>existing quantity</th>
<th>Order Quantity</th>
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<tbody>
<tr>
<td>PA0029</td>
<td>PIECE</td>
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<td>1-2</td>
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<td>A</td>
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<td>PA0010</td>
<td>PIECE</td>
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</tbody>
</table>
Periods

Inventory Optimization: A Case Study at the Emergency Department in a Lebanese Academic Medical Center

1  Jan. 1 - 8
2  Jan. 9 - 18
3  Jan. 19 - 25
4  Jan. 25-31
5  Feb. 1 - 7
6  Feb. 8 - 14
7  Feb. 15 - 23
8  Feb. 24-29
9  Mar. 1 - 8
10 Mar. 9 - 16
11 Mar. 17 - 24
12 Mar. 25 - 31
13 Apr. 1 - 8
14 Apr. 9 - 16
15 Apr. 17 - 24
16 Apr. 25-30
17 May 1 - 8
18 May 9 - 16
19 May 17 - 24
20 May 25 - 31
21 Jun. 1 - 8
22 Jun. 9 - 16
23 Jun. 17 - 24
24 Jun. 25 -30

Data collected in 2016 year
Illustrations before and after

Inventory Optimization: A Case Study at the Emergency Department in a Lebanese Academic Medical Center

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1) Before

1) After
2) Before
2) After
3) Before
3) After
4) Before
4) After