(OR)²: Operations Research Applied to Operating Room Supply Chain

by

Noa Ben-Zvi

B.Sc. in Electrical and Electronics Engineering, Tel Aviv University, 2007

Submitted to the MIT Sloan School of Management and the Electrical Engineering and Computer Science Department in Partial Fulfillment of the Requirements for the Degrees of Master of Business Administration and Master of Science in Electrical Engineering and Computer Science

In conjunction with the Leaders for Global Operations Program at the Massachusetts Institute of Technology

June 2014

© 2014 Noa Ben-Zvi. All rights reserved.

The author hereby grants to MIT permission to reproduce and to distribute publicly paper and electronic copies of this thesis document in whole or in part in any medium now known or hereafter created.
Abstract

Massachusetts General Hospital (MGH) is ranked as the top hospital in New England and second nation-wide. It is also the largest hospital in New England; it uses an average of 58 operating rooms, where approximately 150 surgical procedures are performed daily. Management of surgical supplies is a critical component of the processes supporting this infrastructure. Specifically, ensuring the right equipment and supplies are available at the right time is critical for the efficiency and quality outcomes of each of the procedures.

The materials management group handles over 10,000 unique items, purchased from more than 400 vendors. The majority (60-70%) of disposable supplies are ordered through Owens & Minor, a medical and surgical supplies distributor. The supplies are stored in multiple locations throughout the hospital, including two central locations as well as carts and cabinets on the surgical floors and in the operating rooms. The work described in this thesis focuses on the inventory management of disposable surgical supplies, where the current system design has inefficiencies in the inventory levels and location of items. Using a data-driven approach, based on historical demand, we calculate base stock levels by item that maintain three days of inventory at a 99 percent service level. In addition, we suggest a methodology to support decisions on inventory locations of the different items.

Implementation of the recommended changes is estimated to result in savings of 30-40% in inventory levels (and space), corresponding to a one time saving of $700,000-$900,000, depending on the implementation scenario. In addition, the reduction in inventory levels can be translated to future savings in inventory holding costs at an estimated 40% rate, leading to a saving of roughly $300,000 annually.

Thesis Supervisor: Retsef Levi
J. Spencer Standish (1945) Prof. of Management, Assoc. Prof. of Operations Management

Thesis Supervisor: David Simchi-Levi
Professor, Civil and Environmental Engineering and Engineering Systems Division
THIS PAGE INTENTIONALLY LEFT BLANK
The author wishes to acknowledge the Leaders for Global Operations Program for its support of this work.
ACKNOWLEDGEMENTS

I cannot begin to express my gratitude to the exceptional team that has been part of this work. I would first like to thank my academic advisors, Professor Retsef Levi for pushing me to high quality work with actionable results, guiding me in the right direction to make an impact with this work, and Professor David Simchi-Levi for providing me with insights on supply chain and inventory management as well as support along the way. Also on the MIT side, I am eternally grateful to Cecilia Zenteno for her endless support and guidance that made this thesis finally come together.

I could not have completed this work without the MIT/MGH collaboration team and some of the perioperative team members that have been key to the success of this project. I would like to thank Dr. Peter Dunn, for always having the answers and insights on why MGH works the way that it does. To Bethany Daily, for being the role model that she is, and for always being there to provide any support that this work required. I would also like to thank Brianna Germain for making sure all the resources are there, and generally making things happen. I have received tremendous support from Kimberly Edwards, Amira Hamzick, Barry O'Shaughnessy and Kathy Rogers, that did not spare their time to make sure I understand the processes and opportunities in the perioperative environment, helped me validate my ideas and provided me with any data I needed. I am indebted to all of them, and hope they enjoy the fruit of this work in return to their hard work.

Last, but definitely not least, I would like to thank my family – Danny, Yonatan and Omer, for always being there for me. Their support is what allowed me to go through the LGO program, and I could not have done it otherwise.
THIS PAGE INTENTIONALLY LEFT BLANK
### TABLE OF CONTENTS

1. **INTRODUCTION** ................................................................................................................................. 13
   1.1. BACKGROUND ................................................................................................................................. 13
   1.2. PRIOR WORK ..................................................................................................................................... 14
   1.3. **THE PERIOPERATIVE SURGICAL DISPOSABLES SUPPLY CHAIN** ............................................... 15
       1.3.1. Inventory Locations ................................................................................................................ 15
       1.3.2. Supply Chain Overview ......................................................................................................... 17
       1.3.3. Key Challenges ...................................................................................................................... 19
   1.4. APPROACH ....................................................................................................................................... 20
       1.4.1. Potential Interventions ......................................................................................................... 20
       1.4.2. Project Focus ......................................................................................................................... 21
       1.4.3. Results andRecommendations ............................................................................................ 21
   1.5. THESIS OVERVIEW ....................................................................................................................... 21

2. **THE PERIOPERATIVE SUPPLY CHAIN** .............................................................................................. 23
   2.1. GENERAL INVENTORY POLICY ................................................................................................... 23
   2.2. INTER-DAY PROCESSES ............................................................................................................. 24
   2.3. INTRA-DAY PROCESSES ............................................................................................................. 25

3. **CURRENT STATE ANALYSIS** .............................................................................................................. 27
   3.1. APPROACH ....................................................................................................................................... 27
       3.1.1. IT Systems and Data Sources ............................................................................................... 27
       3.1.2. Analysis ................................................................................................................................... 29
   3.2. CHALLENGES ................................................................................................................................... 33
       3.2.1. Preference Cards ................................................................................................................... 34
       3.2.2. Inventory Levels and Locations ............................................................................................ 34

4. **POTENTIAL INTERVENTIONS** ............................................................................................................. 35
   4.1. METRICS AND DEFINITIONS ....................................................................................................... 35
       4.1.1. Total Par Levels ..................................................................................................................... 36
       4.1.2. Cost ......................................................................................................................................... 36
       4.1.3. Space ....................................................................................................................................... 36
       4.1.4. Access/Accuracy ................................................................................................................... 36

5. **INVENTORY LEVELS** ......................................................................................................................... 37
   5.1. MODEL .............................................................................................................................................. 37
|
|---|
|5.1.1. Model Inputs........................................................................................................... 38 |
|5.1.2. Detailed Methodology ............................................................................................ 39 |
|5.1.3. Model Output .......................................................................................................... 40 |
|5.2. RESULTS................................................................................................................... 40 |
|5.2.1. Suggested Par Levels for Three Days of Inventory .............................................. 40 |
|5.2.2. Additional Levers .................................................................................................. 45 |
|5.3. IMPACT...................................................................................................................... 46 |
|6. PURCHASE ORDER LINES.......................................................................................... 47 |
|6.1. RESULTS..................................................................................................................... 47 |
|6.2. IMPACT....................................................................................................................... 48 |
|7. INVENTORY LOCATIONS............................................................................................... 49 |
|7.1. MODEL....................................................................................................................... 49 |
|7.1.1. Model Inputs........................................................................................................... 49 |
|7.1.2. Detailed Methodology ............................................................................................ 51 |
|7.1.3. Case Study for Supply Doc Analysis - OR 33 ....................................................... 52 |
|7.2. JACKSON SUPPLY .................................................................................................... 55 |
|8. RECOMMENDATIONS FOR IMPLEMENTATION....................................................... 57 |
|8.1. KEY RECOMMENDATIONS......................................................................................... 57 |
|8.1.1. Adjustment of Par Levels ....................................................................................... 57 |
|8.1.2. Consideration of Change in Order Frequency ...................................................... 58 |
|8.1.3. Inventory Locations ............................................................................................... 58 |
|8.2. NEXT STEPS: STANDARDIZATION FRAMEWORK ................................................. 59 |
|9. CONCLUSIONS.............................................................................................................. 61 |
|10. BIBLIOGRAPHY........................................................................................................... 63 |
|11. APPENDIX.................................................................................................................... 65 |
|11.1. MATLAB CODE FOR PAR LEVELS ANALYSIS (DEMAND DISTRIBUTION) ........... 65 |
|11.2. RECOMMENDED PAR LEVELS DATA EXAMPLES .............................................. 68 |
|11.3. OR 33 CASE STUDY DATA EXAMPLES ................................................................ 69 |
|11.3.1. Differences by item ID, across all cases ............................................................... 69 |
|11.3.2. Item differences in surgical case #1071020 (vaginal hysterectomy, October 3rd, 2013)........... 70 |
LIST OF FIGURES

Figure 1: Map of 3rd floor operating rooms across all buildings .................................................. 16
Figure 2: From surgeon’s preference cards to delivered supplies.................................................. 17
Figure 3: Inventory flow to the operating rooms ........................................................................... 18
Figure 4: Timing diagram of inventory flow activities ................................................................. 18
Figure 5: Examples of typical case carts ...................................................................................... 26
Figure 6: Main IT systems used as data sources and their interfaces ......................................... 28
Figure 7: Example of preference cards variability analysis for a Lap. Chole. procedure ............ 30
Figure 8: Comparison of costs of items that are on pick lists to total spend (07/2012 – 12/2012) .... 31
Figure 9: Histogram of O&M items’ velocity ................................................................................. 32
Figure 10: Cumulative cost/inventory worth of Owens & Minor items (01/2012 – 05/2013) ...... 32
Figure 11: Example of review dates templates for various review periods ................................ 39
Figure 12: Distribution of calculated par levels results by item velocity .................................... 41
Figure 13: Distribution of calculated par levels without pooling, by item velocity (bounded by current state) ......................................................................................................................... 42
Figure 14: Distribution of calculated par levels with pooling, by item velocity (bounded by current state) ............................................................................................................................ 43
Figure 15: Impact of days of inventory held on total inventory levels and worth .................... 45
Figure 16: Results – reduction in purchase order lines by order frequency ............................... 48
Figure 17: Decision tree for location of emergent slow moving items ..................................... 52
Figure 18: Distribution of differences between usage documentation and pick list data across all items/cases .............................................................................................................................. 53
LIST OF TABLES

Table 1: Categorization of challenges in the current state ................................................................. 33
Table 2: Summary of current par levels and inventory worth .............................................................. 44
Table 3: Summary of par levels results for the data-driven scenario .................................................. 44
Table 4: Summary of par levels results for the data-driven and pooled scenario .................................. 44
Table 5: Aggregate estimated Cost/Space Savings for the Suggested Scenarios ................................. 46
Table 6: Distribution of items in locations methodology case study, out of N=293 .............................. 54
1.2. Prior Work

With the changes in healthcare reimbursement policies, hospitals are looking at various ways to reduce costs. Process improvement and supply chain optimization are avenues for reductions in operational costs, allowing for better utilization of resources. Previous projects within the MGH-MIT collaboration have focused mostly on patient flow. The recent work of Schlanser 2013, focused on reduction of inventory levels using an optimization model that suggested a modular structure for custom surgical packs (procedure specific pre-packed kits of disposable surgical supplies), driving smoother demand and lower safety stocks. In addition, it acknowledged the timing of orders and deliveries, and more generally was a valuable basis for our analysis of the current state and understanding the potential solutions as it analyzed the potential impact of using data-driven inventory levels for disposable supplies.

Similar work has been done in other hospitals as well. The Ontario Hospital Association has published an entire guide on optimizing the perioperative supply chain, suggesting different initiatives around preference cards (lists of supplies required by a surgeon for a type of procedure), inventory management, standardization and data usage, and includes a few case studies regarding implementation and results. The Vanderbilt University Medical Center re-designed its OR supply chain with an expansion in mind, setting goals of reduction of clinicians’ involvement in the process and minimization of inventory across locations. In their case, they changed the process such that case carts (dedicated surgical cart holding the instruments and supplies required for a specific surgical case) were built in a separate warehouse location to facilitate a lower level of inventory at the hospital. In addition, they reviewed the preference cards and added a post-procedure review to the process, creating a feedback loop for improved accuracy.


5 (Optimizing Your Perioperative Supply Chain: A Guide to Improvement Projects)

6 (Unleashing Efficiency: A Vanderbilt University Medical Center Case Cart Study, 2012)
1. INTRODUCTION

This thesis discusses the application of operations research principles to the inventory management of disposable surgical supplies at Massachusetts General Hospital (MGH). We focus on the inventory management of disposable surgical supply, including the respective base-stock target levels of surgical supply items and the placement of inventories in various locations throughout the perioperative system.

Based on historical purchasing data, we study the impact of different inventory policies, and also suggest a framework to decide where to place the inventory of various item types. The new policies would lead to a more efficient system design and better utilization of resources.

1.1. Background

Massachusetts General Hospital is a Harvard Medical School teaching hospital, ranked as the top hospital in New England and second nation-wide based on its quality of care, patient safety and reputation in 16 clinical specialties. MGH is a founding member of Partners HealthCare, an integrated health care delivery system that includes two founding academic medical centers, community hospitals, primary care and specialty physicians, specialty facilities, community health centers and other health-related entities. It is the largest hospital in New England, with more than 90,000 emergency room visits and over 38,000 operations performed annually. Perioperative Services at MGH has been collaborating with Professor Retsef Levi at MIT Sloan School of Management for the past seven years, using an analytical approach to improve different aspects of the perioperative environment, such as patient flow and bed utilization. The team consists of experts on the clinical, administrative and operational aspects, allowing a fruitful collaboration that takes into account all stakeholders and actual implementation challenges. Projects are chosen based on the hospital's needs in order to obtain measurable and sustainable benefits.

1 (Leonard 2013)
2 (Hospital Overview)
1.3. The Perioperative Surgical Disposables Supply Chain

Perioperative Services manages about 58 operating rooms with an average of 150 procedures performed on a typical business day. In this thesis project we worked with the materials management group in the Central Sterile Processing and Supplies Department (CSPS) to study the supply chain of disposable surgical supplies required for surgical cases. Currently, CSPS handles over 10,000 unique items, purchased from more than 400 vendors.

The perioperative disposables supply chain is challenging to manage due to the combination of high required service levels and high variability in demand that exists due to the diversity of patients and surgical methods. These factors have led to a very conservative operational approach to managing the respective supply chain, that is driven by the hospital’s concern to stock out and not have the required supply. This in turn leads to inefficiencies in aspects such as inventory location and levels (for example, items that are not used frequently yet stocked in multiple operating rooms). Some of the inefficiencies stem from the fact that many decisions are made with lack of appropriate rigor and based on local rather than overall systematic considerations.

1.3.1. Inventory Locations

The high surgical volume and required service levels, along with the configuration of the MGH campus, have led to over 150 inventory locations throughout the perioperative care system (see Figure 1). These can be divided to three types:

1) **Centralized inventory locations**: These include a central location at CSPS and a secondary storage location (Jackson Supply). These inventory locations are used for picking of supplies for surgical cases as well as for re-stocking of the operating rooms stock.

2) **Carts and cabinets on the surgical floors**: These include carts of supplies used by specific surgical services and clean cores (sterile supply storage locations in the operating rooms area) that exist on every surgical floor.

3) **Operating rooms** (i.e., room stock).

The operating rooms (ORs) at MGH are located in two main areas. There are several ORs in the older **Legacy area**, which spans four different buildings (White, Gray, Blake and Jackson). In addition, there are ORs in the new **Lunder Building**, which has operating rooms on three floors (2, 3 and 4). Jackson Supply is located in the Legacy area and CSPS is located in the basement of the Lunder
Building. These two locations are about a ten minute walk away from one another. Nevertheless, they function almost independently. In particular, each of the central locations operates independently with no cross coordination to decide and review the item inventory levels and place appropriate purchase orders. Prior to the opening of the Lunder Building in 2011, there was no central supply location and nurses were in charge of picking supplies for each case. With the opening of Lunder and CSPS, the hospital switched to a case cart system, where most of the picking is now done by warehouse staff at CSPS. We describe this system in detail in Section 1.3.2. Jackson Supply operates as a secondary central supply location, used for the re-stocking of the Legacy operating rooms, as well as a location for backup supplies and specialty items, similar to the Lunder clean cores.

Figure 1: Map of 3rd floor operating rooms across all buildings
1.3.2. Supply Chain Overview

The demand for disposable supplies is driven by the surgical procedures. The list of items required by a specific surgeon for a specific type of surgical case is called a preference card, and includes the required items and quantities. The preference cards include several types of items, such as surgical instruments (that are sterilized in CSPS after each use), custom surgical packs (pre-packed and sterilized procedure-specific kits), and disposable supplies, also referred to as soft goods. Some of the disposable supplies on the pick lists are defined as standby items, and these are picked but should not be opened in the room unless there is a need. Items in custom surgical packs cannot be returned since they are not wrapped individually. Thus, once the pack is opened they must be used or be disposed.

The process that converts a surgeon’s preference card to delivery of supplies for a specific surgical case (shown in Figure 2) is as follows. Nursing staff review the surgeon’s preference card for each procedure and make patient specific changes, typically a day or two prior to the procedure. This reviewed preference card generates a pick list that includes the required items, quantities and pick locations. The day prior to each scheduled surgical case, items on the pick list are picked onto a dedicated case cart that will be taken to the respective OR, in which the surgery is scheduled to take place. Most of the items on the pick list are stored and picked in CSPS. Some specialty items are stored on the surgical floors (in service specific specialty carts or clean cores) and picked by operating room specialists (ORSs), who are part of the CSPS staff and work with the surgical services. Specialty items can be surgeon specific supplies or a type of supply that is only used by one surgical service. Ideally the case cart would hold all the necessary items, but the requirements are not always known ahead of time. An item might be accidentally dropped, or a surgeon might realize they need additional items during the course of the procedure. Additional items that are used during the procedure and were not supplied on the case cart are mostly taken from the room stock, or supply cabinets located nearby if necessary. This is why each OR stores inventory of various items.

Figure 2: From surgeon's preference cards to delivered supplies
Figure 3 below shows the flow of inventory from the various locations to the operating rooms, and the different ways supplies are moved. Figure 4 shows the timing of the different activities throughout the day.

Figure 3: Inventory flow to the operating rooms

Figure 4: Timing diagram of inventory flow activities
The operating rooms and clean cores are re-stocked every night from CSPS and Jackson Supply to Lunder and the Legacy ORs, respectively. The inventory levels at the central locations are reviewed each morning and purchase orders are placed to maintain the required target level of supplies. In particular, each item has a specified *par level* that typically corresponds to three days of demand for this item.

The majority (60-70%) of disposable supplies are ordered through Owens & Minor (O&M), a leading medical and surgical supplies distributor. In addition to distribution services, O&M provides inventory management services and a private label product. They offer their customers custom solutions for cost reductions and collaborate to reduce complexity for both sides\(^7\). About 1,200 unique disposable surgical supplies are purchased through O&M, such as sutures, catheters, drapes, gloves, tubes and needles. Purchase and inventory management of these items are the focus of this work.

1.3.3. Key Challenges

In our analysis of the current state, we identified a number of challenges that could be addressed by changes in the system design. There are challenges on both the supply side and the demand side of surgical supplies.

Surgical supply challenges mostly have to do with inflated inventory levels. The excessive inventory levels are driven by a number of factors, mainly the overly conservative and non data-driven inventory policies, the high number of inventory locations and the lack of appropriate coordination across locations. The inflated inventory target levels drive higher inventory holding costs (previously estimated at 40% annually by an external consulting firm working with Perioperative Services) and higher inventory worth value owned by the hospital, as well as increased warehouse space.

On the demand side, there are concerns about inaccuracy in the pick lists (inaccurate item, quantity or location), and a high volume of returns due to excessive standby items on the pick lists and in-room picking. In addition, while custom surgical packs are standard, there is no standardization of the other supplies used in each case type, driving a high number of item types and high variability of demand. The high variability is an additional factor leading into the excessive inventory levels.

\(^7\) Supply Chain Partners: Virginia Mason and Owens & Minor, Harvard Business School
1.4. Approach

1.4.1. Potential Interventions

In general, the inventory policies and picking processes should rely on the available data that provides demand patterns by item and by procedure type. Such a data-driven approach suggests opportunities for cost reduction or improved accuracy.

The current inventory levels should be determined and adjusted, based on historical demand data. Further reductions can be obtained by pooling safety stocks across the different locations, which would require a centralized ordering policy. Reductions of the inventory levels and number of locations can lead to savings in cost and space while maintaining the currently required service levels. This work proposes a robust data-driven model to determine the appropriate inventory target levels.

In addition, we propose a data-driven methodology to decide on inventory locations by considering the usage characteristics of each item. The methodology could incorporate more accurate data on item usage that will be collected in the future.

Accurate preference cards better support having the correct supplies and quantities in the operating room during the surgical procedures, hence reducing the amount of picking done by the nursing staff and the need for operating room stock. It also reduces the amount of work needed to handle returns of unused supply to the centralized locations. Standardization of preference cards among surgeons can reduce the number of types of items kept in stock, again driving total inventory levels down. This can be achieved by analyzing the differences in preferences cards used by various surgeons for the same type of procedure, highlighting potential errors and high cost items and driving standardization of the items used.

The impact of such interventions can be assessed using the following metrics:

- Total par levels: the aggregated inventory levels across all items and locations, accounting for the total number of units in inventory. This value drives inventory worth and space.
- Cost: the total cost of supply owned by the hospital, and the consequent inventory holding cost.
- Space: the supply storage space required in the area of the operating rooms (that could be better utilized for clinical use).
- Accuracy: the required service levels and access to the required supply.
1.4.2. Project Focus

This work focuses on the inventory management of disposable surgical supplies, in a number of aspects. In Chapter 5, we describe an approach to data-driven inventory levels, using base stock policies and purchasing history as an approximation of demand. Using the available data, we calculate the required inventory levels for each item, and do so for different scenarios, such as pooling of safety stocks across multiple locations and different values for days of inventory held by the hospital. Chapter 6 describes the impact of these scenarios on the annual number of purchase order lines and potential savings opportunities with O&M. As a complement to data-driven inventory levels, Chapter 7 suggests a methodology to inform the decisions regarding inventory locations for every item using available usage data, to minimize the operating room stock to essential items only.

1.4.3. Results and Recommendations

The main benefits of improved inventory management are improved efficiency, cost reductions and additional space for clinical purposes, allowing better utilization of the available resources without compromising the quality of care. Using a data-driven approach to the inventory management of surgical supplies, we estimate a reduction of 30-40% in the total inventory levels and corresponding space, allowing MGH to save hundreds of thousands of dollars annually.

In order to realize these savings, we recommend a number of implementation steps. In addition to changing the base stock levels to those we calculated, we recommend going to one central inventory location at CSPS, and reducing Jackson Supply to a clean core setting. This would streamline the pooling of safety stocks across the OR locations, and free space in the Legacy area which is due to be renovated in the coming years. Application of the full locations methodology might require additional data collection, but there are first steps that could be implemented immediately, such as the elimination of items that are rarely used from the operating rooms' stock. A framework for the standardization of preference cards is suggested as future work.

1.5. Thesis Overview

This thesis is structured as follows. In Chapter 2, we describe the MGH perioperative supply chain and inventory management policies and practices. In particular, we highlight the challenges and possible interventions in Chapters 3 and 4, and provide a detailed description of the methodology
that was used for analysis in Chapters 5 - 7, based on available data sources including but not limited to historical purchase orders, preference cards and stock lists. In Chapters 0 and 9 we suggest concrete recommendations for implementation and summarize the impact of this work.
2. THE PERIOPERATIVE SUPPLY CHAIN

There are various processes that take place to support the delivery of disposable surgical supplies to the operating rooms. Surgical supplies are stored in two central locations, Central Sterile Processing and Supplies (CSPS) and Jackson Supply, as well as in the operating rooms and on the surgical floors (in specialty cabinets or clean cores, which are sterile areas in the OR area used for storage of sterile supplies). The operating rooms are located in two main areas: (i) the older Legacy area, which consists of the operating rooms in four different buildings, and (ii) the newer Lunder Building, which has operating rooms on three floors, and was opened in the summer of 2011.

Since the opening of the surgical floors in the Lunder Building, the main physical outlets of the system are CSPS as a central location and Jackson Supply as a secondary supply location. These are shown above in Figure 1: Map of 3rd floor operating rooms across all buildings.

There are intra-day processes that directly manage the supply fulfillment of the daily surgeries and surgical procedures, and higher level inter-day processes, such as re-stocking of inventory locations and ordering and delivery of supplies from external suppliers. The flow and timing of these activities are shown above in Figures Figure 3Figure 4. In what follows we describe the respective processes in detail.

The subsequent discussion is based on information obtained from interviews and shadowing. Specifically, interviews were conducted with different stakeholders involved in the supply chain, including administration, surgeons, nursing staff and various Central Sterile Processing and Supplies staff (i.e., case pickers, operating room specialists and supervisors). Shadowing was performed within CSPS, while picking on the surgical floors and in the operating rooms during procedures. In this chapter we describe the processes of the perioperative supply chain, and in Chapter 3 we describe the data analysis that was performed to analyze the current state.

2.1. General Inventory Policy

MGH aims to hold three days of inventory for each item type. This is defined through the notion of a par level, which is the target inventory level for an item in a specific location. Three days of inventory may be considered conservative given the fact that inventory is reviewed and orders are placed daily from Owens & Mino, who guarantee same day delivery. However, the hospital cannot
afford to run out of items that do not have appropriate substitutes, and is not likely to decrease this safety factor as long as tracking of actual usage is not complete (see more in the discussion below). It should be noted that the hospital also prepares for known delays (e.g., snowstorms) by ordering more or earlier.

The decisions regarding the specific locations and inventory levels of items are distributed among different stakeholders. For operating room stock, the decisions of what items to stock and at what quantity are made by the nursing staff (of each respective service), based on the view that they are the main users of this stock location. Operating room specialists (ORSs) decide how much to stock in the specialty carts, and materials management staff controls the par levels of the items in the central locations (CSPS and Jackson Supply). While some of these decisions were made early on during the transition to a central supply location, some changes are made based on need and trends in use. For example, there are cases when nursing staff requests to add an item to room stock. However, these stocking decisions are mostly made based on assumptions and anecdotal information regarding what is needed, not in a well informed, data-driven and systematic manner.

2.2. Inter-Day Processes

Inventory levels across all locations are reviewed on a daily basis. Each weekday morning, materials management associates walk through the different stock locations, identify items with inventory levels below their specified par levels and note the quantity that should be ordered to bring these items to their par levels. Following the review, orders are placed out of CSPS and Jackson Supply separately and independently. For specialty items that are not kept in the central locations, the ORSs make a request, and materials management staff will place a purchase order on their behalf. These orders will be delivered by CSPS staff to a temporary storage location in Jackson Supply, and the ORSs will use that to stock their specialty carts.

The majority of generic supplies (60%-70%) are purchased through Owens & Minor (O&M), a leading medical and surgical supplies distributor that provides "just in time" delivery, and the rest of the orders are either supplied by Cardinal (custom surgical packs, drapes and gowns) or by other vendors though FedEx/UPS deliveries. Orders that are placed with O&M in the morning are supplied in the afternoon of the same day. O&M fulfills the orders from a warehouse in Franklin, MA, about an hour drive from MGH. It is one of 55 distribution centers they have nationally, where
they hold two-three months of inventory for MGH. Generally, O&M provides this service for a markup on the prices that MGH (or Partners HealthCare) negotiates directly with its suppliers.

Each night, the operating rooms’ inventory levels are reviewed and re-stocked as necessary as per the specified par levels. The Lunder operating rooms are stocked from CSPS and the Legacy rooms are stocked from Jackson Supply. Specialty items located in the clean cores or specialty carts are re-stocked by the ORSs, and the generic supplies in the clean cores are re-stocked by the materials coordinators who stock the rooms (“room stockers”).

2.3. Intra-Day Processes

Each surgical case requires surgical instrument sets and disposable sterile supplies, most of which are picked and brought to the OR prior to the procedure on a dedicated case cart. The list of items that are required by a specific surgeon for a specific procedure is kept on a respective preference card, which is reviewed by nursing staff a few days before the procedure to make any patient specific adjustments. The reviewed card is the basis for a pick list, which includes all the required items, their quantities and exact locations. Pick lists typically include three types of items:

(i) Surgical instruments (e.g., forceps, retractors) that are sterilized in CSPS after each time they are used; some of them are kept in instrument sets and some independently,

(ii) Custom surgical packs, which are procedure specific kits pre-packed and sterilized by the distributor,

(iii) Individually packed disposable supplies, also referred to as “soft goods”, such as sutures, blades and tubes.

Some of the items on the pick list are defined as standby items, and those should not be opened unless required, to prevent waste (or re-processing, in the case of a standby surgical instrument).

Each morning, the pick lists for the cases scheduled for the next day are printed in CSPS for picking. A case cart is (see Figure 5) designated for each case, and case pickers pick the disposable supplies and custom surgical packs that are stocked at CSPS, and later pick the sterilized surgical instruments. Typically, the soft goods are put in a bin on top of the cart. Once picking of the items that are located in CSPS is complete, the case cart is brought up to the surgical floor, where the ORS that works with the relevant surgical service completes the picking of specialty items that are located on the floor (either at Jackson Supply, specialty carts or clean cores). Implants, if required, are brought
directly to the room by the nurse or ORS. Before the beginning of a surgical case, the nurse and surgical technician assigned to the case open all the non-standby items that were brought on the case cart and prepare them for use on the sterile field. At the end of the procedure, unopened supplies are put back in the bin on the case cart, which is returned to CSPS. CSPS staff later return all the unused supplies to their respective locations, which may be outside of CSPS in some cases (e.g., an item that was picked on the floor by the nurse but was not opened would still be returned to CSPS).

Figure 5: Examples of typical case carts

3. CURRENT STATE ANALYSIS

3.1. Approach

We studied the processes that are part of the delivery of supplies to the operating rooms, and the systems that support them. We performed active data collection regarding the different aspects of the system: surgeons' preference cards and procedure specific pick lists, historical purchase orders and hospital spend financial data, and current inventory levels and locations.

3.1.1. IT Systems and Data Sources

There are two main information systems involved in the perioperative supply chain:

- **PeopleSoft**: This is an Oracle software package that provides human resources management, financial management solutions and supply chain management applications. The relevant data points we used from this system are:
  - Supply (product) data, including the unique item ID, description, unit of measure, manufacturer, etc.
  - Purchase order data, such as order date, order number, item IDs, quantities, purchase amount, etc.
  - Profile carts data describe inventory locations and their contents. Each profile cart has a location ID, a cart description, item IDs and their respective target quantities (par levels) and more. Profile carts exist for the shelves in CSPS and Jackson Supply, specialty cabinets, clean cores and some of the operating rooms.

- **PeriScope**: This is an MGH custom software program for perioperative management. It holds the following information:
  - Supply and Profile Carts data, from the PeopleSoft fields described above
  - Case data (patient name, medical record number, surgeon, service, procedure, etc.)
  - Preference cards data
  - Pick lists
  - *Supply Doc* a recent addition for documentation of actual usage in the OR, still in the process of implementation throughout the operating rooms. This PeriScope module is
designed to allow nursing staff in the operating rooms to track the supply used in each surgical case. The module provides access to all available items and fields for the quantity used and the quantity wasted, and automatically populates the fields with the pick list data. Nursing staff can then change the quantities and add items to the list. Typically, the nurses keep the packages of the items that are opened during the procedure, and add them in Supply Doc when they are free during the procedure, or at the end of the case. Currently, Supply Doc has been adopted in some of the surgical floors (e.g., Legacy, Lunder 2) and some of the surgical services, but is still in the process of full implementation throughout the operating rooms.

- **Billing data**
  - *Stock Lists* - not all room stocks are represented as profile carts, and instead have an Excel-based stock list. As part of this work we had an inventory count performed in some of the rooms to update the stock lists.

Most of the data used for this analysis was taken from PeopleSoft and PeriScope. The main interfaces between these systems are shown in Figure 6 below (with color coding to show where the data is created, as PeriScope receives data from the other systems). There are additional interfaces that are not described here, to the instrument sterile processing system (SPM) and to Mobile Aspects, a system of RFID cabinets that tracks usage of billable items and is used for high cost items such as implants.

![Figure 6: Main IT systems used as data sources and their interfaces](image)

Some of the data sources mentioned above, such as the profile carts, are known not to be entirely accurate, though they are a reasonable estimate in most cases (based on validation we have
performed in the actual locations, including several operating rooms and CSPS shelves). Other data, such as past purchase orders or pick lists, are assumed to be accurate as they are a reflection of the actual data used when purchasing or picking. To complete missing or inaccurate data regarding operating room stock, an inventory count was performed in a number of rooms, each representing similar rooms used by the same service. These stock lists were an additional data source for the analysis of current inventory levels that will be described below.

3.1.2. Analysis
Following the process mapping described in the previous chapter, and using the data from the IT systems described above, we focused our analysis of the current state on four areas: (i) variability in demand, (ii) spend mix, (iii) item velocity (i.e., its ordering frequency) and (iv) total inventory levels.

- **Variability in demand**
  We analyzed the differences across surgeons’ preference cards for the same procedures. We grouped preference cards of different surgeons by type of procedure, identified item commonalities across those cards and compared the total costs. Error! Reference source not found. This analysis was performed for 26 groups of preference cards in the general surgery service.

  Some of the groups analyzed were more consistent, but in many cases the analysis identified outliers in cost. These outliers were considered by the clinicians to separate a real need (e.g., a surgeon that uses a different surgical method that requires different supplies than most other surgeons) from costly items that could be eliminated from the preference card and replaced by a substitute. That was the case for the example presented below, in which the surgeon was not aware of the cost of the item. In addition, many of the high cost items are not billable (i.e., the reimbursement for the procedure does not depend on the supplies used) and in some cases the hospital spend might be higher than the reimbursement.

  Figure 7 below is an example of the output of this analysis, listing three of the 18 preference cards on file for a laparoscopic cholecystectomy (“Lap Chole”), presenting the preference cards with the minimum, median and maximum of total cost. The column marked as \%request describes the portion of all preference cards analyzed where this item is used, and the Weighted column factors the number of procedures performed annually into this value, as a sense for how often the item is used. The red circle indicates a high cost item used by only one surgeon. This
analysis demonstrates the variability in items used by different surgeons for similar procedures and the associated different costs. The analysis could be used to implement (potentially partial) standardization in preference cards, driving physicians to use the same supplies for the same types of cases. This would require an assessment of possible effects of use of the non-common supplies on clinical outcomes.

### General Surgery Preference Cards Analysis (basic items only, no standby)

Procedure Group 7: Lap Chole  
Number of Preference Cards: 18

<table>
<thead>
<tr>
<th>Preference Card ID</th>
<th>Frequency of Use</th>
<th>Item Description</th>
<th>PS #</th>
<th>Min</th>
<th>Med</th>
<th>Max</th>
<th>%request</th>
<th>Weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>2456</td>
<td>7</td>
<td>NEEDLE SURGICAL 150MM</td>
<td>8333</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>1010</td>
<td>87</td>
<td>TROCAR SURGICAL 5012</td>
<td>17901</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.94</td>
<td>1.00</td>
</tr>
<tr>
<td>6965</td>
<td>5</td>
<td>SOLUTION IV 1000ML IN</td>
<td>28293</td>
<td>0.89</td>
<td>0.89</td>
<td>0.89</td>
<td>0.72</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SUTURE VICRYL 4-0 PS-</td>
<td>29461</td>
<td>6.13</td>
<td>0.00</td>
<td>0.00</td>
<td>0.17</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SYRINGE W/O 30ML NEED</td>
<td>37180</td>
<td>0.21</td>
<td>0.21</td>
<td>0.21</td>
<td>0.78</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SUTURE VICRYL 0-0 UR-</td>
<td>74454</td>
<td>1.62</td>
<td>1.62</td>
<td>1.62</td>
<td>0.94</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TROCAR BLADELESS 5X10</td>
<td>106772</td>
<td>46.94</td>
<td>46.94</td>
<td>46.94</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TROCAR ENDOPATH 11X10</td>
<td>106774</td>
<td>0.00</td>
<td>60.28</td>
<td>60.28</td>
<td>0.89</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TROCAR ENDOPATH 5X100</td>
<td>109796</td>
<td>54.82</td>
<td>27.41</td>
<td>54.82</td>
<td>0.94</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CONTAINER SPECIMEN 12</td>
<td>128509</td>
<td>0.51</td>
<td>0.51</td>
<td>0.51</td>
<td>0.89</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CLIP APPLIER MED LG 5</td>
<td>130741</td>
<td>0.00</td>
<td>0.00</td>
<td>1301.46</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PREP SKIN 26ML CHLORA</td>
<td>132484</td>
<td>0.00</td>
<td>6.57</td>
<td>0.00</td>
<td>0.50</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SUTURE MONOCRYL 4-0 P</td>
<td>145126</td>
<td>0.00</td>
<td>7.66</td>
<td>7.66</td>
<td>0.83</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BAG SPEC RETRIEV 4INX</td>
<td>157653</td>
<td>11.02</td>
<td>11.02</td>
<td>11.02</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TROCAR ENDOPATH 11X10</td>
<td>309178</td>
<td>34.60</td>
<td>34.60</td>
<td>0.00</td>
<td>0.61</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MGH OR ONLY PACK LAP</td>
<td>331184</td>
<td>71.09</td>
<td>71.09</td>
<td>71.09</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SCISSORS REPOSABLE ME</td>
<td>358555</td>
<td>0.00</td>
<td>40.00</td>
<td>40.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Total Cost:

- Procedure 2456: 227.84  
- Procedure 1010: 308.81  
- Procedure 6965: 1596.51

Figure 7: Example of preference cards variability analysis for a Lap. Chole. procedure

**Spend mix**

We compared the purchase spending on items that appear on pick lists to the total spend on supplies. Specifically, we contrasted the total spend on items that are on pick lists to items that never appear on pick lists, over a six month period. Items are grouped by categories that fall under three main groups – medical/surgical supplies (the disposable supplies that are the focus of this work, referred to in the figure as “med/surg”), trauma and implants. Figure 8 shows the spend on items by their categories. This figure is based on purchasing data from July 2012 to
December 2012. While there are some categories that are mostly managed through pick lists, such as the custom packs and sutures, about half of the items on the general medical/surgical category, which has the biggest spend, are not on pick lists at all. We should note that the items that are on pick lists can also be taken from the room or on the floor.

The fact that much of the spending is for items that are not on pick lists suggests that the savings that could be obtained via improvements in the management of preference cards are limited, and that an overarching improved inventory policy should be implemented. In addition, the preference cards might not be comprehensive enough, and additional items should be added to them.

![Graph showing comparison of costs of items on pick lists to total spend (07/2012 - 12/2012)](image)

Figure 8: Comparison of costs of items that are on pick lists to total spend (07/2012 – 12/2012)

- **Item velocity** (frequency of use)

  Highlighting the less commonly used items is useful to identify items that could possibly be eliminated if appropriate substitutes exist, or otherwise be kept at a minimal quantity. Generally, we categorized items as *slow moving* or *fast/non-slow moving* based on the number of purchase orders over the course of a year, otherwise referred to as the **item velocity**. We defined slow moving items as those that were ordered less than once a month on average.
Figure 9 shows a histogram of O&M items by the number of annual purchase orders, demonstrating that roughly 50% of these items are defined as slow moving. Some items are ordered as little as once a year, yet others are ordered a few times per week.

![Figure 9: Histogram of O&M items' velocity](image)

Using the purchase order data, we also looked at the cumulative cost and cumulative inventory worth of the different O&M items with respect to item velocity to understand how items of different velocity drive overall inventory. As shown in Figure 10, while most of the purchasing cost is based on the fast moving items, the inventory worth is mostly in slower moving items. This figure is based on 17 months of purchase orders data, from January 2012 to May 2013.

![Figure 10: Cumulative cost/inventory worth of Owens & Minor items (01/2012 – 05/2013)](image)

32
Current Total Par Levels

We estimated the total levels of inventory across all items and locations as a reference for any inventory par levels intervention, in order to be able to estimate the potential impact of such an intervention. The main data sources for the current state were the profile carts and room stock lists (which include the specific items and respective par levels in every location). It should be noted that only 70% of the rooms are covered in this estimate as the others are not represented in profile carts and an inventory count was not performed for them, so it is a conservative estimate of the current inventory levels.

Items have different units of measure, e.g., each or box, and the purchase orders are placed in those units of measure. The profile carts and room stock lists vary, where lists for rooms and specialty carts are typically counted in "each", and had to be converted to the standard unit of measure. For most items, the conversion factor exists as a data field in PeriScope and was used to more accurately estimate the current par levels.

The resulting estimated total par levels are given in Table 2, under the results section of Chapter 5.

3.2. Challenges

We identified issues both on the supply side as well as the demand side of surgical supplies. Some of the challenges had to with inaccuracies with respect to the required items (on the preference cards) or their locations, and others with waste that could be reduced by changes in the system design or processes.

<table>
<thead>
<tr>
<th>Inaccuracy</th>
<th>Demand of Surgical Supplies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inaccurate locations on pick lists</td>
<td>Inaccurate items on preference cards</td>
</tr>
<tr>
<td>Incomplete instrument sets</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waste</th>
<th>Demand of Surgical Supplies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple inventory locations</td>
<td>Highly variable preference cards</td>
</tr>
<tr>
<td>No tracking of inventory levels</td>
<td>Excessive standby items leading to high volume of returns</td>
</tr>
<tr>
<td>Inventory levels that are too high</td>
<td>Slow moving items in rooms</td>
</tr>
</tbody>
</table>

Table 1: Categorization of challenges in the current state
The three main concerns that emerged were: (1) inaccuracies in the preference cards and lack of standardization, (2) multiple stock locations, particularly for slow moving items, and (3) inventory levels that are higher than required. These issues are somewhat related since lack of confidence in the preference cards system creates the need for more backup inventory locations and higher par levels. Specifically, we considered addressing the following issues:

3.2.1. Preference Cards

- Different surgeons use different supplies for the same procedures, as described in Section 3.1.2. The high variability drives a higher number of item types used, with higher variability for each item.
- There is a lack of awareness of cost of supplies in the creation or review of preference cards. There have been some initiatives aimed at increasing awareness of costs, but the costs are often not available to the clinical staff.
- Actual usage of supplies in the OR is not linked back to the preference cards or par levels. While tracking of usage has started with Supply Doc, there is no analysis on the difference between the amount used and the amount on the pick list, and no feedback to the items and quantities on the preference cards.

3.2.2. Inventory Levels and Locations

- Items' inventory levels are not based on data-driven analysis, and respective decisions are made purely based on estimates of need rather than on existing data regarding purchasing or usage. In addition, there is no tracking of the current inventory or returns.
- Slow moving items are kept in multiple locations, driving unnecessarily high par levels. Some of these items are rarely used, e.g., purchased once over the course of a year, yet are stocked in a number of operating rooms and additional locations on the surgical floors.
- There is no coordination across the two central inventory locations. In particular, par levels are reviewed in each of them and orders are placed separately, driving a higher variability and higher inventory levels.
4. **Potential Interventions**

While there is an opportunity for major improvement in the standardization of preference cards, this thesis is focused on improved inventory management of the disposable surgical supplies ordered from Owens & Minor. This decision was driven by several factors. First, MGH is just starting to collect data on actual usage of supplies in different procedures using the Supply Doc module, which is an essential input for a revision of preference cards. In addition, as shown in Figure 8 above, the majority of the purchasing cost is spent on items that are not included in preference cards. Considering the medical/surgical supply item categories, we can see that some are mostly managed through preference cards and pick lists (e.g., custom packs and sutures), but for the general category, which has the highest spend, half of the items that are purchased are never picked through pick lists. This indicates the strong need for detailed supply usage data that can provide accurate demand data to determine the correct inventory levels and adjust the preference cards according to actual usage. A suggested framework for improving the preference cards will be discussed in section 8.2 as suggested future work.

Given the current state, we hypothesized that improved management of this inventory could lead to significant cost reductions. In addition, a new contract that was negotiated between Partners HealthCare and O&M in 2013 suggested rebates based on annual reduction in purchase order lines. Such a reduction could possibly be achieved by coordinating and joining orders that are currently done separately for the different locations. Based on this initial analysis, we chose to study the following interventions:

- Compute data-driven par levels for all items
- Pool safety stocks across locations
- Reduce the annual number of purchase order lines by using joint orders
- Define a methodology for inventory locations
- Adjust the ordering frequency and number of days of inventory held

4.1. **Metrics and Definitions**

In this section we define the key metrics that were used to assess the impact of this work.
4.1.1. Total Par Levels
We compute the total par level for each item. The par level of an item is the target inventory level (the quantity that should be “on the shelf” after restocking, at the beginning of the day). The total par level of an item is the sum of its par levels in the different locations where it is stocked. The total number of units in inventory is the basis for the total inventory cost (and inventory holding cost), as well as the total space required.

4.1.2. Cost
As shown in Figure 8, disposable supplies are a major cost for the perioperative administration. By reducing overall spending, these funds can be better utilized for other areas of the hospital’s work. This includes both the purchasing cost, as well as the inventory holding cost which depends on the total inventory worth. The purchasing cost would have a one-time reduction by decreasing the inventory levels, but would also benefit from reduced waste and more efficient use of the items on hand. In Schlanser’s work, inventory holding cost rate was taken to be an annual 40% per dollar invested, based on warehouse capital cost, as calculated by an external consulting firm that was working with Perioperative Services regarding the move to the Lunder Building and CSPS.

4.1.3. Space
While a little over 50% of the items are stored in CSPS and Jackson Supply, many are stored in the operating rooms and on the surgical floors. Reducing storage space would allow for better utilization of the available space, including for clinical purposes. With an increasing volume of procedures and an upcoming renovation of the Legacy area, there is an opportunity to make an impact based on the implementation of this work.

4.1.4. Access/Accuracy
The mission of CSPS is to have the right item, at the right place, at the right time. This implies very high service levels and a desire to minimize the likelihood of shortages. This is more of a constraint than a metric, driving the safety factors that the hospital uses for inventory levels.

5. INVENTORY LEVELS

In this chapter, we propose a robust methodology to compute the total par levels resulting from different scenarios, and compare them to the current state using the metrics described in Section 4.1, primarily cost and space. The scenarios we consider are as follows:

- Current ordering policy but with data-driven par levels, that are computed based on historical purchase orders data as an approximation of demand.
- Data-driven par levels as well as pooling of safety stocks across the central locations, using the benefits of the lower relative variability of the joint demand.
- Different review period and lead time assumptions for the two scenarios above. The review period is the time between inventory reviews, and the lead time is the lag between when an order is placed and when it arrives.

5.1. Model

Using data regarding current inventory levels and locations, as well as historical purchasing data, we compare the current par levels to suggested demand-driven levels. We computed the par levels for the central locations since they represent aggregate demand over all locations. In addition, the short lead times (minutes) between the various locations support the assumption of one location for the purpose of calculating overall inventory or safety stock needed.

Generally, inventory levels should be driven by the expected demand over the lead time and inventory review period, with additional safety stock to account for variability over this time period. The target base-stock level is a function of the lead time and review period, the desired service level (probability for having the item in stock) and the variability of demand over the lead time and review period. The following equation is a known formula for computing base-stock levels:

\[
\text{Base - Stock Level} = E[\text{demand over lead time and review period}] + k \sigma \text{[demand over lead time and review period]}
\]

where \( E \) and \( \sigma \) represent the mean and standard deviation of the demand over the lead time and review period and \( k \) is the standard score of the normal distribution for the required service level (e.g., \( k=2.33 \) for 99% service level). Alternatively, if we have the empirical demand distribution over the lead time and review period, we can simply take the target base-stock level to be the \( 99^{th} \)
percentile of the cumulative demand distribution for the same service level. We calculated both values, and while for some of items there was only a minor difference, we chose to use the empirical distribution as it was more accurate, and did not make the assumption of a normal distribution.

The analysis varied slightly depending on the item velocity. While we generally aimed for the 99th percentile, that value was zero for some of the slow moving items that were only ordered once or twice over the year. For these items, we used the 100th percentile, or maximum demand, to be conservative in our suggested inventory levels. As stock-outs are not a problem currently and rarely happen, inventory levels should not be increased, even if the results of the calculation show otherwise.

5.1.1. Model Inputs
Next we discuss how we estimated the required inputs to the model, including the demand distribution and other parameters.

5.1.1.1. Empirical Demand Distribution
For this analysis we used the data regarding all purchase orders in 2012. Since items are ordered daily to compensate for the supply used, this is a reasonable approximation, though there might be inaccuracies based on units of measure (e.g., number of units in different box sizes), that we will discuss below. Since this data provided us with an approximation of the empirical distribution of the demand, we used it to calculate the 99th percentile of demand over different time periods. This is in fact an upper bound on the true quantile since purchase orders have higher variability due to the fact that they might aggregate demand.

5.1.1.2. Parameters: review period (R) and lead time (L)
All inventory locations are reviewed daily and orders are placed in the morning. Since our analysis focuses on Owens & Minor items which all have a same-day lead time, we take the combined lead time and review period as one day. However, the approach of MGH is quite conservative. The hospital might wish to be prepared for scenarios in which the daily shipments could be disrupted for some periods of time (e.g., snowstorm). To capture these trade-offs and estimate the impact of the number of days of inventory held by MGH, the model that was developed can consider different values for the combined review period and lead time (R+L).
The required service level was assumed to be 99% for all the scenarios considered.

5.1.2. Detailed Methodology

Using the data consisting of all purchase orders in 2012, we created lists of purchase orders for each item, to calculate the total demand over different periods of time (one day, two days, three days, one week). To aggregate the demand over these time periods, we assume specific days on which there would be an order/review and create “templates” that include all possible dates for these days (see Figure 11 for examples):

- R+L=1: Mon/Tue/Wed/Thu/Fri for daily review (one day of inventory)
- R+L=2: Mon/Wed/Fri (roughly two days of inventory)
- R+L=3: Mon/Thu (roughly three days of inventory)
- R+L=4: Monday only for weekly review (5 days of inventory)

Since these are mostly generic items used by most surgical services, there is not much variance across different days of the week for the fast moving items. As for the slow moving items, there would be at most one order in any of these review periods, so a different breakdown of the weekdays would not affect the distribution.

<table>
<thead>
<tr>
<th>R+L=1</th>
<th>R+L=2</th>
<th>R+L=3</th>
<th>R+L=4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Week</td>
<td>Day</td>
<td>Index</td>
</tr>
<tr>
<td></td>
<td>(1-52)</td>
<td>(1-7)</td>
<td>(1-365)</td>
</tr>
<tr>
<td>1/2</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1/3</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1/4</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>1/5</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>1/6</td>
<td>1</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>1/9</td>
<td>2</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>1/10</td>
<td>2</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>1/11</td>
<td>2</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>1/12</td>
<td>2</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>1/13</td>
<td>2</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 11: Example of review dates templates for various review periods

For each item and time period, we take all purchase orders and aggregate the demand over the respective time period according to the template: for every review/order day (index i) noted as curr_date, we aggregate the demand (i.e., the quantity in the purchase orders, noted as PO) from the
previous days that were not a review/order day (all \( i \)'s greater than the previous order date, noted as \( \text{prev\_date} \)), or put in zero if there would not be an order on that day:

\[
\text{Total Demand for Current Order Day} = \sum_{\text{prev\_date} < i \leq \text{curr\_date}} PO_i
\]

5.1.3. Model Output

Once the demand is calculated for different time periods, we use it to identify the 99th percentile of demand for that item, or 100th percentile (maximum demand) when the 99th percentile is zero. As mentioned above, since MGH does not observe stock-outs currently, we use an upper bound for the new par levels at the existing level, even if the calculated par is higher.

Since purchase orders are coming from different locations, mostly CSPS and Jackson Supply, the base stock level is calculated for each of them separately. The result is a list of data-driven par levels for every item; we consider the total of those par levels (adding CSPS total par, Jackson total par, and the total par for the other locations).

To gauge the impact of computing data-driven par levels and pooling of stock locations, we considered three scenarios: (i) the current state, (ii) data-driven par levels (noted in some of the figures as \( DD \)) and (iii) data-driven par levels and pooling of safety stocks (noted as \( Pooled \)).

For the pooled scenario, we repeat the calculation described above using the joint demand from all locations. By using a joint safety stock and joint orders across the different locations, the variance in demand is lower, driving lower safety stocks.

Using the par levels for the different scenarios (current, data-driven, and pooled, for the different time periods), we calculate the respective inventory worth, and the estimated space. While the system does not include data regarding items' size, items were categorized by experienced nursing and materials management staff based on their classes as Small/Medium/Large, and we use a quantitative scale (Small=1, Medium=3, Large=5) to estimate the required space for the par level results, in reference to the current state.

5.2. Results

5.2.1. Suggested Par Levels for Three Days of Inventory
As MGH currently aims to hold three days of inventory, we focus first on this scenario, essentially assuming a three-day combined lead time and review period (R+L=3). The main result of the analysis is a new suggested total par level for every item. The potential impact can be shown by comparing the aggregated suggested levels to the current inventory levels. We first present the existing par levels (their conservative estimate) compared to the proposed data-driven par levels (not pooled, total par across locations) without bounding at the current par levels. Figure 12 plots the ratio of the current level and the suggested level for each item, with respect to the item velocity:

The black line represents the suggested par levels (in relative sense, at 100%) in the data-driven, not pooled, scenario, for three days of inventory. Each point in the scatter plot represents an item, and how its current par level compares to the suggested level, with respect to velocity (from slow to fast), for the data-driven scenario.

In some cases, the calculated par levels are higher than the current levels, inferring that these items are under-stocked. These are the items under the black line. We believe that this may be the result of two factors:
- For some of the supplies, the minimum order unit is a box or a case, which may hold tens or hundreds of individual items. For these items, the purchase history is not as good of an approximation of demand as it creates artificial variability, leading to higher safety stocks.

- The current inventory levels we use for the comparison are only an estimate, as some of the data sources for this count are not completely accurate – we only cover about 70% of the room stocks, and profile carts may not be accurate as well.

If the perioperative administration decides to increase inventory levels for the items that appear to be under-stocked, we note that there would still be a reduction in inventory worth, but the overall number of items in stock would increase and it would not be feasible given the current space limitations (a calculated 20% increase for the pooled scenario). Given the assumption that par levels would not be increased, Figure 13 below shows the results with the bounded par levels:

![Cumulative reduction in inventory $ value (without pooling)](image)

Figure 13: Distribution of calculated par levels without pooling, by item velocity (bounded by current state)

In this figure, the secondary axis refers to the resulting cumulative reduction in inventory worth (with three days of inventory held), with respect to the item velocity. This figure demonstrates that
most of the reduction in inventory worth is driven by the slow moving items (on the left, low number of purchase orders), as these are most of the items that are currently over-stocked. Figure 14 shows the results for the scenario in which the safety stock of Jackson Supply and CSPS is pooled. In this scenario, the results show similar trends but the cumulative reduction in inventory worth is greater.

![Graph showing cumulative reduction in inventory worth](image)

Figure 14: Distribution of calculated par levels with pooling, by item velocity (bounded by current state)

To assess the reduction in inventory levels and savings, we consider the aggregate results across all items. We consider the total number of units in inventory at the current state and in the suggested scenarios, as well as the total inventory worth, summing all items by their quantities (par levels) and costs.

Table 2 below shows the estimated current total inventory levels (and total worth), broken down in two ways – by item velocity, and by number of current locations (the multiple locations column
includes items that are stocked in more than one location, e.g., CSPS and Jackson, or a number of operating rooms).

<table>
<thead>
<tr>
<th>Current State (estimate)</th>
<th>ONE LOCATION</th>
<th>MULTIPLE LOCATIONS</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLOW</td>
<td>145</td>
<td>509</td>
<td>654</td>
</tr>
<tr>
<td></td>
<td>1,371</td>
<td>7,704</td>
<td>9,075</td>
</tr>
<tr>
<td></td>
<td>$83,525</td>
<td>$671,340</td>
<td>$754,865</td>
</tr>
<tr>
<td>NON SLOW</td>
<td>31</td>
<td>528</td>
<td>559</td>
</tr>
<tr>
<td></td>
<td>1,166</td>
<td>20,708</td>
<td>21,874</td>
</tr>
<tr>
<td></td>
<td>$13,571</td>
<td>$897,260</td>
<td>$910,831</td>
</tr>
<tr>
<td>Totals</td>
<td>176</td>
<td>1,037</td>
<td>1,213</td>
</tr>
<tr>
<td></td>
<td>2,537</td>
<td>28,412</td>
<td>30,949</td>
</tr>
<tr>
<td></td>
<td>$97,096</td>
<td>$1,568,600</td>
<td>$1,665,696</td>
</tr>
</tbody>
</table>

Table 2: Summary of current par levels and inventory worth

Table 3 and Table 4 summarize the aggregated results for both three-day scenarios, where each cell shows the inventory levels (number of units) and inventory worth ($):

<table>
<thead>
<tr>
<th>3-day bounded (data-driven)</th>
<th>ONE LOCATION</th>
<th>MULTIPLE LOCATIONS</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLOW</td>
<td>925</td>
<td>3,638</td>
<td>4,563</td>
</tr>
<tr>
<td></td>
<td>$40,322</td>
<td>$281,300</td>
<td>$361,622</td>
</tr>
<tr>
<td>NON SLOW</td>
<td>1,166</td>
<td>15,565</td>
<td>16,731</td>
</tr>
<tr>
<td></td>
<td>$13,571</td>
<td>$601,488</td>
<td>$615,059</td>
</tr>
<tr>
<td>Totals</td>
<td>2,091</td>
<td>19,203</td>
<td>21,294</td>
</tr>
<tr>
<td></td>
<td>$53,894</td>
<td>$882,787</td>
<td>$936,681</td>
</tr>
</tbody>
</table>

Table 3: Summary of par levels results for the data-driven scenario

<table>
<thead>
<tr>
<th>3-day bounded (with pooling)</th>
<th>ONE LOCATION</th>
<th>MULTIPLE LOCATIONS</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLOW</td>
<td>917</td>
<td>3,049</td>
<td>3,966</td>
</tr>
<tr>
<td></td>
<td>$39,966</td>
<td>$209,026</td>
<td>$248,991</td>
</tr>
<tr>
<td>NON SLOW</td>
<td>1,164</td>
<td>13,539</td>
<td>14,703</td>
</tr>
<tr>
<td></td>
<td>$13,056</td>
<td>$450,515</td>
<td>$463,571</td>
</tr>
<tr>
<td>Totals</td>
<td>2,081</td>
<td>16,588</td>
<td>18,669</td>
</tr>
<tr>
<td></td>
<td>$53,022</td>
<td>$659,541</td>
<td>$712,562</td>
</tr>
</tbody>
</table>

Table 4: Summary of par levels results for the data-driven and pooled scenario

The estimated space reductions are very close to the reductions of inventory levels, roughly 30% and 40% for the data-driven and pooled scenarios, respectively.

Clearly, the main driver for reductions are the slow moving items that are stocked in multiple locations. This effect is even stronger in the pooled scenario, where items in one location are not
affected by pooling. These results validate the initial hypothesis that slow moving items are kept in larger than needed quantities across multiple locations.

5.2.2. Additional Levers

The figure below shows the potential reductions for additional scenarios, if the perioperative administration decides to hold less than three days of inventory, given the daily review and same day delivery. The bars represent the inventory levels (number of units in inventory, with labels indicating the percentage reduction from the current state), and the dollar values are the corresponding inventory worth:

![Bar Chart](image)

Figure 15: Impact of days of inventory held on total inventory levels and worth

It appears that the three-day and two-day scenarios are quite comparable. While the two-day scenario suggests greater reductions as expected, the effect is not dramatic a transition to this scenario might not be worth the reduced safety factor.
As will be discussed under future work, inventory levels could be reduced further by smoothing the demand of surgical supplies, which could be achieved by reducing variability of supplies across different surgeons where possible. Refining the location of items is another driver, as slow moving items should be pooled into central locations to reduce overall inventory; alternative items (substitutes) should be considered as well.

5.3. Impact

In addition to the reduction in space, there are two types of cost savings associated with the reduction in inventory levels: a one-time saving directly based on the reduced par level by reducing purchases and using the excessive stock, as well as an annual saving based on the estimated 40% rate for inventory holding cost:

<table>
<thead>
<tr>
<th>Implementation Scenario (3 days of inventory)</th>
<th>Reduction in inventory levels/space</th>
<th>One time saving (purchase)</th>
<th>Annual saving (holding cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data-driven (no pooling)</td>
<td>31%</td>
<td>$729K</td>
<td>$292K</td>
</tr>
<tr>
<td>Pooled</td>
<td>40%</td>
<td>$953K</td>
<td>$381K</td>
</tr>
</tbody>
</table>

Table 5: Aggregate estimated Cost/Space Savings for the Suggested Scenarios
6. PURCHASE ORDER LINES

In addition to the calculation of data-driven par levels as described in the previous chapter, the demand over the different time periods was also used to calculate the potential reductions in purchase order lines for longer review periods. The change in the review period and lead time parameters affects the frequency of orders, and the corresponding number of orders was calculated by item. Assuming the same day delivery as $L=0$, the combined lead time and review period $R+L$ in fact describes the review period, directly related to the frequency of orders.

By ordering from one location, orders that are now separate could be joined together; the change in order frequency increases the reduction in purchase order lines further. Such a reduction lowers complexity for the distributor (O&M) and could result in reduced costs if the reduction is above the threshold defined in the contract. However, such a change affects the MGH processes, since the materials associates would need to move supplies between the central locations in order to fulfill demand and meet the target inventory levels in all locations. While the system has this capability, since ORSs currently deliver supplies when needed unexpectedly, a high volume of intra-day deliveries might require additional labor. Currently, the perioperative administration is not interested in reducing the order frequency for all items, mostly since there is not sufficient accurate demand data for the operating rooms. To assess this trade-off, we test the impact of different review periods on the purchase orders.

6.1. Results

The reductions in purchase order lines for different review periods, assuming pooling and joint orders across locations, is shown in Figure 16 below (with the percent reduced from the current state labeled). This figure is based on the 2012 purchase order data that was used for the par levels analysis described in Chapter 5.

The reduction obtained from joint orders is not enough to meet the minimum threshold for the O&M savings. To attain those savings, the required purchase order lines reduction is at a much greater scale (an order of magnitude above these results), as the required reduction is across all MGH (and Brigham and Women’s Hospital). While that may be possible by changing IT systems, it is not feasible as currently orders are delivered to different locations at the hospitals and separating joint orders would be a major operation, probably more expensive than the potential savings.
Figure 16: Results – reduction in purchase order lines by order frequency

6.2. Impact

While the reduction in purchase order lines does not directly lead to cost savings with O&M, lower frequency of review for slow moving items could reduce the labor associated with the current daily review of all items. A change in review frequency for only some of the items might require a dramatic change in the workflow or the physical layout of the system to clearly indicate which items are reviewed on which days. CSPS is currently organized by item type, not item velocity. This could be re-considered, in addition to other methods which could be implemented more easily, such as color coding as an indication of review time.
7. **INVENTORY LOCATIONS**

The previous chapters describe a data-driven approach to determining inventory levels. Such an approach would also be useful in driving inventory locations, so that items are stored in the locations they are picked at, and room stock is minimized to essential items only. Generally, item locations can be categorized into three groups: (i) operating room stock, (ii) surgical floors and (iii) central inventory locations. In this chapter, we describe a model that uses item data to inform the decision of where it should be stocked. This model is based on the item type and its usage patterns, and is particularly valuable for the slow moving items that are currently stocked in too many locations.

In addition, we discuss the central locations and the appropriate functionality for Jackson Supply. Jackson Supply’s current function as a secondary central supply location and its use for re-stocking of rooms feed into the excessive locations and inflated inventory levels, and should be reconsidered.

7.1. **Model**

We suggest a type of location for each item, based on the urgency of the item (how immediate is the need for the item during surgery), the predictability of usage (does the preference card hold an accurate quantity) and the item velocity. The location can be one of the following:

- **Operating rooms**: These items also have safety stock in the central locations or on the floors.
- **Floor**: Inventory locations on the surgical floors, in proximity to the operating rooms. Items in these locations might have safety stock in a central location, but could also be stocked in a specialty location alone.
- **Central**: Central “warehouse” locations, e.g., CSPS. These items are only picked via pick lists.

7.1.1. **Model Inputs**

The data sources used for this model provide an understanding of the factors described above, as those are not all currently defined (specifically urgency and predictability). The available data for this analysis was:

(i) Item velocity, as previously defined (slow/non-slow) based on the annual number of purchase orders.
Item usage, the quantity used in each surgical case as tracked in Supply Doc (current data is incomplete) – while this model cannot be fully implemented at the current state, once the usage data exists for all rooms and services, it can be used to determine where items were picked. As the case study below will demonstrate, we compare the items and quantities on the pick lists to the items and quantities tracked in Supply Doc, for each specific surgical case, and the difference indicates whether an item was used as picked, wasted, or if the nursing staff had to pick additional items during the specific procedure.

For each item, in each surgical case, we define:

$$\Delta_{item, case} = Item\ Quantity_{Supply\ Doc} - Item\ Quantity_{Pick\ List}$$

A positive value (i.e., $\Delta > 0$) implies that for that specific case, the quantity tracked was greater than the quantity picked and the item was picked during the procedure. A negative $\Delta$ suggests a returned or wasted item, and when it equals zero we assume that the quantity picked matched the quantity used in that case.

Item urgency, describing the nature of an expected need for an item and where it should be stocked accordingly. Items’ urgency could be categorized in to three groups, which correspond to the three types of locations: (1) emergent items, that are needed within seconds, must be in rooms, (2) urgent items, needed within a few minutes, need to be on the floor and (3) non-urgent items, for which the surgeon can wait for more than a few minutes, can be stocked in a further, central location. This field does not currently exist for all items.

Item class, a field defined by the nursing staff to categorize the item (e.g., blade, sponge). In the absence of the item urgency classification, the class can sometimes be used to give a measure of urgency. There are 127 different classes, which were grouped by experienced nursing staff into three by the characteristics of the items in them: Group 1 includes the classes of items that are emergent for all surgeries that should generally be kept in room stock, as they may be needed urgently early on in the procedure. Group 2 classes are of specialty items that should be kept in specialty carts or service specific locations. Group 3 includes classes that cannot be easily categorized, as they may hold some items that are kept in every room and some that are service specific. Items in these classes have to be treated independently.
7.1.2. Detailed Methodology

The item location is determined based on the inputs described above. We decide if an item should be kept in room stock based on its velocity, urgency, and prior usage patterns – using the difference between the pick list quantity and the usage quantity $\Delta$ defined above. This difference may vary across different surgical cases and the distribution of $\Delta$ for each case type should be used. A metric for urgency is not currently captured, and is also required to fully carry out this methodology.

Phase I: Adjustment of Preference Cards

In addition to the location decision, this analysis can improve the accuracy of the preference cards. This should be the first phase of this methodology. The items that were consistently returned or wasted ($\Delta < 0$) are picked in a quantity that is too high, and the preference card should be adjusted accordingly. As for the items that are consistently picked during the procedure, the quantity should be increased if the amount used is predictable. This concept is similar to the base-stock formula used to compute the data-driven par levels described in Section 5.1; we want to guarantee a certain service level, and the quantity on the preference card should be driven by the distribution of the demand for this item in this case type. Once Supply Doc is fully adopted and there is sufficient data, the demand distribution for each item, in each case type, can be computed. The quantile of demand to be used for the preference card quantity depends on the service level required from picking, and is a function of the trade-off between the cost of returns (for a high quantile that might not always be fully used) and the cost of keeping additional items in room stock, at higher par levels. The quantile used for slow moving items should be higher than the quantile used for non-slow items, since we generally want to eliminate slow moving items from room stock.

Phase II: Locations Decision

Following the adjustment of the preference cards quantities to data-driven levels based on Supply Doc, a methodology for the locations of the items can be applied. The decision to locate an item in a room can be done by surgical service, as MGH has started to standardize rooms by service.

Non-slow moving items should be classified into locations directly based on their urgency, as described in Section 7.1.1. All emergent items should be in rooms, urgent items on the floors and the rest of the items could be stocked in CSPS. This supports a lower service levels for these items on the preference cards. Since the location decisions are made separately for each surgical service, an item's urgency could vary for different services, driving different location decisions.
As for the slow moving items, we suggest the following methodology. We consider the variability of demand for the item (or the respective distribution of $\Delta$), the number of case types and cases performed in which it is used and the item’s urgency. Similar to the non-slow items, urgent items should be stocked on the floors and non-urgent items in CSPS. In the diagram below we propose a framework to decide whether an emergent slow moving item should be kept in room stock, or should the amount on the pick list be increased to the maximum demand.

![Decision tree for location of emergent slow moving items](image)

Figure 17: Decision tree for location of emergent slow moving items

The usage data could also be used to drive the par levels for all items stocked in rooms, similar to the work described in Chapter 5. This would be done by analyzing in-room usage, by surgical service.

7.1.3. Case Study for Supply Doc Analysis – OR 33

As a case study, we analyzed available Supply Doc data for OR33, over a four month period (October 2013 – January 2014). Over this time period, we have tracking for 147 surgical cases, which include a total of 5,505 item-case combinations (an item type that was used in a specific case). The data used for this case study is not sufficient to be the basis for any preference card quantity or location decisions, but demonstrates the insights provided by Supply Doc data. For each surgical
case, we compared the quantity on the pick list to the quantity used, computing the value for $\Delta$ defined above. Figure 18 shows the distribution of these differences:

![Figure 18: Distribution of differences between usage documentation and pick list data across all items/cases](image)

According to this data, about two thirds of the items were used as picked. The negative values, where pick was greater than use, are only 1% of the occurrences, which is less than expected given the high volume of returns. This might have to do with this specific room (some of the procedures in this room are done with the da Vinci surgical robot, which has more accurate preference cards), or with problems in the on-going implementation of Supply Doc. For one third of the items (1,796 occurrences), the usage was greater than the picking, and we can deduce that 79% of these were not on the pick list to begin with (1,420 occurrences). This implies that these items are not picked during the procedure due to inappropriate quantities on the preference card, but that they were not picked to the case cart at all. On average, 12 additional units of supplies are picked during a surgical case.

To assess the potential of adjusting the preference cards, we considered the most common procedure performed in OR33 over this time period (23 cases), a laparoscopic radical prostatectomy with da Vinci Robot. Since some of the items were used once or twice, this is not sufficient data to create a full distribution, yet we consider the percent of the occurrences for which $\Delta$ was positive, as a different measure for items that would require adjustment of the preference card. Out of the 115 types of items used in these cases, 56 (49%) had a positive $\Delta$ in over 95% of the cases. Only one of these items is currently on a preference card for this procedure, and would only require adjustment of the quantity. The rest could all be added to the preference cards for this type of procedure.

Since this data is not sufficient to carry out the proposed location methodology by item, we consider the maximum value of $\Delta$ as a sense of whether items are ever picked in rooms. There are 555
different items that can be analyzed using the suggested methodology, 293 of them are O&M items. These are all items that were tracked in Supply Doc and actually used in the room. The table below shows how they are distributed, where the percentages refer to the total number of unique O&M items in this analysis (not to the total number of unique O&M items, which is about four times as much).

<table>
<thead>
<tr>
<th></th>
<th>Maximum $\Delta \leq 0$ (picked quantity was sufficient)</th>
<th>Maximum $\Delta &gt; 0$ (picked at least once during a procedure)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N=57</td>
<td>N=236</td>
</tr>
<tr>
<td>Slow</td>
<td>6% (18 items)</td>
<td>17% (50 items)</td>
</tr>
<tr>
<td>N=68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Slow</td>
<td>13% (39 items)</td>
<td>63% (186 items)</td>
</tr>
<tr>
<td>N=225</td>
<td>Emergent: 23 items</td>
<td>Emergent: 110 items</td>
</tr>
</tbody>
</table>

Table 6: Distribution of items in locations methodology case study, out of N=293

To summarize, roughly 45% of the O&M items discussed here are non-slow and emergent, so suggested to be kept in rooms. If we compare to the current state, most of these are in fact kept in rooms (except for six items, four of them sutures that were generally classified as emergent unless slow moving).

Considering the slow moving items, out of the top left cell, of items that should not be kept in rooms, nine items are currently held in room stock and could be eliminated. There are only three slow moving items that based on this analysis might go in room stock ($\Delta > 0$ and emergent); in fact, all three are sutures that could be places on a suture cart and eliminated from room stock. In addition, given the analysis of the laparoscopic radical prostatectomy with da Vinci Robot described above, two of the three emergent slow moving items that supposedly need to be in the room could be added to the preference card of that procedure. That might be the case for the other types of procedures in which these items are used.
The complete proposed analysis would ideally be done for all rooms used by a specific service to adjust the preference cards to demand-driven quantities and inform the decision of keeping an item in the room or centrally on the floor.

7.2. Jackson Supply

As described above, Jackson Supply currently functions as a secondary central supply for the Legacy area. It is stocked with supplies required for re-stocking of all the Legacy operating rooms, leading to an increase in the required inventory levels for these supplies, as demonstrated by the reduction attained in the pooled scenario described in Chapter 5.

Jackson Supply could be reduced to a clean core functionality, similar to the Lunder Building clean cores, and only hold intra-day backup supplies and specialty items for the surgical services using the rooms in proximity to it. Such a change would require all operating rooms to be re-stocked from CSPS. While re-stocking the Legacy ORs will require a greater walking distance with the supplies, materials management leaders see such a change as feasible, possibly requiring the addition of equipment to support this operation.

The par levels that were calculated for Jackson Supply in the non-pooled scenario would need to be reduced, but suggest how demand from this location is distributed and could be used for the initial decision of the adjusted inventory levels.
THIS PAGE INTENTIONALLY LEFT BLANK
8. RECOMMENDATIONS FOR IMPLEMENTATION

8.1. Key Recommendations

The analysis results suggest opportunities for savings by reducing the number of locations items are kept in and their inventory levels. However, some changes might not be feasible or could lead to major organizational and process consequences that could overcome the potential benefits. These aspects were discussed with the various MGH stakeholders.

Given the size of the hospital, and the 10-15 minutes distance between CSPS and the Legacy operating rooms (which is substantial in urgent situations), completely eliminating a secondary supply area is not a viable solution. We recommend adjusting to the proposed pooled par levels, re-stocking all rooms from CSPS and keeping Jackson Supply for specialty supplies and intra-day backup, similar to the Lunder Clean Cores. This supports the general recommendation of minimizing inventory locations to where we must have these items available, and at the minimal quantities that would still satisfy the required service levels.

In order to minimize locations, the location methodology should be used to support the locations decisions. Specialty items are on the floors or in clean cores, and CSPS is used for generic items that are picked based on the preference cards, as well as inventory for re-stocking of the rooms. The ideal state is that of a standard room setting - the described methodology can support the decision of what items are essential in the room, and those should be the only items in room stock. The next step is understanding what needs to be on the floor (e.g., carts or clean cores). In addition to specialty items, this also includes backup supplies for some of the room stock in case more are needed during the day.

Our key recommendations are provided in detail below.

8.1.1. Adjustment of Par Levels

As described in Chapter 5, using data-driven par levels would be more accurate and prevent excess inventory. Par levels could easily be adjusted to the data-driven values without any other changes in the system. Since the documentation of in-room usage is incomplete, the reduction of par levels should generally be implemented in the central locations, not in the rooms. We recommend using
the "pooled" (and data-driven) par levels, which would be expressed in a major reduction of inventory levels and costs. This change should be implemented if re-stocking is done from CSPS only, as will be discussed in Section 8.1.3.1 below.

Eventually, once Supply Doc data exists for every room, it can be used to calculate accurate par levels by room. As long as the calculation is based on aggregate demand, it would be preferable not to change the par levels in the operating rooms, only the safety stock at CSPS.

8.1.2. Consideration of Change in Order Frequency

As discussed in Chapter 6, lower order frequency does not have a direct financial benefit based on reduction of O&M purchase order line, yet it could reduce the labor involved in reviewing inventory levels of all items on a daily basis. Since MGH is already holding three days of inventory, the service level would be maintained. There is a trade-off between the daily review and the complexity introduced to the system in order to indicate when items are reviewed, and that should be considered.

8.1.3. Inventory Locations

8.1.3.1. Jackson as a Clean Core/Re-stocking from CSPS Only

While a supply location in proximity to the Legacy operating rooms cannot be completely eliminated, we understand that it could be greatly reduced. Jackson Supply should hold two types of items:

- Specialty Supplies – items used by services that operate in this area, and picked by ORSs once the case cart is brought up to the floor. These items should remain in Jackson, as they are specific to the Legacy operating rooms and should remain proximal to them.

- Backup Supplies – items that might need re-stocking during the day, including when operating at the off-hours (nights and weekends). We should carefully review what these items are, but once the items and quantities are agreed upon, these should also be kept at Jackson Supply. Currently, these items are held at high par levels since Jackson is used for re-stocking of rooms.

Re-stocking could be done from CSPS for all rooms, not just those in the Lunder Building. This change has a number of implications, mostly on the par levels in Jackson Supply and CSPS that could be adjusted to the proposed pooled levels. This is also a change in the workflow, and might
require additional labor or equipment as the distance between CSPS and the Legacy rooms is significant. Implementation of the recommendations below, that involve reductions in the room stock, would make the re-stocking process more efficient, which could balance the additional work involved in re-stocking Legacy rooms from CSPS.

8.1.3.2. Reduction of Room Stock to Essential Items

As described above, the main driver to high par levels is the number of locations. By keeping only essential items in the rooms, we can reduce the number of items that are kept in multiple locations. Standardizing the room stock would also improve access for the nursing staff, as all rooms will be stocked with the same items, as well as items that are specific per service. This is a process that has already started at MGH by the nursing staff, and should be informed by the results of the locations methodology.

Specifically, slow moving items should not be in the room stock. These items should be kept only at a central location and brought to the room on the case cart. If there are slow moving items that are considered essential, their par levels in the room should be considered carefully and reduced to a minimum. Generally, Supply Doc data can be used for the decision of where to keep what items, as described in the OR33 case study in Section 7.1.3, as well as the potential adjustments of preference cards that would also reduce the need for in-room picking.

8.2. Next Steps: Standardization Framework

Our work focused on optimizing the inventory levels and locations given our understanding of demand, using the available purchase and inventory data. Complete actual usage data by operating room should become available in the near future with the Supply Doc system. This will provide more accurate demand data that can be used to re-calculate the par levels by item and by specific location, i.e., to better allocate the items across the operating rooms. In addition, the usage data can also be used to optimize the demand side, by standardizing supplies for common procedures and highlighting costly items.

Actual usage data can be used in two main ways on the demand side:

- Improved Accuracy
By comparing the usage to the requested preference cards, we can identify inaccuracies in items and quantities, and adjust the preference card accordingly. Accurate preference cards carry a dual benefit – not only are the correct supplies provided to the operating room on time, but waste is reduced – unnecessary items will not be opened and wasted or returned to CSPS.

- **Standardization**

Comparing usage and preference cards of different surgeons for the same procedures can highlight commonalities and differences. Common items can be added to the custom surgical packs when possible, and reduce the amount of work associated with picking for a procedure. The items that differ can be inspected if in fact needed to be different, and potentially reduce the types of items used and exceptionally expensive items.
9. CONCLUSIONS

The interventions discussed in this thesis provide a data-driven approach to improve the inventory management of surgical supplies for the operating rooms at MGH. The main result is the reduction in inventory levels, of roughly a third of the current state. Such a reduction would result in savings in both cost and space, and the levels could be further reduced in a few ways, as discussed in Chapter 5 – pooling of safety stocks, holding less than three days of inventory, or smoothing of the demand of surgical supplies by suggesting a standard for surgeons’ preference cards.

While the suggested reduction in purchase order lines would not result in cost savings given the current contract, it would be worth considering in the future, or possibly as part of a hospital-wide initiative.

The location methodology should act as a driver to the reduction of the number of inventory locations, specifically for slow moving items. Generally, this methodology can be used to inform decisions regarding locations of supplies, and aligns with the process of standardizing operating rooms’ stock that has recently started taking place at MGH.

In conclusion, application of basic operations research concepts such as pooling and inventory replenishment models can be useful in a hospital setting and lead to improved accuracy and reduced costs. This work described an analysis on the impact of data-driven inventory levels and locations at Mass General Hospital, using historical purchase orders as an approximation of demand. In the case described here, the recommended change can lead to savings of roughly 30-40% in inventory levels/storage space, which correspond to hundreds of thousands dollars annually. However, in addition to the data-driven models, we must remember that the hospital is a conservative environment, where some items can never stock out. This has to be taken into account when implementing any theoretical model, yet this analysis shows that there could still be considerable benefits while keeping the desired service levels.
10. **BIBLIOGRAPHY**


Lee, J. (2012, August 20). Supply-side economics: Purchasing practices at hospitals and health systems continue to evolve, with the supply chain continuing to be a target for large non-labor cost savings. *Modern Healthcare*, 42.34.


*Unleashing Efficiency: A Vanderbilt University Medical Center Case Cart Study*. (2012, February 29). Retrieved from Vanderbilt University Medical Center.
11. **APPENDIX**

11.1. **MATLAB Code for Par Levels Analysis (Demand Distribution)**

```matlab
function basestock()

clearvars;
clic;

PO = xlsread('PO4matlab.xlsx','export');
% date | date index | weeknum | weekday | PO num | item id | qty | $ amount | location code | account
% order location code: 1=csps, 2=jackson, 3=other

OM_ITEMS = xlsread('PO4matlab.xlsx','items'); % O&M items only
% item id | average price | sum of merchandise amount | count of PO numbers
om = ismember(PO(:,6),OM_ITEMS(:,1));
PO = removerows(PO,-om);

% "calendars"
CAL1 = xlsread('PO4matlab.xlsx','R=1'); % M-Tu-W-Th-F dates
CAL2 = xlsread('PO4matlab.xlsx','R=2'); % M-W-F dates
CAL3 = xlsread('PO4matlab.xlsx','R=3'); % M-Th dates
CAL4 = xlsread('PO4matlab.xlsx','R=4'); % M dates

% % parameters
% % R = 1; % review period
% % L = 0; % lead time
k = 2.3268; % 99% service level

items = unique(PO(:,6));
Items_Table = [items zeros(length(items),19)];
% item id | # orders | mean demand | stddev demand | ...

% % all O&M items

for i = items'

    % create submatrix of POs for item i
    % change PO(:,9) according to location: 1=csps,2=jackson,3=other
    ind_i = find(PO(:,6) == i & PO(:,9) == 3); %PO(:,9)=location id >0 = all
    P_i = PO(ind_i,:);
    count_i = size(P_i,1);

    % R=1: M,Tu,W, Th,F (daily)
    P1 = [CAL1(:,4) zeros(length(CAL1),1)]; % date index | spaceholder for total quantity
```

65
\( P_l(1,2) = \text{sum}(P_i(\text{find}(P_i(:,2) \leq CAL(1,4)),7)); \)

\hspace{1cm} \text{for } j = 2 : \text{length}(CAL_l) \\
\hspace{2cm} \text{curr} = CAL_l(j,4); \hspace{1cm} \text{prev} = CAL_l(j-1,4); \\
\hspace{2cm} P_l(j,2) = \text{sum}(P_i(\text{find}((P_i(:,2) > \text{prev}) \& (P_i(:,2) \leq \text{curr})),7)); \\
\hspace{1cm} \text{end} \\

\( L_l = \text{nnz}(P_l(:,2)); \) \% number of purchase orders for this item in this location 

\( p99_1 = \text{prctile}(P_l(:,2),99); \hspace{1cm} p100_1 = \text{prctile}(P_l(:,2),100); \)

\% calculate mean and std. dev. over R+L for each location + pooled 

\( \text{mean}_l = \text{mean}(P_l(:,2)); \) \% mean order 
\( \text{std}_l = \text{std}(P_l(:,2)); \) \% std. dev. order 

\( B_l = \text{mean}_l + k*\text{std}_l; \)

\%\% R=2: M,W,F (Sa-M,Tu-W,Th-F) 
\( P_2 = [CAL_2(:,4) \hspace{0.5cm} \text{zeros(size} \hspace{0.5cm} \text{CAL}_2,1)]; \) \% date index | spaceholder for total quantity 

\( P_2(1,2) = \text{sum}(P_i(\text{find}(P_i(:,2) \leq CAL_2(1,4)),7)); \)

\hspace{1cm} \text{for } j = 2 : \text{length}(CAL_2) \\
\hspace{2cm} \text{curr} = CAL_2(j,4); \hspace{1cm} \text{prev} = CAL_2(j-1,4); \\
\hspace{2cm} P_2(j,2) = \text{sum}(P_i(\text{find}((P_i(:,2) > \text{prev}) \& (P_i(:,2) \leq \text{curr})),7)); \\
\hspace{1cm} \text{end} \\

\( L_2 = \text{nnz}(P_2(:,2)); \)
\( p99_2 = \text{prctile}(P_2(:,2),99); \hspace{1cm} p100_2 = \text{prctile}(P_2(:,2),100); \)

\% calculate mean and std. dev. over R+L for each location + pooled 

\( \text{mean}_2 = \text{mean}(P_2(:,2)); \) \% mean order 
\( \text{std}_2 = \text{std}(P_2(:,2)); \) \% std. dev. order 

\( B_2 = \text{mean}_2 + k*\text{std}_2; \)

\%\% R=3: M,Th (F-M,Mu-Th) 
\( P_3 = [CAL_3(:,4) \hspace{0.5cm} \text{zeros(size} \hspace{0.5cm} \text{CAL}_3,1)]; \) \% date index | spaceholder for total quantity 

\( P_3(1,2) = \text{sum}(P_i(\text{find}(P_i(:,2) \leq CAL_3(1,4)),7)); \)

\hspace{1cm} \text{for } j = 2 : \text{length}(CAL_3) \\
\hspace{2cm} \text{curr} = CAL_3(j,4); \\
\hspace{1cm} \text{end} \\

\hspace{1cm} \hspace{1cm} \hspace{1cm} \hspace{1cm} \text{end}
prev = CAL3(j-1,4);
P3(j,2) = sum(P_i(find((P_i(:,2) > prev) & (P_i(:,2) <= curr)),7));

eend

L3 = nnz(P3(:,2));
p99_3 = prctile(P3(:,2),99);
p100_3 = prctile(P3(:,2),100);

% calculate mean and std. dev. over R+L for each location + pooled
mean_i3 = mean(P3(:,2)); % mean order
std_i3 = std(P3(:,2)); % std. dev. order
B3 = mean_i3 + k*std_i3;

%% R=4: M (weekly)
P4 = [CAL4(:,4) zeros(length(CAL4),1)]; % date index | placeholder for total quantity
P4(1,2) = sum(P_i(find(P_i(:,2) <= CAL4(1,4)),7));
for j = 2 : length(CAL4)
    curr = CAL4(j,4);
    prev = CAL4(j-1,4);
    P4(j,2) = sum(P_i(find((P_i(:,2) > prev) & (P_i(:,2) <= curr)),7));
end

L4 = nnz(P4(:,2));
p99_4 = prctile(P4(:,2),99);
p100_4 = prctile(P4(:,2),100);

% calculate mean and std. dev. over R+L for each location + pooled
mean_i4 = mean(P4(:,2)); % mean order
std_i4 = std(P4(:,2)); % std. dev. order
B4 = mean_i4 + k*std_i4;

%% add calculated values to item table
table ind i = find(items == i);
    Items Table(table ind i,2:20) = [mean_i1 std_i1 count_i L1 L2 L3 B1 B2 B3 B4 p99_1 p99_2 p99_3 p99_4 p100_1 p100_2 p100_3 p100_4];

end

totals = sum(Items_Table(:,4:20));
11.2. Recommended Par Levels Data Examples

<table>
<thead>
<tr>
<th>Item ID</th>
<th>Item Description</th>
<th>Slow moving?</th>
<th>Current Par</th>
<th>&quot;DD&quot; Par</th>
<th>&quot;Pooled&quot; Par</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>BAG DRAINAGE MED 19OZ LATEX FR</td>
<td>1</td>
<td>58</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>13</td>
<td>SHEET SHROUD 72X108IN CMPLT PL</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>18</td>
<td>DRAPE CASSETTE 21X36IN XRAY DI</td>
<td>0</td>
<td>80</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>22</td>
<td>DRAPE IRG 19X23IN POUCH W/ ADH</td>
<td>1</td>
<td>13</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>39</td>
<td>BAG PAPER 6 1/2X13IN STRL BROW</td>
<td>1</td>
<td>118</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>181</td>
<td>BLADE SURGICAL SZ 10 SCLPL STR</td>
<td>0</td>
<td>21</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>182</td>
<td>BLADE SURGICAL SZ 11 SCLPL STR</td>
<td>0</td>
<td>21</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>183</td>
<td>BLADE SURGICAL SZ 15 SCLPL STR</td>
<td>0</td>
<td>21</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>186</td>
<td>BLADE SURGICAL SZ 12 SCLPL STR</td>
<td>1</td>
<td>7</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>191</td>
<td>BLADE NEUROLOGY BAYNT SICKLE S</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>192</td>
<td>BLADE SURGICAL 15DEG 3.0MM OPT</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>193</td>
<td>BLADE SURGICAL 1.5MM OPTHLMC M</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>194</td>
<td>BLADE SURGICAL 4MM OPTHLMC KNI</td>
<td>0</td>
<td>11</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>256</td>
<td>BLADE SAW 6.9X19.8X0.3MM BONE</td>
<td>1</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>362</td>
<td>CATHETER MALECOT 12FR LATEX AB</td>
<td>1</td>
<td>15</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>373</td>
<td>CATHETER IV 14GAXS 1/4IN LATEX</td>
<td>1</td>
<td>19</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>374</td>
<td>CATHETER FOLEY 24FRX30ML LATEX</td>
<td>1</td>
<td>24</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>378</td>
<td>CATHETER IV 14GAX.881IN LATEX</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>402</td>
<td>CATHETER COUDE 18FRX30ML LATEX</td>
<td>1</td>
<td>18</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>403</td>
<td>CATHETER COUDE 20FRX30ML LATEX</td>
<td>1</td>
<td>18</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>404</td>
<td>CATHETER FOLEY 20FRX5ML LATEX</td>
<td>1</td>
<td>18</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>405</td>
<td>CATHETER FOLEY 22FRX5ML LATEX</td>
<td>1</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>406</td>
<td>CATHETER FOLEY 16FRX5ML LATEX</td>
<td>1</td>
<td>28</td>
<td>27</td>
<td>12</td>
</tr>
<tr>
<td>410</td>
<td>CATHETER URETERAL 24FR LATEX W</td>
<td>0</td>
<td>26</td>
<td>26</td>
<td>15</td>
</tr>
<tr>
<td>411</td>
<td>CATHETER FOLEY 8FRX3ML LATEX B</td>
<td>1</td>
<td>28</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>412</td>
<td>CATHETER FOLEY 10FRX3ML LATEX</td>
<td>1</td>
<td>18</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>413</td>
<td>CATHETER COUDE 16FRX30ML LATEX</td>
<td>1</td>
<td>18</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>420</td>
<td>CATHETER FOLEY 18FRX5ML LATEX</td>
<td>1</td>
<td>18</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>424</td>
<td>CATHETER COUDE 14FRX5ML LATEX</td>
<td>0</td>
<td>24</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>428</td>
<td>CATHETER COUDE 20FRX5ML LATEX</td>
<td>0</td>
<td>18</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>429</td>
<td>CATHETER COUDE 18FRX5ML LATEX</td>
<td>0</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>430</td>
<td>CATHETER COUDE 16FRX5ML LATEX</td>
<td>0</td>
<td>24</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>434</td>
<td>CATHETER FOLEY 14FRX5ML BALLOO</td>
<td>1</td>
<td>18</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>442</td>
<td>CATHETER FOLEY 16FRX5ML BALLOO</td>
<td>1</td>
<td>18</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>443</td>
<td>CATHETER FOLEY 18FRX5ML BALLOO</td>
<td>1</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>444</td>
<td>CATHETER FOLEY 5CCX20FR BALLOO</td>
<td>1</td>
<td>18</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>445</td>
<td>CATHETER FOLEY 5CCX22FR BALLOO</td>
<td>1</td>
<td>18</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>446</td>
<td>CATHETER FOLEY 5CCX24FR BALLOO</td>
<td>1</td>
<td>22</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>447</td>
<td>CATHETER FOLEY 18FRX30ML LATEX</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>448</td>
<td>CATHETER FOLEY 20FRX30CC LATEX</td>
<td>1</td>
<td>18</td>
<td>16</td>
<td>11</td>
</tr>
</tbody>
</table>
### 11.3. OR 33 Case Study Data Examples

#### 11.3.1. Differences by item ID, across all cases

<table>
<thead>
<tr>
<th>Item ID</th>
<th>Item Description</th>
<th>Count of Delta</th>
<th>Max of Delta</th>
<th>Urgency?</th>
<th>Slow?</th>
<th>In rooms?</th>
</tr>
</thead>
<tbody>
<tr>
<td>181</td>
<td>BLADE SURGICAL SZ 10 SCLPL STR</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>182</td>
<td>BLADE SURGICAL SZ 11 SCLPL STR</td>
<td>22</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>183</td>
<td>BLADE SURGICAL SZ 15 SCLPL STR</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>402</td>
<td>CATHETER COUDE 18FRX30ML LATEX</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>442</td>
<td>CATHETER FOLEY 16FRX5ML BALLOO</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>443</td>
<td>CATHETER FOLEY 18FRX5ML BALLOO</td>
<td>7</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>444</td>
<td>CATHETER FOLEY 5CCX20FR BALLOO</td>
<td>39</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>761</td>
<td>TIP SUCTION 8FR FRZR STRL W/ C</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1829</td>
<td>STENT URETERAL 7FRX90CM DIV SG</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3045</td>
<td>CATHETER FOLEY 16FRX5CC LATEX</td>
<td>19</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4173</td>
<td>ADAPTER CATHETER 4TO6FR URETH</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4317</td>
<td>SOLUTION SCRUB 26ML SURG SKIN</td>
<td>23</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4483</td>
<td>DRAPE STERI 12.5CM 35-5/8IN ST</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4537</td>
<td>DRAPE UNDR 40X44IN BUTT W/ FL</td>
<td>7</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4670</td>
<td>GLOVE ORTHO SZ 6 1/2 LATEX PER</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4673</td>
<td>GLOVE ORTHO SZ 7.0 LATEX PERRY</td>
<td>18</td>
<td>14</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4679</td>
<td>GLOVE ORTHO SZ 7 1/2 LATEX PER</td>
<td>10</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5205</td>
<td>PEN ELECTROSURG HANDSWITCH STR</td>
<td>19</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6240</td>
<td>SOLUTION IV 2000ML IRG STRL H2</td>
<td>22</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6242</td>
<td>SOLUTION IV 3000ML IRG LR FLX</td>
<td>45</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6244</td>
<td>SOLUTION IV 2000ML IRG NACL 0.</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6246</td>
<td>SOLUTION IV 1500ML IRG H2O STR</td>
<td>50</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6290</td>
<td>TUBE IRRIGATION CYSTO INTERMIT</td>
<td>32</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8333</td>
<td>NEEDLE SURGICAL 150MM LAPSCP P</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8780</td>
<td>STOCKINETTE ORTHOPEDIC 3.0X46I</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10108</td>
<td>LABEL BLANK STRL</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>12097</td>
<td>TRAY CATHETERIZATION URETH W/</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12261</td>
<td>TAPE ADHESIVE 1 1/2INX10YD POR</td>
<td>30</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>12262</td>
<td>TAPE ADHESIVE 4INX10YD PORS WH</td>
<td>43</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>12268</td>
<td>DRESSING SPNG 3.0X4IN STRL GZ</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>12280</td>
<td>DRESSING TEGADERM 4.0X4 3/4IN</td>
<td>37</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>12287</td>
<td>DRESSING TELFA 3.0X8IN NONADH</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>12303</td>
<td>SPONGE LAP 8X36IN DISP CURITY</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>12314</td>
<td>DRESSING SPNG 16PLY 4.0X4IN GZ</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>12326</td>
<td>TAPE ADHESIVE 3INX10YD LATEX F</td>
<td>53</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
11.3.2. Item differences in surgical case #1071020 (vaginal hysterectomy, October 3rd, 2013)

<table>
<thead>
<tr>
<th>Item ID</th>
<th>Description</th>
<th>Tracked Quantity</th>
<th>Pick List Quantity</th>
<th>Delta Tracked - Pick</th>
</tr>
</thead>
<tbody>
<tr>
<td>4317</td>
<td>SOLUTION SCRUB 26ML SURGICAL S</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>12361</td>
<td>SOLUTION STERI 2/3CC STRIP SKI</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>6240</td>
<td>SOLUTION IV 2000ML IRRIGATION</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>28308</td>
<td>SOLUTION IRRIGATION 500ML 0.9</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>29334</td>
<td>BAG DRAINAGE 350TO2500MLX58IN</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>115369</td>
<td>GOWN IMPERVIOUS XL CS/18EA</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>351424</td>
<td>MGH OR ONLY KIT URO GYN CS/2</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>91444</td>
<td>PACK UTERINE CS/1EA</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>105701</td>
<td>SPONGE CUSTOM SURGIWALL CS/20E</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>29228</td>
<td>CATHETER FOLEY 5CCX16FR BALLOO</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>17411</td>
<td>SUTURE VICRYL SIZE:0-0 LENGTH:</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>17578</td>
<td>SUTURE VICRYL SIZE:0-0 NEEDLE:</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>18064</td>
<td>SUTURE VICRYL SIZE:0-0 NEEDLE:</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>29531</td>
<td>SUTURE VICRYL SIZE:0-0 NEEDLE:</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>87407</td>
<td>SUTURE PDS SIZE:2-0 NEEDLE:CT-</td>
<td>1</td>
<td>2</td>
<td>-1</td>
</tr>
<tr>
<td>48438</td>
<td>PAD SANITARY OBSTETRICAL MATER</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>128509</td>
<td>CONTAINER SPECIMEN 120CC CLIKS</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>162061</td>
<td>SPONGE LAPAROTOMY 18X18IN LATE</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>39349</td>
<td>SOLUTION Povidone 4OZ IODINE C</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>329367</td>
<td>BLADE ASSEMBLY FOR 9661 CLIPPE</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>37580</td>
<td>GLOVE SURGICAL SIZE 6 1/2 LATE</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>42344</td>
<td>GLOVE BIOGEL SIZE 6 1/2 LATEX</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>45674</td>
<td>GLOVE NEOPRENE SIZE 6 1/2 LATE</td>
<td>20</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>45686</td>
<td>GLOVE NEOPRENE SIZE 7 1/2 LATE</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>136843</td>
<td>SUTURE MONFILAMENT SIZE:CV-0 N</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>