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Decision Support in Healthcare Supply Chain Management and Pharmaceutical Inventory Control

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ABSTRACT

This exploratory research examines the pharmaceutical inventory control practices of a local area hospital and demonstrates the utility of two alternative quantitative approaches. Pharmaceuticals represent a large cost factor for most hospitals due to the significant costs of these products and the storage and control requirements. The hospital stores drugs in the Central Pharmacy and at various Care Units (CUs) throughout the hospital and employs advanced technology to manage inventory and automate the ordering processes at these local storage units. This research examines current hospital policies, employs quantitative methods to improve upon these practices, and provides a decision support tool that allows managers to quickly understand operational, tactical, and strategic implications of changes in the formulary (pharmaceutical product mix available in hospital). This decision support tool affords managers the opportunity to improve management practices and the capacity to support negotiations with stakeholders on issues related to the formulary.

Keywords

Healthcare Decision Support, Pharmaceuticals, Supply Chain Management

INTRODUCTION

According to statistics published by the Centers for Medicare and Medicaid Services, healthcare spending topped $2 trillion or 16% of its Gross Domestic Product (GDP) in the United States in 2005 (CMMS, 2007). Especially given the current economic crisis, a growing amount of attention is being given to the rising costs of healthcare and specifically pharmaceuticals. Healthcare providers, insurance companies, government agencies, and consumers alike are forced to address this issue and to explore alternative methods of cost reduction or cost containment (Jönsson and Musgrove, 1997). To gain a better understanding of the significance of this issue, one must first identify the magnitude of healthcare expenditures. According to The Plunkett Research Group (2008), "The health care market in the U.S. in 2007 was made up of hospital care (about $697.5 billion), physician and clinical services ($474.2 billion), prescription drugs ($229.5 billion), nursing home and home health ($190.0 billion), and other items totaling $668.8 billion."

A significant part of healthcare costs is the pharmaceutical area, which represents approximately ten percent of annual healthcare expenditures in the United States and about $550 billion globally in 2007 (Plunkett Research, 2008). Despite the size and importance of this industry around the world, the area of healthcare supply chain management (SCM) and decision support has been given relatively little attention. Inventory investments in healthcare range between 10% and 18% of total revenues (Holmgren and Wentz, 1982). Any measures taken to control expenditures in this area can have substantial impacts on the overall efficiency and profitability of healthcare providers.

Pharmaceuticals represent both a large cost factor for organizations and a source of tremendous conflict amongst the supply network stakeholders (Prosser and Walley, 2005). Physicians and pharmacists/pharmacy directors often clash over medications offered by the hospital. The basic conflict revolves around the issue of product variety versus economies of scale. Physicians have professional and clinical preferences that are reflected in their prescription decision-making (Alexander et al., 2005). Physicians value their individual freedom of choice in selecting the medications that they feel best meets the specific needs of the patients. Physicians can also be influenced by drug manufacturers, pharmaceutical representatives, and the appearance of new drugs in the marketplace. Kowalczyk (2009) reports that states are banning pharmaceutical and medical device companies from providing gifts to physicians, limiting what companies can pay for

doctors' meals, and requiring companies to publicly disclose payments to doctors over $50 for certain types of consulting and speaking engagements in an effort to control costs by reining in unnecessary prescribing of expensive drugs.

In contrast, the pharmacy directors are concerned with the costs associated with specific medications and promote the usage of generic rather than brand drugs when available. Another divergence appears between hospital administration and the group purchasing organization (GPO) on issues of product variety. Hospitals focus on negotiating the best prices for a wider selection of drugs. The GPO, on the other hand, strives to minimize costs in the overall system by seeking generic drugs as substitutes for medicines preferred by physicians and by considering a limited (Shrank et al., 2006; Shrank et al., 2005).

Next, we present an overview of our research site. Consequently we introduce the research question and objectives of the study. We describe our research methods and quantitative modeling followed by analysis, interpretation of results and discussion. We conclude with contributions, constraints and lessons learned toward the development of best practices for healthcare decision support systems.

OVERVIEW OF ORGANIZATION XYZ

This research will look at the inventory management problems and lack of decision support within the pharmacy department in a local area healthcare hospital (**Organization XYZ**). The study is based on over 70 hours of observations, two focus groups and five in-depth interviews with:

- Rick, Pharmacy Director
- Michael, Pharmacy Assistant Director
- Patrick, Pharmacy Technician
- Preston, Group Purchasing Organization
- Candace, Group Purchasing Organization

The quantitative portion of this work attempts to optimize the inventory control values, specifically the reorder point (s) and the order quantity (Q) for all items in the local storage depots while considering the overall volume of the machine (space constraint) and the required high service level (service level constraint). The hospital uses a (s, S) policy. The current control values suggested by the pharmacy supplier (GPO) employ a fixed day-supply, T_{min} and T_{max} policy, and do not consider demand variability or storage space requirements. This simplistic policy results in frequent shortages and emergency refills for some drugs and also a large number of regular refills putting an overload on the pharmacy staff. Based on experiences the pharmacists are frequently modifying the fixed day-supply policy, but there is a need for appropriate decision support in how to modify the reorder point (s_i) and order up to (S_i) control parameters. The primary goals of Organization XYZ are to (a) reduce workloads (emergency and daily refills) and refilling costs at the local storage depots, (b) reduce holding costs, and (c) implement a healthcare decision support system to strengthen pharmaceutical negotiations with key stakeholders.

Background of Organization XYZ

Organization XYZ is a regional referral center and Children's Hospital that houses 763 licensed beds. It is the largest hospital in the research area, has an average daily census of 500-550 patients, and employs over 950 medical staff members. Organization XYZ uses an inventory management solution driven by information technology (IT). Specifically, this solution, *Pyxis MedStation®*, allows for local storage depots to be distributed at the various CUs around the hospital. These *Pyxis®* machines house the drugs needed for patient care in that CU, as well as, track every inventory transaction, prompt replenishment orders, generate necessary documentation, and facilitate the billing processes related to pharmaceutical treatments. While these *Pyxis MedStations®* allow for the automation of a number of tasks associated with this supply network, it is important to recognize that pharmaceutical inventory management is still a very labor-intensive process due to the number of *Pyxis®* machines in the hospital (~85), the large volume of drugs in each depot (250-500), and the workload required during the restocking process; thus costly to Organization XYZ. The pharmacy management would like to reduce refilling occasions at the *Pyxis®*-level while maintaining the necessary high quality of service. As such, this research focuses on the following:

RQ1: Can a healthcare DSS for pharmaceutical inventory management reduce expenditures and workloads in the pharmacy department?

The *Pyxis®* machines have a fixed storage capacity, which must be divided amongst the large number of items (250-300 in one *Pyxis®*) of the items needed at the specific care units. Flexible drawer dividers are used to create individual storage space for each drug within the machines since drugs can not share space. There is also a high service level requirement, which necessitates safety stocks, for medications due to the importance of having drugs available for use and the high costs associated with emergency refills. However, this creates several practical problems.

1. How to set the reorder point and reorder level, min and max par levels, (s, S) for each drug in one *Pyxis®*?
2. How to allocate the space among the drugs in each *Pyxis®*?
3. How to allocate the safety stocks among the drugs in each *Pyxis®*?

We address our quantitative methodology in the following section.

METHODOLOGY

This portion of the case presents three quantitative models examined in this investigation. We use the example of a particular *Pyxis®* of the case hospital for illustration. All transactions (demand, refill, inventory position) and control parameters (s_i, S_i) for two years are available in Excel files. We selected 70 drugs with highest usage rate out of the 214 drugs. These items make up 71% of the total usage and around 70% of the total volume of the *Pyxis®*. This sample was used to illustrate the relevant managerial tradeoffs. In addition, a number of quantitative models are utilized to determine the optimal inventory control parameters given the goals of the individual models and the various constraints. The notations and basic models are presented here; however, more details on the procedures and solutions are available in Woosley (2009).

Model 1: A General Multi-product (s, S) Model with Space Constraint and its Approximation

The ultimate goal of the hospital pharmacy operation is to find the optimal values of the decision variables

- s_i : the reorder point (the *min par level*) and

- S_i: the reorder level (*max par level* or order up to level) for each drug i (i = 1 to n)

to minimize the total expected *refilling* (ordering), inventory holding and shortage cost under volume constraint of the local depots. The total space is subdivided into separated and dedicated storage areas for each drug, and they must be large enough to hold the max par level for each drug. The cost factors for item i are:

K_i : cost of a refill (order),

$h_i = r \, c_i$: holding cost for a drug with value of c_i , and holding cost factor, r

p_i: shortage cost of an emergency refill that is independent of the size of the shortage.

The optimization problem can be formally expressed in

Model 1:

$$\text{Min} \quad \sum \left[K_i \, N_i(s_i, S_i) + h_i \, H_i(s_i, S_i) + p_i \, P_i(s_i, S_i) \right] \tag{1}$$

$$\text{s.t.} \quad \sum (v_i \, S_i) \leq M' \tag{2}$$

with the notation for each item

$N_i(s_i, S_i)$ = the expected number of orders per period,

$H_i(s_i, S_i)$ = the expected average inventory in a period,

$P_i(s_i, S_i)$ = the probability of shortage per period,

v_i = volume requirement for a unit,

M' = total volume of the space available for the n items.

Solving this problem using the above model is very difficult due to the use of renewal functions and the non-convex cost function. In addition, the approach is too time and data-intensive given our practical case. This procedure can be applied as a benchmark in our case, but it is too cumbersome for practical application at this time. As such, two simplified optimization models were formulated concentrating on the key goals of Organization XYZ. First, in Model 2 consideration is given to both ordering (refill) and holding cost under service level constraint. In the subsequent Model 3, we only consider ordering (refill) cost minimization under service level constraint. In both models the space limit constraint is also included. These approaches offer simplified solutions and incorporate Excel spreadsheets that are familiar and easy to interpret.

Model 2: Optimal Allocation Based on Ordering and Holding Costs

In the inventory management literature the difficulty of providing the appropriate cost factors is well known, especially the shortage cost is hard to quantify. This is valid in our pharmacy case, so we follow the common practice and consider a service level constraint instead of shortage cost in the next two models. Since the shortage means an emergency refill in our case with a fixed cost (depending only on the number of shortage occasions per days and not on the amount of the shortage) it is appropriate to consider the so-called α service level which is the chance that there is no shortage in a period (day). Using this service level Model 1 can be modified and simplified into the following form.

Minimize the total refills (orders) cost plus the inventory holding cost for a *Pyxis®*, subject to the constraints:
- the service level (chance of no shortage) for each drug is high (at least α),
- the total space needed for the maximum possible inventory level for all drugs is not more than the available total space of the *Pyxis MedStation®* (M').

Using the notation, expressions and approximations from the previous section, we can formulate

Model 2:

$$\text{Min} \sum \left[K_i (d_i / Q_i) \right] + h_i H_i (s_i, S_i) \tag{3}$$

s.t.

$$\text{Prob (shortage for drug i)} \leq 1-\alpha, \quad (i = 1 \text{ to } n) \tag{4}$$

$$\sum (v_i S_i) \leq M' \tag{5}$$

The solution of Model 2 is still quite complex because of the multiple variables, the nonlinearity and the stochastic constraints. To simplify the solution, we consider the two types of constraints, service level (4) and space (5) constraints, separately and also the two sets of decision variables (s_i and S_i) separately and solve the optimization Model 2 iteratively, using Power Approximation (Schneider et al., 1995) for handling the service level. This problem cannot be solved directly, but the iterative solution procedure suggested by Ziegler (1982) can be applied to determine the near-optimal value of the order quantity, Q_i, for each item. This solution employs two embedded iterative procedures for the optimization of Model 2. For more details on the procedure and solution of Model 2, see Woosley (2009).

Model 3: Optimal Allocation Based on Ordering Cost

In this applied organizational overview, the major goal of the hospital pharmacy is to minimize the refill (emergency and daily) workload. Inventory holding cost is marginal and is not even considered currently in the *Pyxis®* database. This is motivation to simplify Model 2 and provide a simple, goal-oriented decision support tool for the pharmacy management. Consider next the simplified constrained optimization problem.

Minimize the total number of expected refills (orders) per day for a *Pyxis®*, subject to the constraints:
- the service level (chance of no shortage) for each drug is high (at least α), and
- the total space needed for the maximum possible inventory level for all drugs is not more than the available total space of the *Pyxis MedStation®* (M').

Model 3:

$$\text{Min} \sum (d_i / Q_i) \tag{6}$$

s.t.

$$\text{Prob (shortage for drug i)} \leq 1-\alpha, \quad (i = 1 \text{ to } n) \tag{7}$$

$$\sum (v_i S_i) \leq M' \tag{8}$$

Despite the objective function of Model 3 less complex when compared to Model 2, the problem of having the same large number of decision variables still exists, as well as, the nonlinearity and stochastic constraints as before. As such, a similar iterative solution is applied, but it proves to be faster and easier to interpret than optimization Model 2. Here we also consider the two constraints, service level (7) and space (8) constraints, separately and the two sets of decision variables (s_i

and S_i) separately and solve the optimization Model 3 iteratively. This method is quite straightforward, intuitive and sheds light on the simple structure of the optimal allocation of the safety stock and cycle stock separately. See Woosley (2009) for further explanation of these models and procedures.

ANALYSIS AND MANAGERIAL INTERPRETATION

Application for Managerial Decision Support

For this project a modeling application and simulation were developed using MS Excel. There are a number of reasons this software was chosen. First, the demand and usage **data** is available for extraction and manipulation in a file format compatible with this program. The IT-based solution currently employed by the hospital to monitor and control pharmaceutical inventory works quite well with this software. Second, **pharmacy administrators** are familiar with this application, as well as, with the MS Office Suite. MS Excel is used extensively by the staff and is one of the most commonly used spreadsheet applications around the world. As such, this was a logical application to utilize for the program and subsequent analysis.

Levels of Decision Support

This section identifies the manner in which the simplified approach of Models 2 and 3 supports decision making at multiple levels. The resulting decision support tool serves as a model for managers allowing them to examine changes in the formulary or item usage, to evaluate options for modifying the control parameters, and to choose the par values that best fit hospital and management criteria. First, the operational decisions are discussed. Second, the tactical considerations are presented along with the utility of this decision support tool in analyzing managerial tradeoffs. Third, a breakdown of the strategic implications is provided.

Operational Decision Support

At this level of decision making, the focus is on the management of individual items. The high service level requirement dictates a high reorder point, s_i, be used to maintain healthcare standards and to avoid expensive emergency refills. Additionally, the order up level, S_i, for each item must be reduced to accommodate the other products in the *Pyxis®* given the space constraints of the storage unit. The reduced space for cycle stock generates a need for additional daily refills, which results in higher refilling costs and workloads for the pharmacy. Any changes at the item level can impact the operations and workloads associated with the local depot. Managers needed help in evaluating their current practices and in improving these procedures.

Cost Comparison of Allocation Strategies

Here comparisons are made between the current hospital inventory policy (HM) and the alternative approaches of Model 2 and Model 3. Model 2 is designed to find the optimal allocation of space across all items being considered by minimizing the sum of holding and ordering costs. Model 3 was established to satisfy an exact desire of the hospital pharmacy by minimizing the total number of expected refills (orders) per day for a *Pyxis®*, subject to the service level and storage capacity constraints. Figure 1 illustrates the costs as calculated using actual product prices.

As shown below in Figure 1, the holding cost, refill cost, and total cost of refill and holding are substantially different for the three policies. Holding costs are nearly identical for HM and Model 2 with the Model 3 policy resulting in holding costs around 40% higher than the other strategies. Refill costs are substantially higher for the HM policy than for either Model 2 or Model 3 with the refilling cost being 71.1% and 83.9% higher respectively. These higher refill costs result in a much higher total cost for the HM policy and is evidenced by a 52.8% higher cost than Model 2 and 36.4% higher cost than Model 3. These differences are summarized in Table 1.
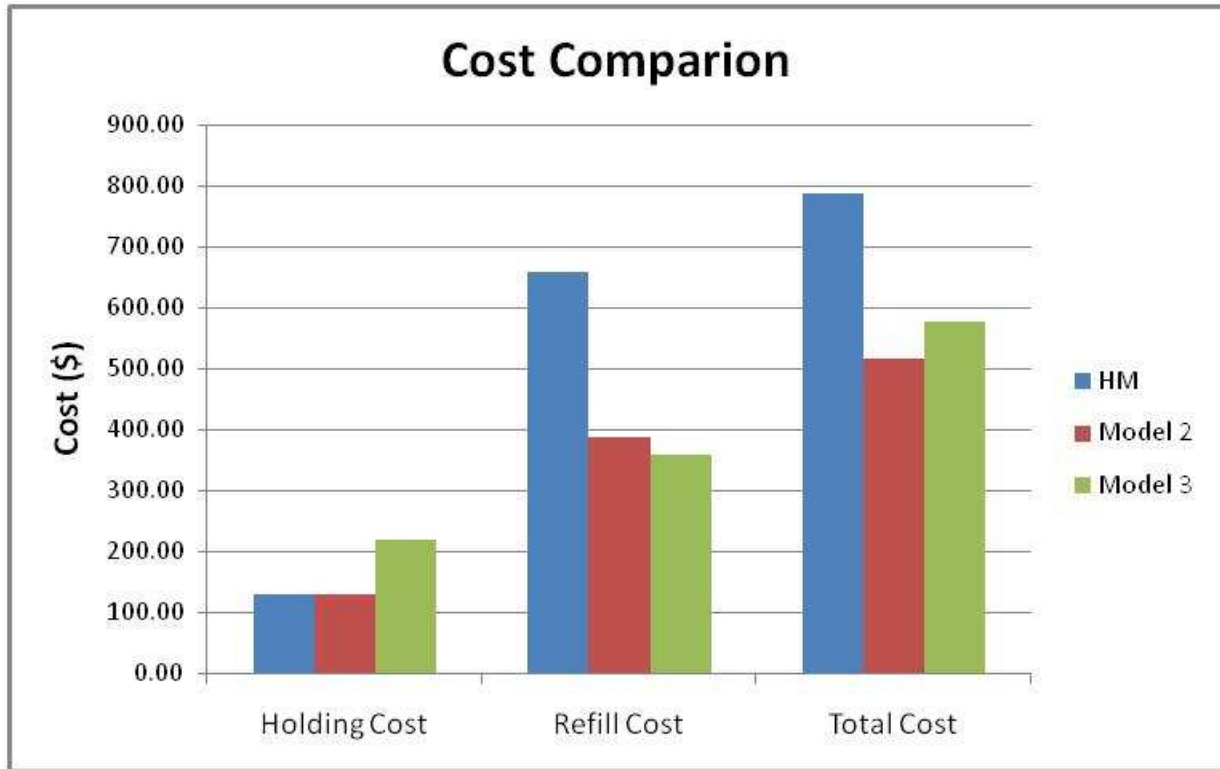
Figure 1: Cost Comparison for Allocation Methods

	Percent Difference		
	Holding Cost	**Refill Cost**	**Total Cost**
Model 2	1.3%	-71.1%	-52.8%
Model 3	41.4%	-83.9%	-36.4%

Table 1: Percent Differences in Model Costs to Hospital Policy Costs

Tactical Decision Support

In this section discussion shifts to the tactical implications. Specifically, we compare our Model 3 (OM), which was designed to address the explicit needs of the pharmacy, to the GPO Suggested (GPO) and Hospital Modified (HM) policies. As we demonstrate, the developed application allows managers to quickly evaluate the performance of numerous policies on our key performance indicators of service level, space utilization, and average daily refills.

Inventory Control Policy	Avg. Service Level	Service Level Range	Avg. daily Refills
GPO Suggested (GPO)	99%	7.15%	5.56
Hospital Modified (HM)	99%	5.14%	5.74
Our Model 3 (OM)	99%	0.44%	4.70

Table 2. Policy Comparison with Constant Space Utilization (M)

Table 2 is an example of the potential comparisons available to management. Here we hold one performance measure constant in order to examine the effects on other measures by setting the space availability (M) equal to the value that is currently used by the HM policy. As shown above, all three policies perform very well on the average service level criteria with the OM policy outperforming the others in the consistency of the service level, measured by the service level range (max – min service level) achieved across all items in the *Pyxis®* unit. With respect to the number of refills required per day, the OM method outperforms both of the other approaches. This is but a single example of the possible comparisons.

A primary result from a practical point of view is that the optimal allocation strategy of the space for the order quantities (cycle stock) of the items is proportional with the *square root of the demand over space rate*. The decision support tool allows for quick comparisons with different allocation schemes in reducing the total number of expected orders per day. We have compared five different allocation strategies for illustration. Table 3 summarizes the average percent increases in the total number of refills applying an allocation rule that is different from the optimal one.

The expected refill size Q_i is proportional to	Percent increase in total # of orders per day
$SQRT(d_i/v_i)$ – the optimal	0%
Demand rate, d_i	10%
Unit space requirement, v_i	400%
$d_i * v_i$	177%
d_i/v_i	38%

Table 3: Comparison of the Different Space Allocation Strategies

Strategic Decision Support

Thus far, this research focused on decision support in pharmaceutical inventory management within the hospital; however, there are a number of additional stakeholders interested in the product formulary. According to pharmacy managers at Organization XYZ, efforts are made to accommodate doctors and to offer greater variety, but product and operational costs are also a concern. Unfortunately, the cost impacts of changes in the product formulary are not documented and remain essentially unknown to these parties. We estimate the influence of these costs using our models to provide valuable information for the hospital when negotiating with doctors or the GPO on issues related to the formulary and pharmaceutical inventory management.

A significant benefit of using this decision support tool is the allowance of quick evaluations of the managerial tradeoffs. When suggestions are made that impact the number of workers or work shifts available in the pharmacy or when changes to the formulary are discussed, the pharmacy director can quickly analyze the issues based on our results and identify the impacts on service levels, workloads, and operating costs.

Model 3 provides a simple and efficient strategic decision support tool to analyze the tradeoffs among the three key performance indicators:
1. the service level (emergency refill workload),
2. the available space (depending on the variety of drugs – *formulary*), and
3. the number of orders (*refill workload*) per day.

Here we examine the impacts of changing formulary, available space, and worker capacity on our primary performance measures. For a fixed service level the tradeoff curve has a hyperbola shape that is shifted to the right (higher space requirement) with increasing service level requirement. This property allows a simple visual tradeoff analysis, and a simple example is illustrated next.
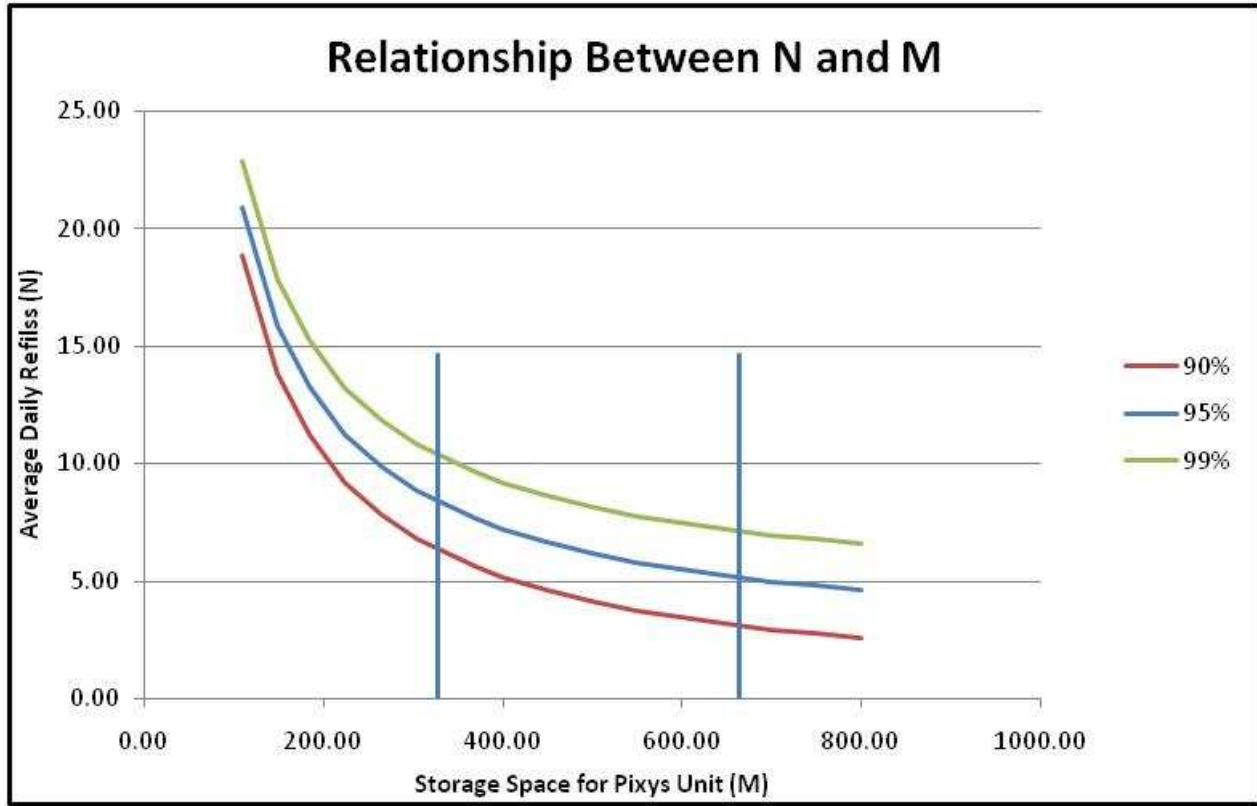

Figure 2: Performance Indicator Relationships and Tradeoffs

Figure 2 illustrates the relationship between available space for cycle stock, M, and average daily refills, N, at a given service level. Consider what happens when the available space increases at the 95% service level. As space availability increases, there is a decrease in the average number of daily refills. For example, if we double the space allocated for items from 300 to 600, the number of orders will decrease from 9 to 5. Understanding this relationship between space and refills allows us to analyze what will happen if we change service levels. If we shift from 95% to 99% service level at the same space utilization, we can see the expected increase in the refill requirements. Consider what happens at a fixed storage capacity level of 600. As the service level increases from 95% to 99%, the expected number of refills per day increases approximately by 25%.

Formulary Changes

The available space is directly connected to the *formulary*. Even if the total demand for the drugs does not increase, a bigger number of items require a larger amount of safety stocks. As such, we investigate the effects of adding or removing items from a *Pyxis®*. The inclusion of extra items means that less space is available at the item level for cycle stock in the *Pyxis®*. Reducing the number of items stored in the *Pyxis®* will have the opposite effect as more space becomes available for cycle stock for individual items in the machine.

Table 4 provides a simple demonstration of the formulary changes and the resulting influence on pharmacy workload. Again, we start with the sample of 70 drugs found in a particular *Pyxis MedStation®* and modify the product mix to include or omit 20% of items. To establish a reasonable idea of the impact such changes to the formulary will have on the number of expected refills (N), we consider both high usage and low demanded items for the situation where items are added. In

contrast, we only consider the low usage items for circumstances where items are removed from the *Pyxis®* given the small likelihood of high usage items being eliminated from the formulary. This allows pharmacy directors to gain valuable insight into the cost implications of such formulary changes.

Changes in Formulary	Expected Number of Daily Refills (N)	% Difference
Baseline (70 items)	3.58	---
20% Additional Low Usage Items	5.31	48.32%
20% Additional High Usage Items	4.08	13.97%
20% Fewer Items	2.70	-24.58%

Table 4: Impact of Adding or Subtracting Items to Local Formulary

As shown above in Table 4, increasing or decreasing the number of items in the *Pyxis®* will influence the numbers of expected daily refills needed for the machine. Regardless of the daily demand, adding items will raise the number of refills. First, consider the situation where low usage items are added to the local depot. In this setting one can observe approximately a 14% increase in the expected daily refills at the *Pyxis®*. This additional workload may seem relatively small; however, this is only for one machine. Considering Organization XYZ has over 85 *Pyxis MedStations®*, this increased workload poses significant problems from both a cost and worker capacity perspective. Second, we examine the effect of adding high usage items with daily demand values similar to the top 20% of items currently housed in the *Pyxis®* unit. This results in an increase in expected daily refills of more than 48%. On the other hand, we noticed almost a 25% drop in refills when the bottom 20% of drugs were removed. This demonstrates the importance of both reasonably restricting the product formulary and evaluating the items in the *Pyxis®* on a frequent basis for possible reductions. Again, these results provide much needed decision support to management.

Worker Capacity

In this context the number of refills that can be accomplished by pharmacists and technicians during an 8-hour shift is relatively fixed. As a result, any increases in the number of refills required at the CUs can only be satisfied through incremental increases in the number of work shifts. As the service level increases, one expects that smaller numbers of items require refills on a daily basis to prevent expensive *stockout* occasions. On the other hand, higher service level, and the resulting higher safety stock, takes away space from cycle stock increasing the expected number of regular refills per day. Table 5 provides a simple illustration of these relationships.

	Refills	
Shifts	95% SL	99% SL
1	10	15
2	20	30

Table 5. Incremental Increases to Worker Capacity

Knowing this relationship and the expected number of refills required at any given *Pyxis®* allows managers to better schedule human resources and ensure that the workload does not exceed worker capacity. By optimizing the allocation of space within the *Pyxis®* such that the number of expected refills is minimized, the hospital pharmacy has the ability to keep workloads at a controllable level and track changes over time. Control charts can be used to detect trends indicating workloads are approaching the pharmacy capacity limits indicate a need to reevaluate pharmaceutical inventory control values and possibly adjust the number of technicians or work shifts refilling the machines.

CONCLUSION

The significance of the healthcare industry is demonstrated by the cost breakdown and by conveying the importance of affordable, quality care to all desired stakeholders. As such, this project is valuable from both the practical and academic perspectives.

The increasing cost of healthcare delivery and medications are as taxing for the individual consumer as they are for the healthcare organization's bottom line. Our research has illustrated that the implementation and use of Models 2 and 3 as a healthcare DSS for pharmaceutical inventory control purposes will reduce pharmaceutical expenditures up to 70-80 percent.

One of the main challenges to the viability of our DSS and other IT is the slow rate of adoption and acceptance by various healthcare stakeholders (e.g. physicians, administrators and GPO). Many physicians are entrenched in their way of practicing medicine, specifically in their prescribing of pharmaceuticals. Our research adequately demonstrates that the DSS provides the pharmacy director with strong and specific quantitative support for negotiations with all stakeholders. However, further research is needed to better understand healthcare professionals' perceptions and attitudes toward this and other clinical decision support systems.

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