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Applying Inventory Control Practices Within the Sisters of Mercy Health Care Supply Chain

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APPLYING INVENTORY CONTROL PRACTICES WITHIN THE SISTERS OF MERCY HEALTH CARE SUPPLY CHAIN

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ABSTRACT

This research lays a foundation for the better understanding of the application and acceptance of more advanced inventory control practices within the health care supply chain. The demand characteristics and optimal control policies for pharmaceutical items within a multi-echelon provider network are examined within the framework of a case study. Demand forecasting algorithms were applied to forecast demand for inventory control procedures. A spreadsheet-based inventory planning tool was used to minimize the inventory holding and ordering costs subject to fill rate constraints. The costs of inventory control models are compared to the current ordering and inventory control strategies to document potential cost savings using both a single echelon analysis and a multi-echelon analysis. The results indicate that there is great potential for significant cost savings within the provider network. It is likely that if other providers adopt such practices that they will be able to better control material supply costs.

This thesis is approved for Recommendation
to the Graduate Council.

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I. INTRODUCTION

Managing and controlling costs are competitive advantages in the today's complicated health care industry. Because of rising costs, the healthcare industry has focused its attention on methods that can reduce costs in areas that may have a big impact. Since the health care supply chain has the largest cost center after personnel cost, it has become a major area of concern. Moreover, supply chain costs are approximately 15%-30% of overall hospital net patient revenue (Williams, 2004). According Ozcan (2009), in a typical hospital budget 25-30% goes for medical supplies and their handling. Consequently, health care supply chain costs require significant attention.

The purpose of this thesis is to investigate systematic methods for applying inventory management practices within a health care supply chain. The methods should take into account the practical realities of applying inventory management practices within health care settings. The method is demonstrated through a case study within the Sisters of Mercy health care supply chain. The case study consists of three focus areas: 1) understanding and depicting the demand and inventory control system for bulk and unit dose items in Mercy Health System of Northwest Arkansas (MHSNA) in Rogers and its supporting distribution center in Springfield, MO, 2) examining a second location, St. Edward Mercy Medical Center in Fort Smith for a comparative analysis, and 3) understanding the multi-echelon nature of the problem and the effect of inventory pooling within the supply chain.

This research focuses on applying analytical models designed to find optimal stock levels for pharmaceutical items through conducting a case study for a multi-echelon health care supply chain. A case study was selected as a research methodology due to the fact that a case study can provide practical information for health care providers and because a case study provides a good way to obtain real results, from which other providers can extrapolate to their locations.

The first contribution of this thesis is the overall method for performing an inventory analysis for health care providers. The second contribution is the examination of multi-echelon inventory control within the health care supply chain with the aim of cost reduction and supporting good inventory management. Another contribution is an improved understanding of demand patterns for pharmaceutical items, and the recommendation for the most appropriate inventory models.

This thesis is divided into five sections. Section 2 presents a literature review regarding inventory modeling within health care supply chains. Section 3 and 4 overview the research methods and plans including a description of the case study that forms a context for the thesis. Section 5 discusses final results as well as modeling issues that must be solved. The last section provides a summary and ideas for future research.

II. LITERATURE REVIEW

This section provides background and context for the application of inventory control methods within health care supply chains. First, a general overview of inventory control methods is provided. This includes fundamental background on inventory control for single items, multiple items, and for multi-echelon situations. Then, an examination of inventory control practices in health care is provided. This includes a summary of currently applied inventory management practices and a review of pertinent academic literature. Since this thesis deals with the inventory control practices within the multi-echelon health care supply chain, health care inventory management with a multi-echelon structure is emphasized. In other words, the primary focus in literature review is inventory management for multi-echelon structured health care supply chains.

A. Fundamentals of Inventory Control

In order to control inventory, two basic questions must be answered. These questions are "When should an order be placed and how much should be ordered?" (Zipkin, 2000). No matter how complex the inventory model, each model is looking for the answers of these fundamentals questions based on the state of the inventory system, as well as, demand and cost factors associated with keeping and ordering inventory.

The order quantity is the answer of the question, how much should be ordered. The calculation of the optimal order quantity has been investigated under a number of different approaches for constant, time-varying and stochastic demand. The economic order quantity (EOQ) developed by F.W. Harris in 1913 can be used to calculate the order quantity, under some assumptions, such as (1) demand is constant and deterministic, (2) lead time is zero, (3) no shortage is allowed, (4) constant unit cost and it does not depend on the replenishment quantity. The EOQ is the optimal order quantity that minimizes the total inventory cost including holding and ordering cost. In the reality, demand is not constant. In the case where the demand is known but varying with respect to time, the Wagner-Whitin algorithm or the Silver-Meal Heuristics can be used. The Wagner-Whitin algorithm, which is an application of dynamic programming, was developed to guarantee optimal replenishment quantity with the aim of minimizing total cost of carrying and ordering inventory (Silver, Pyke, & Peterson, 1998). The Silver-Meal heuristic is a sequential method, and the idea behind this technique is "to choose to have a new delivery when the average per period cost increases for the first time" (Axsater, 2006). If the demand is not known in advance, stochastic inventory models are used. Stochastic inventory models are the focus of this thesis.

The state of the inventory system can be best summarized in the key state variable, inventory position. Inventory position reflects the inventory on hand, pending orders, and backorders. If it is shown as a formula,

$$\text{Inventory position} = \text{stock on hand} + \text{pending orders} - \text{backorders}$$

Inventory position can be managed by periodic and continuous reviews. In a continuous review system, a decision is made to order (or not order) a replenishment quantity whenever the value of inventory position changes. Typically, an order is placed whenever the inventory position reaches a target level (or reorders point). In a periodic review system, the state of the inventory system (either in the form of the inventory position or inventory level) is check at a regularly scheduled time (e.g. every week). The review period is the time interval between reviews (Axsater, 2006). Periodic review generally is used with slow moving items. On the other hand, continuous review is typically utilized for fast moving items or when very inexpensive processes exist for checking the state of the inventory.

There are two common inventory ordering policies, and these policies are (r, Q) and (s, S) policies. When they are combined with periodic and continuous review, a number of fundamental inventory policies are available. These inventory policies are shown in Table

Table 1: Forms of inventory policies

Continuous Review	Periodic Review
(s, S)	(R, s, S)
(r, Q)	(R, r, Q)
	(R, S)

The reorder point, order quantity (r, Q) system is a continuous review policy and the order quantity is constant. When the inventory position is on or under the reorder point (r), the order is placed for order quantity (Q). The advantage of this inventory policy is that it is quite simple and easy to understand due to its easy implementation using a two-bin system. In a two-bin system, the inventory on hand is divided into two-bins. The second bin holds r items. The first bin holds the rest of the items. Whenever a demand occurs, the required items are taken from the first bin. When there are no items left in the first bin, r has been reached, and it is time to reorder Q items. Thus, the 2^{nd} bin holds the safety stock, designed to hold enough inventory to last until the replenishment arrives. After the replenishment order is placed, the bins are swapped, i.e. the 2^{nd} bin becomes the 1st bin (where items are taken), and the original 1^{st} bin becomes the 2^{nd} bin waiting for the replenishment of Q items. When the reorder for Q arrives, the 2^{nd} bin is filled with r items, and any extra are placed in the 1st bin. Then the process repeats. The main disadvantage of the (r, Q) policy is that it is not flexible enough to fit the situations where the individual demands are too large. This means that the replenishment of order size won't be able to raise the inventory level above the reorder point if the individual demands are too large. (Silver, Pyke, & Peterson, 1998). In the case of lumpy demand, an (r, NQ) policy can be used. In this case, orders for size Q are repeated until the inventory position gets above the reorder point. In addition, it can be shown theoretically that the (r, Q) policy will not have the lowest policy cost, when compared under the same assumptions as the (s, S) policy.

The reorder point, order-up-to (s, S) system uses continuous review like an (r, Q) policy. The reorder point is indicated by s, and if the inventory position decreases to or below s, the order is placed up to maximum stock level of S. Because of this, the amount ordered will be (S – I(t)), where I(t) is the current inventory on hand at time t. Thus, the amount ordered will not be constant. A disadvantage of this system is the variable order quantity. This may cause mistakes to occur since suppliers can make mistakes easily if they receive orders with different sizes (Silver, Pyke, & Peterson, 1998). In addition, it is more difficult to synchronize shipment quantities when the size of the order varies. However, this policy can be shown to be a theoretically optimal policy under certain conditions.

The periodic review, order-up-to-level (R, S) system is also known as a replenishment cycle policy. The control procedure is that the inventory level is checked every R units of time, and an order is placed to make the inventory level up to S. The order quantity is not constant. Due to the periodic review feature, it is widely used in practice since it allows combining different orders in R units of time for shipment consolidation. The biggest disadvantage of this system is that it causes more inventory on hand than the systems using continuous review (Silver, Pyke, & Peterson, 1998).

The (R, s, S) system is the combination of (s, S) and (R, S) systems. The control procedure is to check inventory position every R units of time. If the inventory position is under the reorder point, the order is placed to complete the inventory level up to S. The (s, S) is the special case where R=0, and (R, S) is a special case where s=S-1. The disadvantage of this system is that the calculation of three parameters of the system at optimal levels is more difficult.

The (R, r, Q) system is the application of the (r, Q) system at periodic interval. The control procedure is to check the inventory position every R time units. If the inventory position is equal to or under the reorder point, then an order for Q items is placed. This policy is often confused with the (r, Q) policy in practice. In many cases, even if the inventory position is checked continuously, the company will only place an order at the "end of the day". Thus, their review period is in fact 1 day. Unfortunately, the analysis often ignores this defacto period and assumes a continuous review policy, which can make a difference in policy setting procedures (Tempelmeier, 2006).

The reorder point is the answer to the question of when should an order be placed. The reorder point represents the safety stock necessary to cover the demand that might occur during a lead time. If the inventory policy with periodic review is used, the lead time and review period are considered together to set up the reorder point. If continuous review is used, only the lead needs to be considered. Different techniques are considered to determine the reorder point when demand is stochastic. First, the reorder point can be calculated by modeling demand using a stochastic model. Customer demand can be characterized by two components: 1) the time between demands, and 2) the amount of the demand. The amount of demand can be modeled with a discrete random variable. The time between demand occurrences is often modeled with a renewal process governed by a continuous random variable. The Poisson distribution is convenient and useful for modeling demand in practice, since in this case the amount is always 1 unit with the time between demands being exponential. These results in the amount of demand during an interval of time have a Poisson distribution. If demand is large enough, it is often useful to model the demand during a period of time with a continuous distribution. As previously mentioned, the demand during lead time (or demand during lead time plus the review period) is the critical distribution for modeling. The Gamma distribution is commonly used since demand is always positive and this distribution is flexible due to its shape and scale parameters. After deciding the lead time demand distribution, the distribution function will be used to define a reorder point that achieves a desired level of service or minimizes total cost.

So far only a single location for inventory control has been considered. Single-echelon inventory management deals with inventory levels in each echelon independently. In the literature, single-echelon inventory management is more prevelant since managing inventory from single-echelon perspective is easier than a multi-echelon perspective. Moreover, single echelon inventory management does not take care of the inventory at each echelon simultaneously, and it brings many problems due to the nonintegrated supply chain network.

Inventory management is a challenging topic in supply chains with thousands of products even though all products are located in the same echelon. The challenges of managing inventory are much bigger when products are stored in distinct echelons. The typical multi-echelon network includes suppliers, regional distribution centers, distribution centers, and retailers etc. When an item is moving through more than one echelon before reaching the end users, a “multi-echelon” inventory system can be conceptualized. As shown in Figure1, the item is moving from manufacturers to patients by passing more than one echelon. If the inventory management in the multi-echelon structure is not optimal, the network will have many problems, such as (1) excess inventory and safety stock, (2) customer service failures, (3) stockouts in the last echelon from customer point of view, and (4) inadequate demand forecasting, etc (Lee, 2003).

It is difficult to determine the reorder point including safety stock within a multi-echelon structure. Two questions need to be answered: how much total safety stock is needed and how to keep the stock in the different echelons. The Clark-Scarf model is one of the best know techniques to determine the safety stock within the multi-echelon inventory system. The technique is based on decomposition. First, customer demand is met by the most downstream echelons. Shortage at the next echelon leads to stochastic delay having an additional cost. This additional cost affects the process of determining the optimal policy for the next upstream installation (Axsater, 2006).

A seminal paper in multi-echelon structure was published by Sherbrooke(1968), and this paper provided the discussion of the model for recoverable items called METRIC (Multi-Echelon Technique for Recoverable Item Control) in a two-echelon structure including a depot and bases within a military context. The aim of this model is to minimize the total number of average outstanding backorders at the bases for a given level of investment in order to figure out optimal stock levels for each echelon (depot and base) (Sherbrooke, 1968). The Clark-Scarf model is for deterministic demand, on the other hand METRIC is for stochastic demand.

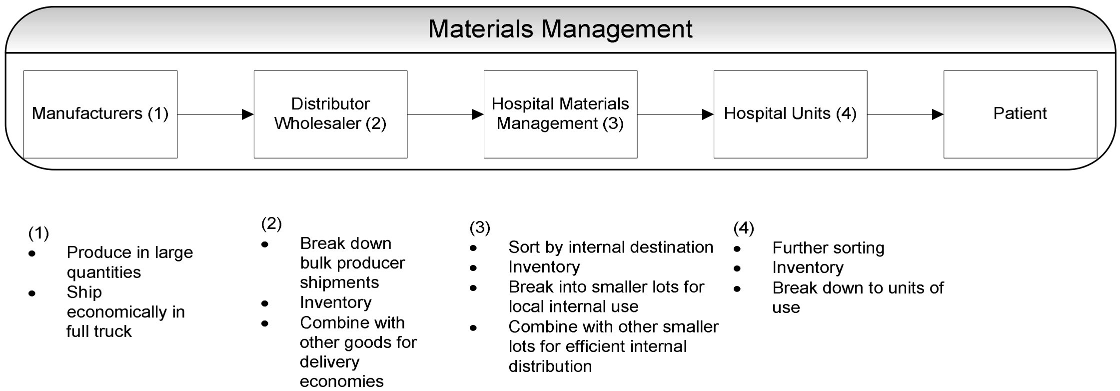

Figure 1: Health Care Material Management **(Chow & Heaver, 1994)**

Deuermeyer and Schwarz (1981) developed analytical models to approximate the service level of multi-echelon supply chain network by assuming (r, Q) policies with stationary Poisson demand. The model was applied to a system consisting of one warehouse that supplies N retailers to obtain the expected service level including fill rate and backorders. This study is important since it considers performance metrics such as fill rate, backorder level, and etc. Moreover, it provides an acceptable model for real life applications. Due to the some assumptions, such as constant lead time, identical retailers' lot size and demand rate, and full shipment of retailer lot size, it has some shortcomings. The results show the relationship between the fill rate and safety stock for warehouse and retailers. The approach used for the multi-echelon analysis within this thesis will be based on the ideas represented in Deuermeyer and Schwarz (1981). In the following section, inventory management practices specific to the healthcare industry are discussed.

B. Inventory Management in Healthcare Supply Chains

Inventory management is the process of balancing inventory needs and requirements with the aim of minimizing costs associated with getting and keeping inventory. Inventory management falls within the area of material management in hospital and has six major areas. These areas are purchasing, production control, inventory control, material handling, traffic, and physical distribution (Nicholson L. A., 2000). Forecasting and inventory control are the main concerns of this thesis, so these issues will be emphasized.

Since the 1990s, enormous pressure has been brought on the some areas in health care industry, such as space utilization, minimizing inventory investment, and labor costs (Nicholson L. A., 2000). Since the 1990s, many studies have been conducted to start to improve health care costs as well as external and internal customer satisfaction. Even with the awareness to improve the healthcare supply chain and the studies addressing inventory management, inventory management in healthcare is still an active and extremely large topic. In its traditional form, healthcare supply chains have not paid adequate attention to inventory management (Nicholson, Vakharia, & Erenguc, 2004).

Much research regarding inventory management in healthcare provide discussions of the general techniques, such as just-in-time, outsourcing inventory management, new models for scheduling decisions, simulations, multi-objective methods to measure performance of hospitals, and new models for demand forecasting, to reduce cost (Rossetti, 2008).

When the research relevant to the inventory management is reviewed, various methods of inventory management are often noted. The most common inventory model in healthcare is the periodic review par level (or order-up to level, (R, S) policy) servicing approach. A main issue is to define the par levels for different items to attain a desired service level. In the most cases, the par levels are defined based on experience and are based on an analysis of data (Nicholson, Vakharia, & Erenguc, 2004). Periodic review par level is used since it is easy to apply and manageable although it does not reflect optimal inventory levels.

In the following, some inventory management practices in health care based on single echelon, multi-echelon, single and multi item, and new approaches are briefly discussed.

1. Single Echelon Structure in Healthcare

Although there are many studies of single echelon applications for industrial companies, the research in this area within health care area is limited. VanderLinde (1983) provided a discussion of the implementation of a computerized ABC/EOQ inventory model in a 146 bed nonprofit community hospital with the aim of maximizing inventory performance involving turnover, month-end inventory cost, and inventory cost per patient, as well as a number of other measures. The results from ABC/EOQ inventory model were compared to the current situation within the hospital, and the improvements noted, such as turnover increasing from 3-4 annual turns to 9-27 annual turns. In addition, inventory cost was reduced by 28.4 %. Pharmacy inventory indicators were also presented as a monthly report.

Prashant (1991) presented a systematic approach for optimization of inventory functions. This study provides solutions for some issues in the inventory management, which include the amount of excess and slow movement inventory, stock-out rate, and PAR level to manage inventory. For excess and no movement inventory, the inventory can be classified based on the age of inventory as a report to monitor the inventory level continuously and to take action proactively. For eliminating and reducing the stock-out, communication is the key practice. The strong communication between material management and the hospital brings on-time delivery. This means, the safety stock level and the number of stock-out situation will decrease. PAR level evaluation brings inventory reduction at the nursing units. This study points out the importance of a systematic approach to managing the inventory optimally. The primary methods of this approach were based on a data driven analysis and decision making as a group.

Dellaert and van de Poel (1996) extended a new and simple inventory rule from EOQ to support a purchasing department at a university hospital in the Netherlands. This new inventory rule is called (R, s, c, S) model, where R is the periodic review period, S is the maximum stock level, s is the minimum stock level, and c is the can-order level. After the (R, s, c, S) model is defined, some theoretical and more sophisticated alternatives are presented to compare the total cost of each models. The (R, s, c, S) model provided many beneficial results, such as reduced holding cost and total cost, increased service level, and decreased total number of orders to suppliers. Vries (2010) focused on the reshaping a hospital inventory system of medicines by conducting a case study that had three phases. In the first phase, the inventory system was analyzed to address the main strengths and weakness of inventory systems. In the second phase of the project, further discussion was made to redesign the inventory system. In the third phase, the new inventory system was partly implemented. The objective of the project was to analyze and improve inventory systems containing pharmaceuticals at the provider level. In the study, a qualitative exploratory case study was conducted since the case study approach allowed an in depth analysis and allowed detailed data to be gathered for the analysis process. Even though all problems were not solved, many improvements were seen in the hospital. These improvements included: partially fixing software problems, better management of rush-orders, re-organizing the communication channel, and changing the organizational structure.

Due to the complexity of inventory systems, including many stakeholders and the unique characteristics of a great variety of products, this system can be very complicated. Thus, reshaping the inventory system is a good starting point to make progress in inventory management. Some topics for the future research that were noted included: a comparison between healthcare and other industries, and a deeper analysis of inventory systems to understand the inventory system in the hospitals by conducting a study. These topics were to be considered in the next study by Vries.

Woosley & Wiley-Patton (2009) examined a local hospital's policies, applied two quantitative inventory models for the inventory control process, and offered a decision support tool for managers to make the inventory process easy-manageable. Actually, three quantitative models were developed, but Model 1 was not used due to its complexity. Model 1 was a general multi-product (s, S) model with space constraint and its application. The purpose of the model was to minimize the total cost including holding, ordering and shortage costs with space constraint. Model 2 was designed to determine an optimal allocation of supplies based on ordering and holding costs by minimizing total cost with fill rate and space constraints.The last model was based on determining the optimal allocation based on ordering cost with the objective of minimizing the total number of expected orders with fill rate and space constraints. This research showed a 70-80 percentage cost reduction when models 2 and 3 are implemented. Even though the rearch results are outstanding, this does not include the reaction of the healthcare stakeholders for this new decision support system. Therefore, the health care stakeholders's reaction toward this decision support system is an unanswered question, and it can be a future reseaarch topic. This study is a good implementation for single-echelon inventory management by using quantitative models.

The literature review of inventory modeling in health care for multi items is related to specific items or item groups. Kwak et.al (1992) dealt with an inventory model for optimizing purchasing of intravenous fluids for hospitals. The two highest usage items in inventory were modeled by using an Economic Order Quantity model to optimize their inventory levels. Nicholson (2000) focused on only stock items, such as bandages, urinals, linens, bedpans, etc to make its study more applicable for other hospitals. Satir and Cengiz (1987) provides a discussion of inventory control within a university health center for 47 different medicines by a stochastic, periodic-review model with the stock-out objective and budgetary constraints. This thesis will examine pharmaceutical items within the Mercy Medical supply chain.

After summarizing the studies for single-echelon structure, the following section presents inventory management based on a multi-echelon structure

2. Multi Echelon Structure in Healthcare

In this section, studies for multi-echelon structure in health care are examined. These studies are crucial for this thesis since inventory management within a multi-echelon structure for health care supply chain form the basis for the modeling.

Nicholson et.al (2004) worked on outsourcing inventory management decisions in healthcare. The purpose of the study was to analyze the inventory decisions within a multi-echelon healthcare network. Two models, which attempt to find the optimal order-up-to inventory levels at each echelon in order to minimize total inventory costs with the constant service level, are presented in the study. These models are “in-house three echelon distribution networks” and “outsourced two-echelon distribution network” for non-critical inventory items. Inventory policies between both models are compared to figure out the most appropriate model. The models were applied to the Shands Healthcare Network. Both models attempted to minimize an objective function over a non-convex constraint set. Solving such a problem is analytically hard, so local optimum results were presented. An upper bound heuristic was used to show how close the analytical solutions were to global optima. As a result, the “outsourced two-echelon distribution network” was selected since it provided considerable savings. It also provided a simpler structure for managing the inventory.

Mustaffa and Potter (2009) conducted a case study with in a healthcare company in Malaysia, which has a single warehouse and a chain of medical clinics. There were problems with service levels to clinics that had a big impact on health care quality. This study specifically concentrates on the inventory management and replenishment process.

The methodology of this study is based on analyzing the current situation by using process mapping, interviews to discuss inventory levels at each echelon, and data analysis. After all the analysis, the most important two issues were defined. These are (1) the number of urgent orders due to ineffective inventory control methods, and (2) stock availability at the warehouse. Some findings from the analysis included: 28 percent of orders cannot be delivered as required and clinics are usually sending urgent orders due to the poor inventory management system. For future research, the authors plan to apply a new inventory policy, a periodic order-up-to policy, for the current inventory system. This study shows that the inventory management in the healthcare is one of the top issues to solve.

Shan (2008) provides a discussion of the analysis of hospital pharmacy inventory control consolidation by using a multi-echelon newsvendor inventory model. The problem is to develop a multi-echelon inventory model for a multi-hospital system to investigate the effects of decentralization and centralization on the inventory distribution system. Each hospital has suppliers to fill orders, its pharmacy to store items from suppliers, and each pharmacy has nursing units to meet patient demands. The main results of this study included (1) analyzing and modeling inventory distribution systems with multi-echelon structure, (2) capturing demand variations in order to model the effects of each nursing units on the other units, (3) improving the quality of care, and (4) reducing total costs. The multi-echelon newsvendor inventory model was applied to determine the optimal inventory level for each pharmaceutical item with the aim of minimizing total costs, including backordering, ordering and holding costs while keeping desired service level. The model was applied to Virtue Health having four hospitals as a case study. This study is important since it indicated that pharmacy inventory consolidation brings 11 percent cost savings. Also it contributes to multi-echelon inventory management within healthcare supply chains.

Even though it is challenging and complex to apply quantitative techniques for health care supply chain, each study shows the importance of the scientific and systematic approaches in the inventory management. The next section will cover some studies related to new techniques in inventory management.

3. New Approach in the Inventory Management

New approaches in inventory management are important because sometimes it is necessary to review all processes and then to re-design them. If members of the health care sector want to conduct inventory management processes in an effective way, they should analyze their inventory management processes and apply new improvement approaches and techniques for their system similar to how industrial companies operate. In other words, industrial companies are following new techniques associated with inventory management to reduce total supply chain cost and optimize their process. Health care providers should also be doing this. For instance, Toyota, one of the biggest automotive companies, invented JIT and Kanban to improve their processes including inventory management. This approach brought significant cost savings to Toyota.

Some healthcare companies have started to apply such techniques to their processes. The study conducted by Persona et.al (2008) focused on a new stock management approach using Kanban and Just-in-time (JIT) to reduce costs associated with inventory management processes and to improve efficiency in the supply chain system. This new implementation is illustrated by a case study performed in the City Hospital of Padua, and the Religious Hospital of Turin, respectively. This study shows that those kinds of new approaches can be successfully applied within the health care industry. Another study conducted by Thummalapalli (2010) focuses on continuous improvement suggestions for controlling inventory cost in health care facilities. This study deals with all improvement efforts, which included: analyzing the inventory system, problem definitions and quantification, documenting best performance from the analysis. This and other studies in healthcare indicate that new approaches can bring savings and improvements within the health care industry.

4. Conclusion

The goal of inventory management is to have the right products available at the right time and location, while maintaining desired service level with as low as possible overall inventory costs. This objective is valid for health care supply; however, it often does not work properly within health care providers, since they tend to have too much inventory for "just in case". On the other hand, industrial companies are able to manage inventory better than in health care since they not only apply inventory models for their systems, but also consider new trends, technologies and the integrations of all components associated with inventory management. Even though health care supply chains are behind of their industrial counter parts, the health care industry has started to apply different approaches because of the growing cost of supplies.

The following section provides a discussion of the methodology to be used within this thesis and outlines some of the important issues to be addressed.

III. RESEARCH METHODOLOGY

A. The Definition of Research Methodology

A research methodology is a systematic and scientific procedure explaining what the activities of research are, how to progress, how to measure progress, and how to attain goals to define and solve problems. A research methodology defines a general approach showing all steps that need to be followed.

Before starting any research in any area, the purpose of the research must be clear since this purpose defines the type of research. There are mainly three categories for scientific research. These are (1) Exploratory research, (2) Constructive research, and (3) Empirical research. This thesis will use empirical research including the case study method. The following section will explain the case study research methodology.

B. Case Study Research Methodology

A case study is a research method that allows a complex issue or object to be more understandable by studying a specific instance. A case study can develop or add strength to prior research. It is a useful tool that allows the application of theoretical models to real world problems. This method of study is not general since "case studies emphasize detailed contextual analysis of a limited number of events or conditions and their relationships" (Soy, 1997). The case study has been used as a research method in a variety of disciplines. Social scientists prefer to use it to examine real-life situation and to support theoretical models (Soy, 1997).

The case study is widely-used because (1) it is useful to test if the scientific models work for the real-life problems, (2) it makes the research and its results understandable, (3) it provides a systematic way of looking at events, collecting data, analyzing information, and (4) it is a good way to test and generate theories and models.

The advantages of the case study are that (1) its applicability to real-life problems to test the scientific models and theories, and (2) it allows the researcher to focus on specific and interesting topics. On the other hand, the main disadvantage of the case study method is that it is not easy to generalize the results of a case study to new/different process or populations.

The process for conducting case study is like the same general processes followed by other research. These processes are (1) plan, (2) collect data, (3) analyze data, and (4) disseminate findings. The first step is planning to identify stakeholders, case study topics, and documents needed for review. The next step is to collect data, and then the data will be analyzed by applying some techniques relevant the case study topic. The last step is to establish the results (Neale, Thapa, & Boyce, 2006).

C. The Use of Case Study Method

Inventory management in multi-echelon networks refers to the management of the inventory levels in the different echelons in a synchronous way to decrease the total costs associated with the inventory. Due to the rising health care costs and the complex networks within health care supply chains, inventory management is a challenging issue.

The thesis will be based on a case study with the Sisters of Mercy Health network. The Sisters of Mercy operate facilities and services in seven different locations with about 26,000 employees and 3,100 physicians. Even though it has a complex supply chain, and it strives to improve its supply chain day by day, Mercy does not use any sophisticated inventory policy setting techniques. The main problem to be addressed within the case study will be to examine the effect of applying inventory policies to Mercy's pharmaceutical distribution system supporting Rogers and Ft. Smith hospitals.

After defining the problem, the data analysis has been conceptualized in three phases. Phase I and II focus on demand and inventory control for different locations in Rogers and Fort Smith. The last phase compare the results from phase I to the results from phase II to observe whether demand is varying by the locations, and the last phase focuses on multi-echelon inventory systems to evaluate the effects of pooling within the supply chain.

As shown in Appendix 1, the methodology developed for the data analysis consists of four steps. These are (1) collection and reviewing of the data, (2) item classification, (3) forecasting, and (4) inventory policy setting. Even though the main concentration of this thesis is to optimize the inventory levels at the different echelons, the analysis at individual echelons must be first improved to understand the benefits associated with an integrated analysis. Before applying the inventory policies, the selection of items and forecasting are supportive steps of inventory management.

This research will then focus on applying analytical models designed to find optimal stock levels for pharmaceutical items within the context of the case study. This approach was chosen due to the fact that (1) it provides adequate and practical information about multi-echelon health care supply chains. (2) It is a good way to obtain real results by analyzing data. (3) The case study makes this study applicable and more likely to be understood by providers.

The following section provides a discussion of the Mercy supply chain network and its processes associated with inventory management.

IV. CASE STUDY

A. Background

"Mercy is an integrated healthcare system including 20 hospitals with 4,062 licensed beds, 26,000 co-workers, 3,100 physicians and a health insurance plan. Mercy would be considered a medium-sized healthcare network" (Moore, 2006). In the late 1990's, Mercy's supply chain was fragmented and had duplicative information systems like many healthcare organizations. In other words, each location was managed independently, and there was no "enterprise process efficiency" and cost savings. Moreover, Mercy used a traditional supply chain model so that all needs were met through outside GPOs and distributers.

In 2002, a supply chain division called Resource Optimization & Innovation (ROi) was created to simplify Mercy's health care supply chain by decreasing its dependence on outside GPOs (Moore, 2006). Mercy now has its own GPO and private transportation fleet for supply chain needs, and it was named as one of the top 20 healthcare supply chain operations in the world, just second overall to Johnson & Johnson, in 2009.

B. Mercy Supply Chain

Each major hospital or Strategic Service Unit (SSU) is a regional hospital system operated by Mercy. Mercy has SSUs in eight different locations and a distribution center as shown in Figure 2.

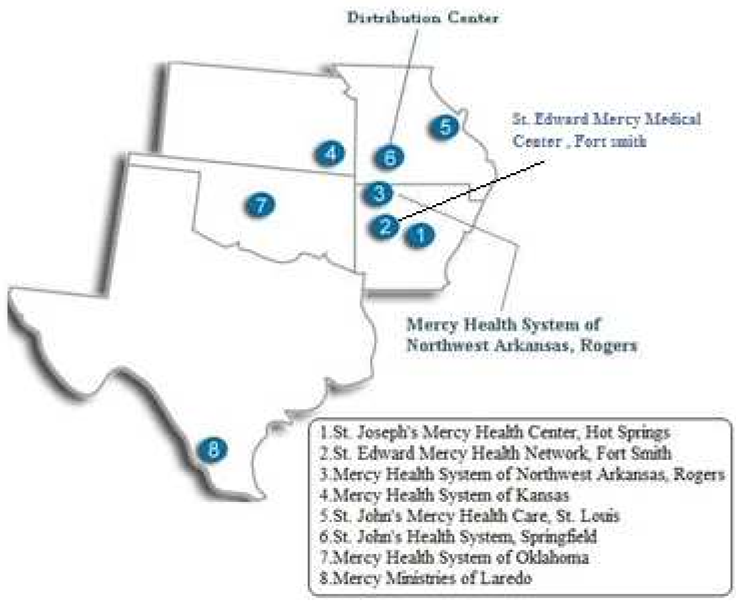

Figure 2: SSU and Distribution Center (CSC) Locations

Each SSU has a central pharmacy (CP), which is responsible for storing pharmaceutical items to meet the hospital's demands. All SSUs are supported by a single distribution center, which is called the Customer Consolidated Services Center (CSC), and is located in Springfield, Missouri. The CSC manages the inventory of all items from SSUs and ABC distributors. ABC is a third party distributor of pharmaceuticals that supports Mercy's distribution network. ABC provides supplies of basic items and serves as a backup supplier in the event of stock outs at the CSC level. Each unit is connected to other units through integrated material management software. The relationship between CSC, ABC, and the SSU for the physical and information flows is shown in Figure 3.

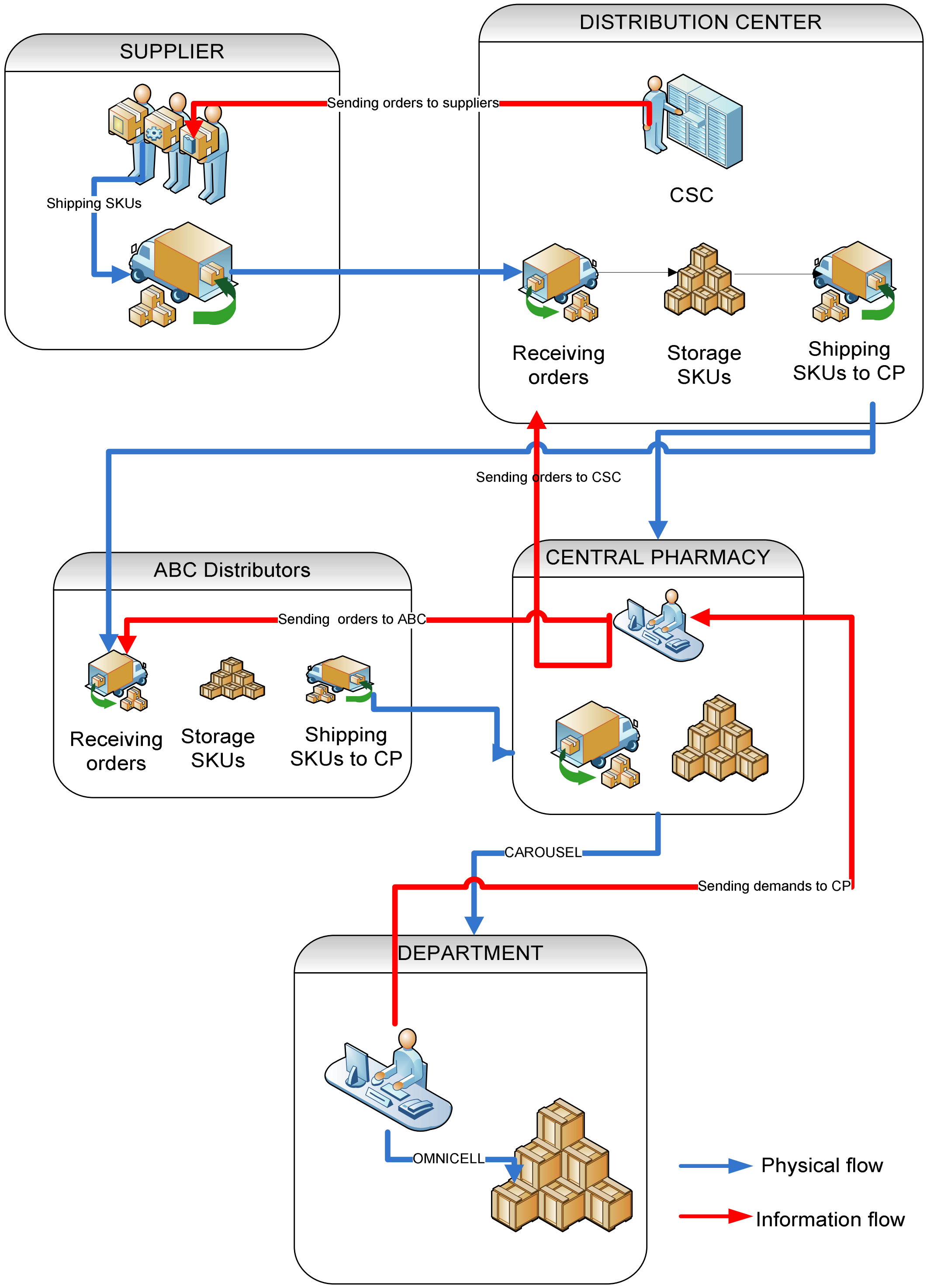

Figure 3: Conceptual System Description

In this thesis, the supply chain activities in each SSU and CSC are divided into three groups, such as inventory management, order replenishment process, and order receiving processes. The details of these relationships will be explained and supply chain activities will be defined in the following sections.

1. Inventory Management

The inventory policy used by Mercy is called the “par-level” method even though there is no scientific inventory policy setting method used in the central pharmacy (CP). According to the “par-level” method, the stocking quantity (the par level) is defined for each item based on average usage and the desired number of days supply. Mercy Medical uses an overall 14 days of supply metric within their network. In other words, the goal is to keep the overall inventory with a fourteen-day quantity of supply. This means each item can have different number of days of supply.

The fill rate goal for CSC is 98.5%, and Mercy currently is operating with a 99% fill rate. On the other hand, the fill rate for central pharmacies might be as high as100% since they always stock up, and they never stock out.

All of the costs components that are necessary to calculate the total inventory cost are not fully available. Thus, approximations based on data from Mercy will be used in a comparative analysis. The holding carrying charge rate is assumed to be approximately 25% for CSC items. Although EDI is used for ordering process, there are still the costs associated with checking and making an order. The ordering cost will be estimated by calculating the average ordering cost from economic order quantity and order frequency equations. There is no data available for calculation or estimating the backordering cost. Instead, the analysis will use a fill rate constraint to ensure high inventory service.

2. Order Replenishment Process

The inventory level is checked every day by stock control personnel to decide whether to place an order. If it is decided to place an order, the stock control manager will decide the location to send to the order. As shown in Figure 4, the central pharmacies can place orders directly to ABC or to CSC.

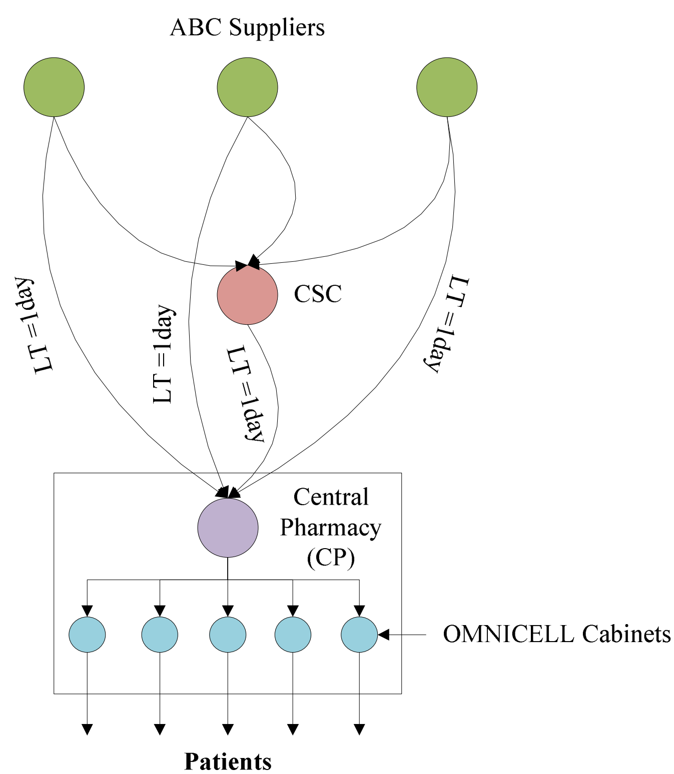

Figure 4: General Logic of Multi Echelon System for Mercy Medical

First, CPs can order items from the CSC, and then the CSC can send items from its stocks if they are available. If the items ordered by the CPs are not available in the CSC's stock, the CSC might ask the other distributor (ABC) to send the item directly to the CP.

Second, the CPs can bypass the CSC and order directly from ABC if required. Consequently, there is no standard procedure to choose the location, but the location is used to classify items, such as CSC and ABC items. If the item is supplied from the CSC, it is called a CSC item. Otherwise, it is called an ABC item. This ordering process is repeated in the afternoon once each day. In other words, the review period is essentially one day.

There is a direct shipment from CSC to the SSU in Rogers. The lead time from both the CSC and ABC to the CP, is 1 day. There are no shipments during weekends from the CSC. The lead time from the external suppliers to CSC is average 3 days.

3. Order Receiving Process

The receiving process for replenishment starts at every morning, except on Sundays. When the replenishments are received, all items are checked. After the checking process is done, some items are stored within a carousel, which consists of shelves that rotate up or down for delivering items to associated departments and storing items. Shelves within the carousel can be easily adjusted, and each of them can contain a different type of drug. This means that each shelf can be shared by different items. The others flow directly to the unit or are stored in other locations in the CP. Each department has OMNICELL cabinets to store items. When any item is needed, the person, who is responsible for this cabinet, picks the necessary items, and then enters the number of items picked into the system to update the inventory level for the item.

The inventory accuracy at the CSC is 99%. As for the central pharmacies, at least 95% is expected because of controlled substances and they get audited time to time from the Food and Drug Administration (FDA) and Drug Enforcement Agency (DEA).

4. Supply Chain Process in the Distribution Center (CSC)

The CSC receives the orders from the SSUs once each day in the afternoon by downloading order data from the mainframe computer. All demands from different SSU locations are combined, and all orders are consolidated by the CSC. The system uses a periodic min-max policy. If it is decided to order, the orders will be sent to the relevant suppliers. If the order is urgent, which means that the ordered item is required as soon as possible, the order is shipped to the central pharmacy (CP) directly from the supplier. Otherwise, the order is shipped from the CSC to the SSUs.

Mercy Medical purchases pharmaceutical items in bulk from a single supplier and then individually re-packages and barcodes medications in its centralized distribution center. The bar-coding of medications in single-dose packages is made by a unit within the distribution center before items are sent to SSUs, and items on the pick list are packed based on their destination and are shipped early in the morning. There are three types of items from a packaging perspective. These are Bulk, OMNICELL (unit dose) and Repack items.

So far only the research methodology and case study have been considered. In the following section, an overview of the data analysis process is presented as well as a discussion of the results.

V. ANALYSIS AND DISCUSSION

This section provides a discussion of the data analysis and its results for CP in Rogers and Forth Smith. The analysis and its results are crucial for the thesis since this illustrates an application of the methodology for real data from the CP in both locations and may indicate whether this methodology works for the real-life problems. The results showed that case study methodology is effective in characterizing many of the inventory management problems.

In the following sections, a brief overview of the steps of the analysis and the results are presented.

A. Available Data

The data that is needed is the total demand from central pharmacy to CSC, and unit cost of each item for CPs in Rogers and Forth Smith. The data set provided by Mercy includes daily record for orders from CPs to CSC and ABC suppliers, and Table 2 explains content of data file and the meaning of column names. The data is daily from April 2008 to May 2010. Moreover, all records are based on the invoice created by CSC for regarding CP's daily orders. The data set for orders from CP to CSC and ABC distributors was received for Rogers, and Forth Smith, respectively. The first data set for Rogers covering the last two years has 101,404 records for 2,432 items. The second data set for Forth Smith covering the last two years has 268,206 records for 4,644.

Before the data was analyzed, the data set was overviewed to make sure that it is good enough to start analysis process. The data was checked for unit cost and total demand for each item since each item might have different types, such as, repack, bulk, and

OMNICELL, which have different unit of measures. In order to get the real total demand and average unit cost, it is required to make all unit of measure the same for each item. During the data reviewing process, there were problems due to non-standard data. The main problem was with the unit of measure (UOM), since total demand for each item must be obtained by converting UOM for sell quantity to UOM1, which is for unit dose. It was not possible to convert UOM for sell quantity to UOM1 for every item even though the conversion logic provided by Mercy was used. The conversion logic did not work for all items. After this problem was shared with Mercy, a solution for this issue was not readily available. Appendix 2 presents all units of measures used by Mercy. As a result, it was decided to analyze the items having the same UOM for sell quantity and UOM1, because no conversion is needed for these items. After this decision, 927 items out of 2,432 items in the first data set were analyzed for Rogers. 1,920 items out of 4,644 items in the first data set were analyzed for Forth Smith.

Table 2: Column Titles in the Data Set

Header	Comments
Invoice Date	Date invoice was generated.
Invoice Nbr	Unique identifier for the invoice
Account Nbr	Unique customer/location identifier used to identify stocking locations
Cust Name	Name for the account number
Corp Code	Mercy internal community code. (e.g. , 20 is Rogers,)
Region	SSU region
ABC Item Nbr	Vendor item number
User Nbr	Mercy item number. This filed will be blank if the item is not built in our ERP system
Item Desc	Description of the item
Manufacturer	Item manufacturer name
NDC Nbr	Nation Drug Code number - another unique identifier of the item
TheraPeutic Class Description	Used for drug classification
GCN	Generic code number
Generic code and name	Generic name
Contract item	Y' if on contract else 'N'
Extended Cost	Total line cost for Qty
Source	If purchased from ABC the source = 'INTERLINX' else 'TECSYS'
Class	Usually ACUTE since we will not include any clinics
Level 1 Therpeutic Class	Drug classification
Level 2 Therapeutic class	Drug classification
Sell UOM	Unit of measure for allocated qty
Allocated qty	Quantity sold
ABC UOM	Vendor unit of measure - should match sell uom if the source is 'INTERLINX'

B. Inventory Pareto Analysis

In the healthcare supply chain, there are thousands of items to be managed. It is very difficult to deal with all items; therefore, it is important to focus on the items that have a significant impact on the overall inventory value.

Although in the literature, there are many different classification techniques, a Pareto ABC inventory analysis was chosen for the classification process due to its simple implementation. ABC inventory analysis is a grouping technique by the demand, average unit cost and usage value. Typically, 20 percent of the items can cover approximately 80 percent of the usage value (dollar value). There are three priority rankings to show importance of the category. Category A is very important, category B is important, and category C is less important (Silver, Pyke, & Peterson, 1998). A Pareto ABC inventory analysis was chosen based on annual usage value because the usage value gives the same importance for both demand and unit cost.

Table 3 shows how many items there are in category A, B and C for the analysis based on usage value, demand and unit cost for Rogers. As seen in Table 4, almost 50% of items are in category C. Table 4 illustrates the results of ABC Pareto analysis for CP in Forth Smith. Moreover, Appendix 3 and 4 provide some statistical results for the ABC analysis.

Table 3: # of Item and % of item in each ABC Category based on Usage Value, Demand, and Unit Cost

	Usage Value		**Demand**		**Unit Cost**	
	# of item	% of item	# of item	% of item	# of item	% of item
A	68	7%	120	13%	109	12%
B	395	43%	344	37%	595	64%
C	464	50%	463	50%	223	24%
Total	**927**		**927**		**927**	

Table 4: # of Item and % of item in each ABC Category based on Usage Value, Demand, and Unit Cost

	Usage Value		Demand		Unit Cost	
	# of item	% of item	# of item	% of item	# of item	% of item
A	154	8%	212	11%	205	11%
B	806	42%	748	39%	755	39%
C	960	50%	960	50%	960	50%
Total	**1,920**		**1,920**		**1,920**	

ABC analysis assigning all items into a category associated with their demand frequency and unit cost will be used to select items for the next step, forecasting analysis. Sometimes, ABC analysis is not meaningful enough to select the most representative items. If so, a technique to determine the intermittent demand pattern can be performed to assign demand classes, such as intermittent, smooth, lumpy, and erratic etc. The software described in (Rossetti, 2008) was used to identify intermittent demand classes based on the mean inter-demand interval (p=1.32) and the squared coefficient of the variation of the demand size (CV^2 =0.49).. The demand class supports the process of selecting items from each category. As seen in Table 5 and 6, most of the items have intermittent and lumpy demands for both locations. In other words, the demand is not smooth and is not very predictable.

Table 5 : # of item in each demand class for CP in Rogers

Demand Class	# of Items
E	11
I	602
L	247
S	67
Total	927

Table 6: # of item in each demand class for CP in Forth Smith

Demand Class	# of Items
E	150
I	996
L	572
S	202
Total	1,920

C. Forecasting Analysis

The goal of the forecasting process is to find the best fitting forecasting model for the selected items and to obtain the mean and variance of the predicted weekly demand from the forecasting process. Demand was classified as weekly to get enough periods for forecasting. For additional information on the effect of aggregating demand periods on inventory forecasting, please see Varghese and Rossetti (2011).

The following steps were used to determine the most appropriate forecasting model: (1) plot the data, (2) interpret the results based on the information from the data plotted, (3) define demand patterns, such as trend, seasonality, and (4) fit the forecasting model while comparing some measures of accuracy, such as the measures of forecasting errors (MAE, MAPE), AIC, BIC, and R-Square, etc. MAE is the average mean absolute errors between actual and predicted demand as shown in the equation (V.1). MAPE is mean absolute percentage errors between actual and predicted demand as shown in the equation (V.2). AIC and BIC are measures of the goodness of fit of forecasting models. Smaller values of these criteria indicate better fit. R-Square measures the proportion of the variation around the mean.

$$MEA = \sum_{t=1}^{n} |x_t - \hat{x}_{t-1}|/n \quad \text{(V.1)}$$

$$MAPE = \left[\frac{1}{n}\sum_{t=1}^{n}\left|\frac{x_t - \hat{x}_{t-1}}{x_t}\right|\right] * 100 \quad \text{(V.2)}$$

In the general case, the AIC is

$$\mathrm{AIC} = 2\mathrm{k} - 2\ln(\mathrm{L}) \quad \text{(V.3)}$$

where L is the maximized value of the likelihood function, and k is the number of parameters in the model.

Forecasting was performed for each selected item for Rogers, and Forth Smith, respectively. There were no significant trends or non-stationary patterns for any of the selected items. In most cases, ARIMA models, which predict future values of a time series by a linear combination of its past values and a series of errors, worked well for the items. Table 7 shows the summary of forecasting for CP in Rogers, and Appendix 5 presents more details of the forecasting results. Table 8 shows the summary of forecasting for CP in Forth Smith, and Appendix 6 presents more details of the forecasting results.

Table 7: Summary of Forecasting for Selected Items

Forecasting Model	The Number Of Items That Used This Model Form
AR(1)	**3**
AR(2)	**1**
AR(3)	**1**
AR(7)	**1**
ARMA (1,1)	**4**
ARMA (2,2)	**1**
ARMA (3,3)	**1**
ARMA(1,1)	**1**
ARMA(2,2)	**3**
ARMA(3,3)	**1**
ARMA(5,5)	**1**
ARMA(6,6)	**2**
ARMA(9,9)	**1**
Cumulative Average	**4**
Cumulative Average	**1**
MA(1)	**2**
MA(2)	**1**
MA(3)	**1**
MA(4)	**1**
Moving Average	**1**
Naïve Forecasting	**1**
Simple Exponential Smoothing	**1**
Grand Total	**34**

Table 8: Summary of Forecasting for Selected Items

Forecasting Model	The Number Of Items That Used This Model Form
AR(1)	4
AR(3)	4
ARMA(1,1)	4
Cumulative Average	3
Simple Exponential Smoothing	3
ARMA(2,2)	2
ARMA(3,3)	2
Damped-Trend Linear Exponential Smoothing	2
AR(2)	1
AR(6)	1
ARMA (1,1)	1
ARMA (2,2)	1
ARMA(3,4)	1
ARMA(5,5)	1
ARMA(6,6)	1
Average Demand	1
Linear (Holt) Exponential Smoothing	1
MA(3)	1
MA(4)	1
MA(6)	1
Total	36

The next step will be an inventory analysis for the items that have forecasts to obtain predicted weekly demand and the forecasting error.

D. Inventory Analysis

Inventory analysis is conducted for CPs and CSC, respectively. First, an inventory model was developed and applied for each CP separately, and then the CSC and CPs are integrated for a multi-echelon analysis.

Model for Inventory policy of single echelon between central pharmacy and CSC

The model to be used is general single-item (r, Q) model with a fill rate constraint. The model attempts to minimize the total cost including inventory holding and ordering costs. The Gamma distribution is assumed to be appropriate for modeling the demand during lead time distribution.

The notation used in the model are as follows:

i	Index for items (i=1,2,….,n)
u_i	Unit cost of item i
c	Inventory carrying rate
A_i	Ordering cost of item i
r_i	Reorder point for item i
Q_i	Order quantity for item i
I_i	Average inventory for item i
OF_i	Order frequency of item i
TC_i	Total cost for item i
FR	Observed fill rate
L	Lead time

The assumptions of the model are as follows:

- The desired fill rate for all individual items at CSC and CPs is 98.5%.
- Inventory carrying cost rate is 25% and 18% for CPs and CSC, respectively.
- Lead time from CSC and CPs is constant and 1 day, and the lead time from the external suppliers to CSC is 3 days and constant.
- Implied ordering cost is used and calculated as follows.

The order frequency, which shows how often Mercy orders the items so as to have 14 days of supply, is known. The ordering frequency is once in two weeks. The formula for the order frequency is as follows:

λ_i: mean demand per week for item i
$\mathrm{OF_i} = \mathrm{Order\ frequency\ of\ item\ i}$
Q_i: order quantity for item i

$$\mathrm{OF_i} = \frac{\lambda_i}{Q_i} \tag{V.4}$$

from the equation, Q_i can be computed, since we know $\mathrm{OF_i} = 0.5$.

$$Q_i = 2 * \lambda_i \tag{V.5}$$

Assuming that Q_i is equal to economic order quantity (EOQ).

$$Q_i = \sqrt{\frac{2 * A_i * \lambda_i}{h_i}} \tag{V.6}$$

And solving the equation for A yield,

$$A_i = \frac{h_i * {Q_i}^2}{2 * \lambda_i} \tag{V.7}$$

After the calculation of the individual ordering cost for each item, the average ordering cost can be calculated by the formula (V.8)

$$\hat{A} = \frac{1}{n}\sum_{i=1}^{n} A_i \tag{V.8}$$

Equation V.8 yields an implied ordering cost based on current inventory ordering, which can be used within inventory models as an approximation for the true ordering cost. In the analysis that follows, a sensitivity analysis on the ordering cost will also be used to show the effects of different ordering costs and the number days of supply on the total cost.

The model with the objective of minimizing the total cost with 98.5% of fill rate for each item is as follows. The model was implemented in Excel 2007. Appendix 7 shows a general view of this Excel spreadsheet created to solve the model for CPs and CSC.

Minimize $TC_i = I_i * u_i * c + \mathrm{OF_i} * \widehat{\mathrm{A}}_\mathrm{i}$

Subject to

$\mathrm{FR} \leq 1.00$	[Upper bound for the fill rate]
$\mathrm{FR} \geq 0.985$	[Lower bound for the fill rate]
$Q_i \geq 1$	[Minimum order quantity]
$Q_i, r_i \geq 0$	[Non-negativity]

Inventory policy was applied for the selected items by following an inventory analysis process. The total cost and inventory turnover are performance metrics to compare current inventory model that has been used at Mercy and the new model offered by this analysis.

Inventory analysis process is divided into three phases. The first phase is basically to calculate the parameters, such as the mean and standard deviation of the demand associated with the Gamma distribution. The Gamma distribution is commonly used since demand is always positive and this distribution is flexible due to its shape and scale parameters. Forecasting analysis provides the estimated weekly demand and MAE of forecasting errors, which are starting points for the first phase of inventory analysis. First, it is necessary to obtain the standard deviation of forecasting error by using the equation (V.9), since this formula is usually used for many forecasting models (Axsater, 2006).

$$\sigma_i = MAE_i * \sqrt{\frac{\pi}{2}} \qquad (V.9)$$

The next step is to calculate the variance of forecasting error from the equation (V.9) by squaring of standard deviation. The mean lead time demand (μ) and variance of the demand during lead time (σ^2) are necessary to calculate the parameters of Gamma distribution, which are shape (α) and scale (β) parameters. The equations (V.10) and (V.11) show the formulas for calculation of the shape and scale parameters. These parameters are used to calculate the mean and standard deviation of the demand.

$$\alpha = (\mu/\sigma)^2 \qquad (V.10)$$

$$\beta = \mu/(\sigma)^2 \qquad (V.11)$$

Gamma distribution has mean ($\alpha * \beta$) and variance ($\alpha * \beta^2$) to be used in the following phase.

The second phase of inventory analysis is the calculation of stock-out, average inventory level, order frequency, holding cost, and ordering cost to determine the order quantity and the re-order point in order to minimize total cost with the fill rate constraint. The calculations of performance metrics are shown in the equations from (V.12) to (V.15). At end of the second phase, the total inventory cost for the new model will be obtained.

$\overline{SO}_i$ = average stocout frequency for CP_i

$\overline{B}_i$ = average backorders for CP_i

$\overline{I}_i$ = average inventory for CP_i

$\overline{FR}_i$ = fill rate for CP_i

$$\overline{SO_i} = \frac{1}{q_i}[G^1(r_i) - G^1(r_i + q_i)] \quad \text{(V.12)}$$

$$\overline{B_i} = \frac{1}{q_i}[G^2(r_i) - G^2(r_i + q_i)] \quad \text{(V.13)}$$

$$\overline{I_i} = \frac{1}{2}(1 + q_i) + r_i - \lambda_i L + B_i \quad \text{(V.14)}$$

$$\overline{FR_i} = 1 - \overline{SO_i} \quad \text{(V.15)}$$

G^1 and G^2 represent the first-and second-order loss function of the demand during lead-time distribution.

The last phase involves computing the results for the current model by determining the order quantity, safety stock, average inventory level, and order frequency, ordering and holding costs based on the policy of 14 days of supply. If all items have a safety stock (SS) set equal to the same number of supply periods then the safety stock can be determined for all items.

Assume that all items have T periods of supply, which is the safety stock.

$$SS_i = \lambda_i * T \quad \text{(V.16)}$$

The equation (V.17) would be the approximate reorder point.

$$r_i = \lambda_i L + \lambda_i T \quad \text{(V.17)}$$

Under this model, the average inventory level for the current model is shown in the equation (V.18) (Ballou, 1999).

$$\bar{I}_i \cong \frac{Q_i}{2} + SS_i \quad \text{(V.18)}$$

The calculation of the total cost for the current model has the same logic as in the new model. ($TC_i = I_i * u_i * c + \mathrm{OF_i} * \widehat{\mathrm{A}}_\mathrm{i}$)

Consequently, the total inventory costs from the second and last phases for current and new models can be compared to show the differences in cost.

After the inventory analysis for CPs is defined, the multi-echelon analysis will be discussed in the following steps.

General demand in continuous time, non-identical regional warehouse is an approach introduced by de Kok et al. (2004) is used to aggregate ordering process for central warehouse (CSC). This approach considers the different supply chain with customers arriving on a continuous time axis like the approach introduced by Deuermeyer and Schwarz (1981). However, it assumes that the demand process in the regional warehouse (CP) is characterized by the sequence of customer orders with random interarrival times and random order sizes. In other words, the demand process is not identical for the CPs (Tempelmeier, 2006). The general logic of this approach is seen Figure 5 with the parameters of the demand sizes and interarrival times.

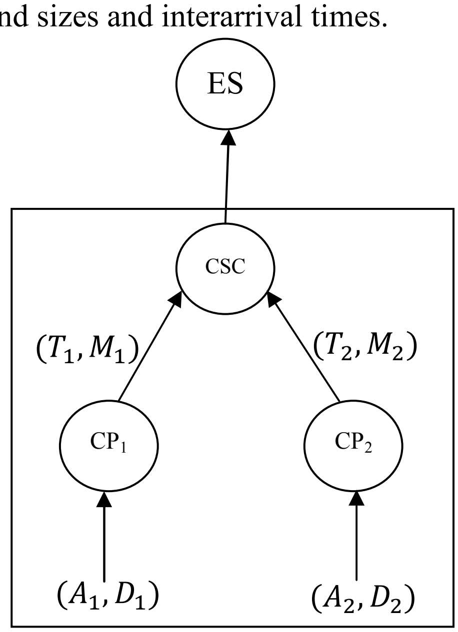

Figure 5: The general logic of the approach with demand processes

The next section will present the application and combination of this approach with multi-echelon analysis.

- Calculate the mean and variance of the order size and interarrival times for each CP

The average weekly demand is calculated by taking average of the order size from CPs to CSC. De Kok used a mixed Erlang distribution for random variables including order size and time between arrivals. Because of the complexity of calculation of the variance of demand size and interarrival times for the second moment of the inter-arrival times, we assume that the arrival process is a compound Poisson process with mean demand size E[D], where D_j is the order size for CP_j.

- Calculate time between arrivals by taking average of actual arrival times for CP_j.

B_j $= the\ actual\ time\ of\ j^{th} arrival \qquad j = 1,2, \dots, J$

$A_j = Times\ between\ arrivals\ per\ day, and\ A_j = B_j - B_{j-1} \qquad i = 1,2, \dots, J$

$$A = \sum_{j=1}^{J} \frac{A_j}{J} \qquad \text{(V.19)}$$

Assuming that the time between demands is distributed exponentially, the mean rate of the corresponding Poisson distribution is $\lambda = 1/E[A]$. The time unit is in days for calculating the time between demand, and it is required to convert it to weeks by multiplying by 7 because the time scale for entire analysis is weekly. The variance of the time between demands is λ^{-2}.

In the next step, the demand size and interarrival times will be used for the transformation of the demand process (A_j, D_j) into a replenishment order process (T_j, M_j) which is the same as the demand process characterized by the interarrival times T_j and the order sizes M_j.

Let (A_1, D_1) be the interarrival time and demand order size at CP_1

Let (A_2, D_2) be the interarrival time and demand order size at CP_2

Let (T_1, M_1) be the time between replenishment orders and order amount size $M_1 = O_1 q_1$ from CP_1, where q_1 is the reorder quantity for CP_1,and O_1 represents the number of times the order was placed to get above the reorder point in order to get actual demand size.

Let (T_2, M_2) be the time between replenishment orders and order amount size $M_2 = O_2 q_2$ from CP_2, where q_2 is the reorder quantity for CP_2

Let (A_z, D_z) be the aggregate of the order processes (T_1, M_1) (T_2, M_2) as seen by the CSC.

First, the first and second moments of actual order quantity are calculated via the equation (V.20) and (V.21).

$$E\{M_j\} = \frac{q_j\, E\{D_j\}}{\int_0^{q_j} P\{D_j \geq x\} dx} \qquad \text{(V.20)}$$

$$E\{M_j{}^2\} = q_j{}^2 \sum_{i=0}^{\infty} [-i^2 + (i+1)^2] * P\{U_j \geq i * q_j\} \qquad \text{(V.21)}$$

Assuming that the moments of the actual order quantity are E$\{M_j\} = q_j$ and E$\{M_j{}^2\} = q_j$, respectively, where due to sufficiently large minimal order size (q_j), see (Tempelmeier, 2006) equation V.20 and V.21 can be approximated.

The number of orders arriving during an order cycle in the regional warehouse is R, and the expected value of R is equal to the expected actual order quantity E{M} divided by the average demand size E{D} of an order as shown in equation (V.22). The second moment of the expected value of order cycle is calculated via equation (V.23).

$$\mathrm{E}\ \{R_j\} = \mathrm{E}\left\{M_j\right\} / \mathrm{E}\left\{D_j\right\} \qquad (\mathrm{j} = 1, 2) \qquad (\mathrm{V.22})$$

$$\mathrm{E}\left\{{R_j}^2\right\} = \frac{\mathrm{q}^2}{\mathrm{E\{D\}}^2} + \frac{\mathrm{VAR\{D_j\}}}{\mathrm{E\{D_j\}}^2} * \frac{\mathrm{q_j}}{\mathrm{E\{D_j\}}} + \frac{\mathrm{E\{{D_j}^2\}}^2}{2 * \mathrm{E\{D_j\}}^4} - \frac{E\{D_j^3\}}{3 * E\{D\}^3} \quad (\mathrm{j} = 1, 2) \qquad (\mathrm{V.23})$$

The first and second moments of total order cycles are calculated by equation (V.24) and (V.25), respectively.

$$\mathrm{E}\{T_j\} = \mathrm{E}\{R_j\}/\mathrm{E}\{A_j\} \qquad (\mathrm{j}=1, 2) \qquad (\mathrm{V.24})$$

$$\mathrm{E}\{T_j^2\} = + \mathrm{E\{R\}} * \mathrm{VAR\{A\}} + \mathrm{E}\left\{{R_j}^2\right\} * \mathrm{E}\{A^2\} \qquad (\mathrm{j}=1, 2) \qquad (\mathrm{V.25})$$

Now, $\mathrm{E}\{T_j\}$, $\mathrm{E}\{T_j^2\}$, and $\mathrm{E}\left\{M_j\right\}$ *which are* the parameters of ordering process for CP_j (j=1,2,……) are known. In the next step, the demand process of CSC will be derived from the ordering processes of CPs.

Aggregation of the order process $\left(T_j, M_j\right)$ (j = 1, 2) of the CP into an overall demand process (A_z, D_z) seen by the CSC.

Let A_z be the average time between two demand arrivals in the central warehouse

$$E\{A_z\} = \left[\sum_{j=1}^{J} \frac{1}{E\{T_j\}}\right]^{-1} \qquad (\mathrm{V.26})$$

The second moment of the aggregate interarrival time of demands in CSC is as seen in equation (V.27).

$$E\{A_z^2\} = 2 * E\{A_z\} * \left[\prod_{j=1}^{J} \frac{1}{E\{T_j\}}\right] * \int_0^{\infty} \left(\prod_{j=1}^{J} \int_0^{\infty} \left[1 - F_{T_j}(y)\right] * dy\right) * dx \quad \text{(V.27)}$$

The moments of the demand sizes in the central warehouse, D_z are calculated via equations (V.28) and (V.29). This concludes the order size and interarrival time for central warehouse (A_z, D_z).

$$E\{D_z\} = E\{A_z\} * \sum_{j=1}^{J} \frac{E\{M_j\}}{E\{T_j\}} \quad \text{(V.28)}$$

$$E\{D_z^2\} = E\{A_z\} * \sum_{j=1}^{J} \frac{E\{{M_j}^2\}}{E\{T_j\}} \quad \text{(V.29)}$$

- Calculate the mean and demand during lead time and the variance of the demand during the lead time for CSC.

Assume that the arrival process to the CSC is a compound Poisson process. Given the moments of $E\{A_z\}$, and $E\{D_z\}$, the mean rate of arrivals at CSC can be calculated as shown in the equation (V.30).

$$\lambda_w = \frac{1}{E\{A_z\}} \quad \text{(V.30)}$$

Let $E[D_w(L)]$ be the mean demand during lead time for CSC.

Let $Var[D_w(L)]$ be the variance of the demand during lead time for CSC.

$$E[D_w(L)] = \lambda_w L\, E(D_z) \quad \text{(V.31)}$$

$$Var[D_w(L)] = \lambda_w L\, E\left({D_z}^2\right) \quad \text{(V.32)}$$

Assume that $D_w(L)$ is distributed according to a Gamma distribution with shape parameter γ and scale parameter β.

$$\beta = \frac{Var[D_w(L)]}{E[D_w(L)]} \tag{V.33}$$

$$\gamma = \frac{(E[D_w(L)])^2}{Var[D_w(L)]} \tag{V.34}$$

$$E[D_w(L)] = \gamma\beta \tag{V.35}$$

$$Var[D_w(L)] = \gamma\beta^2 \tag{V.36}$$

The mean demand during lead time and the variance of the demand during lead time are calculated by using the equations (V.31) and (V.32), respectively.

- The calculation of reorder point and order quantity for the CSC with the performance metrics, such as the average inventory level ($\bar{I}(r_w, q_w)$) , the average number of backorders ($\bar{B}(r_w, q_w)$), the fill rate ($\overline{FR}(r_w, q_w)$), the order frequency ($\overline{OF}(r_w, q_w)$), and the backorder waiting time ($\overline{BW}(r_w, q_w)$) at CSC.

All calculations of the performance metrics for CSC are like ones for CPs. For CSC, the average backorder waiting time is approximated to obtain an approximate lead time for CPs.

$$E[B_w] = \frac{(\bar{B}(r_w, q_w)}{\lambda_w} \tag{V.37}$$

The lead time from CSC to CP is 1 day, and this lead time is transportation time which does not include the backorder waiting time at CSC. The equation (V.38) provides the actual lead time (L_j) for CP_j.

Let V_j be the transportation time to CP_j

$$L_j = V_j + E[B_w] \tag{V.38}$$

The actual lead time is used to calculate the demand during the lead time for each CP. The assumption for the demand during lead time is still Gamma distribution. Now, it is necessary to update the mean demand during the lead time and the variance of the demand during the lead time for CPs.

In the following section, the results of inventory analysis are presented for CP in Rogers, and Forth Smith, and CSC. After an independent analysis by location for the CPs in Rogers and Forth Smith is discussed, the multi-echelon analysis integrating CSC and CPs in Rogers and Forth Smith is presented.

1. Results of Inventory Analysis for Rogers

The results were obtained from the data between CP in Rogers and CSC for 34 items. The model for inventory model was run for each item individually to calculate the order point (r), the order quantity (Q), and the total cost.

The current model is based on 14 days of supply, on the other hand the new inventory model is optimal model for (r, Q) model, and it provides 67% cost saving with the average fixed ordering cost of $34.13 for all 34 items, and total cost per week will decrease from $837 to $278 for the fill rate of 98.5% as shown in Table 9 and Figure 6.

Table 9: Total Costs of New and Current Models for Fill Rate of 98.5%

# of items	**Total Cost for New Model with 98.5% fill rate**	**Total Cost for the Current Model with 98.5% fill rate**	**Improvement (Cost Reduction)**
34	$278	$837	67%

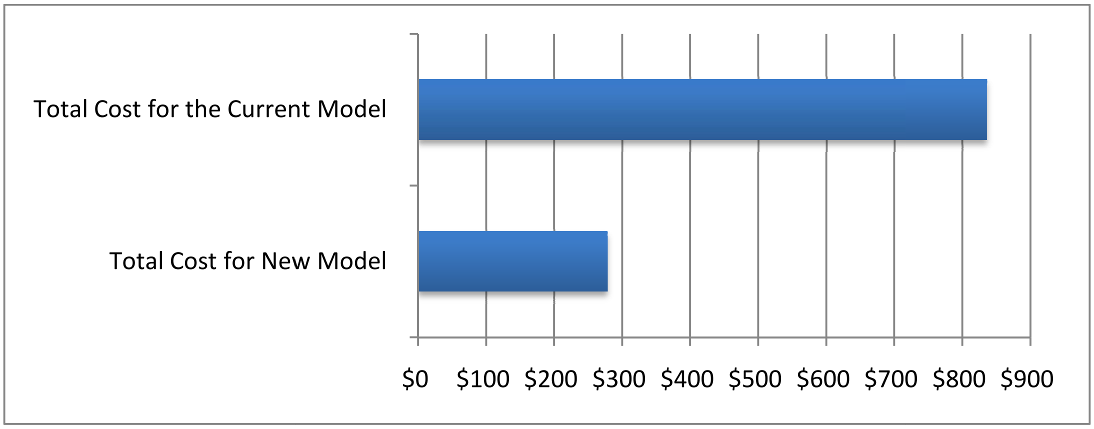

Figure 6: Comparison of Total Costs for New and Current Model

The average ordering cost is higher than the individual holding cost for most items, so the new model tends to keep more inventory instead of placing orders very often. Because of the low order frequency, and higher inventory level, inventory turnover is low. This conclusion shows that different ordering cost for each item will have different impacts on the total cost, so the sensitivity analysis for ordering cost is conducted, and the results are shown in Table10. Table 10 presents the cost savings with the new inventory model for different number of days of supply and ordering cost. The lower number of days of supply and ordering cost does not bring a big cost saving for the new inventory level. The sensitivity analysis indicates that for values of ordering cost greater than $1 per order and greater than 2 days of supply, there will be a cost savings associated with the new inventory model.

Moreover, the average days of supply for category A, B, and C are 22, 65, and 240 days respectively. Inventory turnovers and the number days of supply for the new model are shown in Table 11. Carrying more inventory on hand may be problematic due to space constraints.

Table 10: The sensitivity analysis for different ordering cost and the number days of supply for Rogers

		Ordering Cost ($)									
		1	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**50**
# days of supply	**1**	-5%	18%	35%	45%	51%	56%	60%	62%	65%	68%
	2	2%	21%	36%	46%	52%	57%	60%	63%	65%	69%
	3	8%	25%	38%	47%	53%	57%	61%	63%	65%	69%
	4	13%	27%	40%	48%	53%	58%	61%	64%	66%	69%
	5	18%	30%	41%	49%	54%	58%	61%	64%	66%	69%
	6	23%	33%	43%	50%	55%	59%	62%	64%	66%	70%
	7	27%	35%	44%	51%	56%	59%	62%	65%	67%	70%
	8	30%	37%	45%	52%	56%	60%	63%	65%	67%	70%
	9	34%	39%	47%	53%	57%	60%	63%	65%	67%	70%
	10	37%	41%	48%	54%	58%	61%	64%	66%	68%	70%
	11	39%	43%	49%	54%	58%	61%	64%	66%	68%	71%
	12	42%	44%	50%	55%	59%	62%	64%	66%	68%	71%
	13	44%	46%	51%	56%	59%	62%	65%	67%	68%	71%
	14	46%	48%	52%	57%	60%	63%	65%	67%	69%	71%
	15	48%	49%	53%	58%	61%	63%	65%	67%	69%	71%
	16	50%	50%	54%	58%	61%	64%	66%	68%	69%	72%
	17	52%	52%	55%	59%	62%	64%	66%	68%	69%	72%
	18	53%	53%	56%	60%	62%	65%	67%	68%	70%	72%
	19	55%	54%	57%	60%	63%	65%	67%	68%	70%	72%
	20	56%	55%	58%	61%	63%	65%	67%	69%	70%	72%
	30	66%	64%	64%	66%	67%	69%	70%	71%	72%	74%
	60	80%	77%	76%	76%	76%	76%	77%	77%	77%	78%

Table 11: Inventory Turnover and Average Days of Supply of Individual Items for New Model

No	Turnovers per week	Turnover per year	# of days of supply
1	0.59	30.46	12
2	0.35	18.46	20
3	0.30	15.78	23
4	0.21	11.15	33
5	0.31	16.18	23
6	0.34	17.61	21
7	0.22	11.66	31
8	0.42	21.72	17
9	0.38	19.73	18
10	0.40	20.80	18
11	0.08	4.29	85
12	0.11	5.54	66
13	0.06	2.99	122
14	0.38	19.73	18
15	0.11	5.80	63
16	0.05	2.70	135
17	0.25	12.77	29

No	Turnovers per week	Turnover per year	# of days of supply
18	0.17	9.02	40
19	0.14	7.38	49
20	0.17	8.99	41
21	0.11	5.80	63
22	0.11	5.83	63
23	0.03	1.57	233
24	0.17	8.88	41
25	0.03	1.46	251
26	0.02	0.97	375
27	0.03	1.62	225
28	0.22	11.29	32
29	0.03	1.63	224
30	0.03	1.64	222
31	0.05	2.40	152
32	0.03	1.57	233
33	0.02	0.88	414
34	0.01	0.76	478

An exchange curve is called an optimal policy curve showing the relationship between total inventory cost and the number of total replenishments. The total number of replenishment per time is plotted against the total inventory cost. As seen in Figure 7, the new models present lower total cost and number of total replenishments compared to the current model.

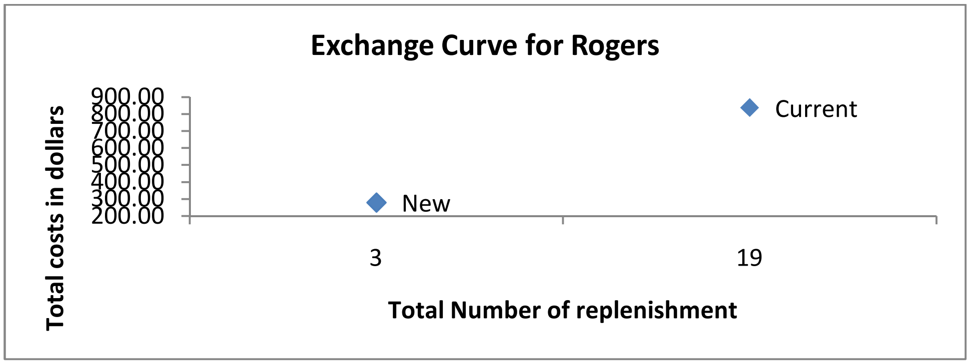

Figure 7: Exchange Curve for Rogers

An exchange curve showing the relationship between the number of orders and the total cost for the current and new inventory model is presented in Figure 8 and Table12. Table 12 indicates ordering and holding costs and total number of replenishment for different ordering cost values for new and current inventory models. Figure 8 is an exchange curve to compare new and current inventory model. For the current model, the number of replenishments is constant.

Table 12: Comparison of the new and Current Inventory Model for Different Ordering Cost Values for Rogers

	Current Inventory Model				New Inventory Model				
Ordering Cost ($/order/ week)	Holding Cost ($/week)	Ordering Cost ($/week)	Total Cost ($/ week)	Total Number of Replenishment	Holding Cost ($/week)	Ordering Cost ($/week)	Total Cost ($/ week)	Total Number of Replenishment	Cost Saving (%)
1	192	19	211	19	101	13	114	13	46%
5	192	94	286	19	115	36	151	7	47%
10	192	189	381	19	129	53	182	5	52%
15	192	283	475	19	137	69	206	5	57%
20	192	378	570	19	143	84	227	4	60%
25	192	472	664	19	155	91	246	4	63%
30	192	566	758	19	162	102	264	3	65%
35	192	661	853	19	167	115	282	3	67%
40	192	755	947	19	175	123	298	3	69%

50	192	944	1136	19	186	140	326	3	71%

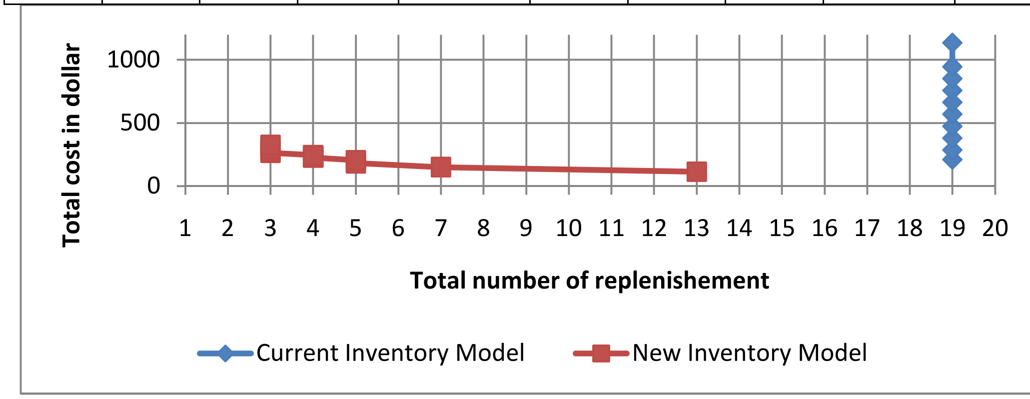

Figure 8: Exchange curve based on 14 days of supply for Rogers

The details of the total cost including holding and ordering cost and the percentage of each cost in the total cost are shown in Figure 9-10 and Table 13-14 for the current inventory model and new inventory model, respectively. Figure 9 and 10 provides an overview of the change in total cost including holding and ordering costs for different ordering cost values for current and new inventory model, respectively. Table 13-14 present the data set used in Figure 9-10. Based on the different ordering cost, the total cost for the new model is changing to get optimal results. On the other hand, total ordering cost for the current model is increasing for different ordering cost per order while holding cost is constant.

Table 13: The details of total cost for 14 days of supply and different ordering costs

	Current Inventory Model				
Ordering Cost ($/order/ week)	**Holding Cost ($/week)**	**Ordering Cost ($/week)**	**Total Cost ($/ week)**	**% HC**	**% OC**
1	192	19	211	91%	9%
5	192	94	286	67%	33%
10	192	189	381	50%	50%
15	192	283	475	40%	60%
20	192	378	570	34%	66%
25	192	472	664	29%	71%
30	192	566	758	25%	75%
35	192	661	853	23%	77%
40	192	755	947	20%	80%

50	192	944	1136	17%	83%

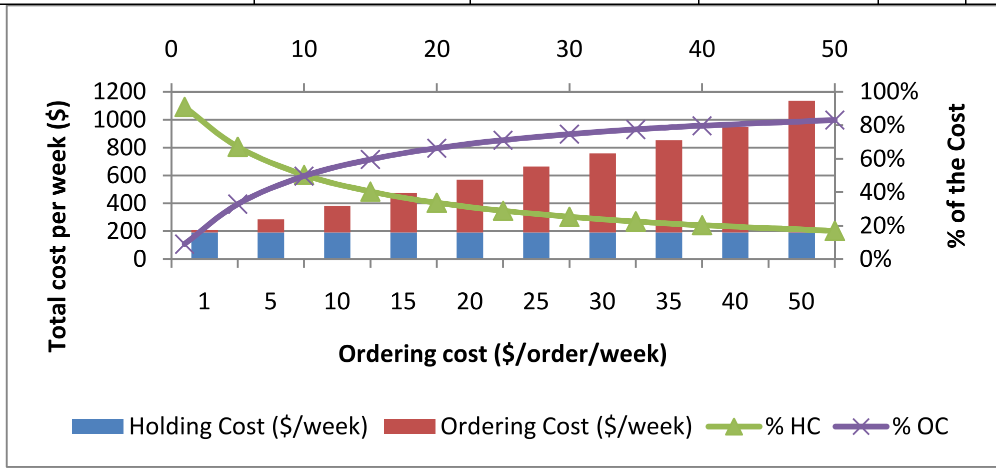

Figure 9: The details of total cost for 14 days of supply and different ordering costs

Table 14: The details of total cost for new inventory model with different ordering costs

	New Inventory Model					
Ordering Cost ($/order/ week)	**Holding Cost ($/week)**	**Ordering Cost ($/week)**	**Total Cost ($/ week)**	**Total Number of Replenishment**	**% HC**	**% OC**
1	101	13	114	13	89%	11%
5	115	36	151	7	76%	24%
10	129	53	182	5	71%	29%
15	137	69	206	5	67%	33%
20	143	84	227	4	63%	37%
25	155	91	246	4	63%	37%
30	162	102	264	3	61%	39%
35	167	115	282	3	59%	41%
40	175	123	298	3	59%	41%
50	186	140	326	3	57%	43%

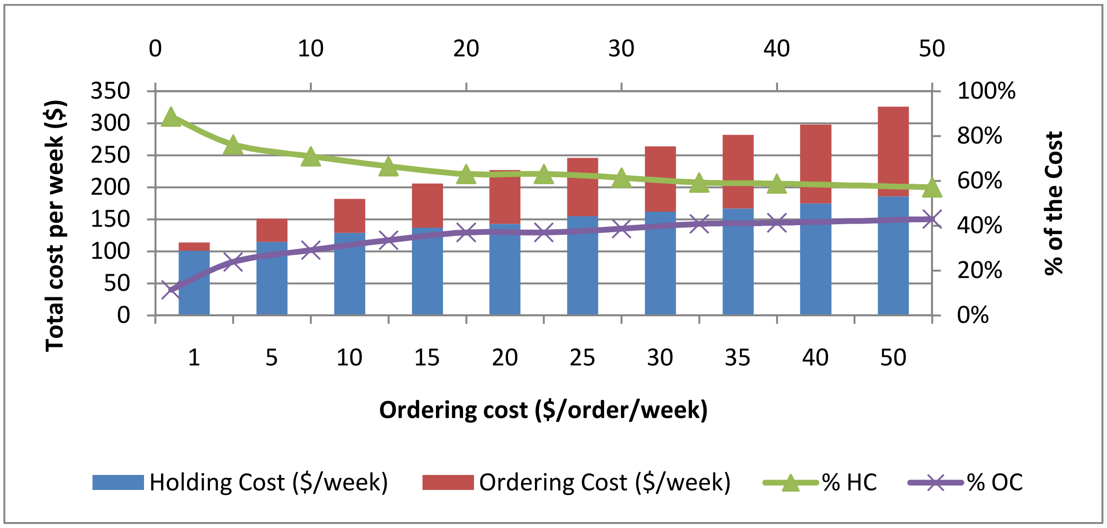

Figure 10: The details of total cost for new model with different ordering cost

As seen in Figure 9, the holding cost, which depends on the numbers day of supply is constant for different ordering cost value. The percentage of the holding cost is decreasing while the percentage of ordering cost increasing. On the other hand, as shown in Figure 10 for the new inventory model, the increment in holding cost is slower than the increment in the ordering cost for different ordering cost. Moreover, the number of total replenishment is decreasing while ordering cost per order is increasing.

The new inventory model is better than the current model since the cost saving increases from 46% to 83% for the range of ordering cost ($1 to $50).

2. Results of Inventory Analysis for Forth Smith

In this section, the results for the central pharmacy at Fort Smith are discussed. The results were obtained from the data between CP in Forth Smith and CSC for 36 items. The model for inventory model was run for each item individually to calculate the order point (r), the order quantity (Q), and the total cost. The new model provides 51% of cost saving for all 36 items, and total cost per week will decrease from $768 to $375 for the fill rate of 98.5% as shown in Table 15 and Figure 11.

Table 15: Total Costs of New and Current Models for Fill Rate of 98.5%

# of items	Total Cost for New Model	Total Cost for the Current Model	Improvement (Cost Reduction)
36	$375	$768	51%

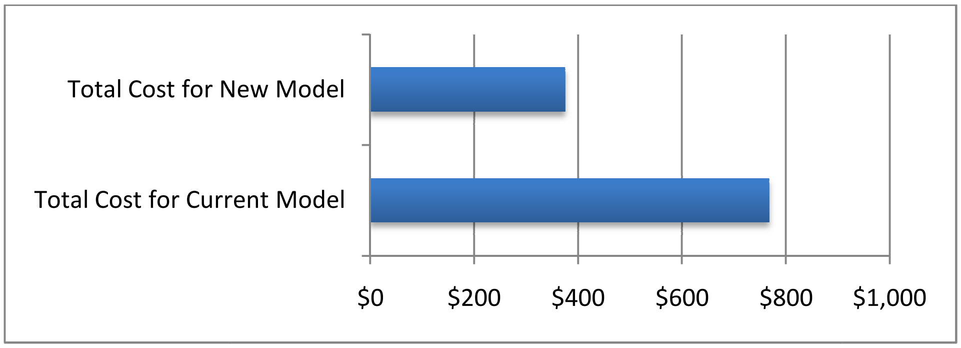

Figure 11: Comparison of Total Costs for New and Current Model

The average days of supply are approximately 79 days for all 36 items, which is higher than 14 days of supply for the current model. Average days of supply for category A, B, and C are 13, 26, and 197 days respectively. Inventory turnovers of individual items for new model are shown in Table 16. Carrying additional the additional inventory suggested by the new model may be very problematic because of space constraints at the CP.

A sensitivity analysis was conducted for the ordering cost at the CP in Forth Smith, as well, and the results are seen in Table 17. As the number days of supply and the ordering cost increase for the current model, the proportion of the cost saving is increasing. The sensitivity analysis indicates that for values of ordering cost greater than $5 per order and greater than 2 days of supply, the cost savings associated with the new inventory model increases. In other words, the lower number days of supply and smaller ordering cost per order brings very low cost saving.

Table 16: Inventory Turnover and Average Days of Supply of Individual Items for New Model

No	Turnovers per week	Turnover per year	# of days of supply	No	Turnovers per week	Turnover per year	# of days of supply
1	0.49	25.64	14	19	0.25	12.92	28
2	0.64	33.27	11	20	0.19	10.10	36
3	0.39	20.43	18	21	0.13	6.93	53
4	0.64	33.06	11	22	0.26	13.77	27
5	0.65	33.82	11	23	0.33	16.95	22
6	0.97	50.55	7	24	0.37	19.32	19
7	0.43	22.35	16	25	0.04	2.02	180
8	0.35	18.21	20	26	0.03	1.82	201
9	0.42	21.94	17	27	0.02	1.28	284
10	1.51	78.36	5	28	0.05	2.81	130
11	1.06	55.06	7	29	0.08	4.15	88
12	0.40	20.96	17	30	0.04	2.09	175
13	0.32	16.47	22	31	0.06	3.05	120
14	0.43	22.61	16	32	0.06	3.15	116
15	0.26	13.36	27	33	0.02	0.94	389
16	0.27	13.86	26	34	0.05	2.74	133
17	0.35	18.09	20	35	0.02	0.89	410
18	0.33	17.09	21	36	0.05	2.69	136

Exchange Curve showing the relationship between the number of order and the total cost for the current and new inventory model is presented in Figure 13 and Table18. For the current model, the number of replenishment is constant. Figure 12 shows that the new models present lower total cost and number of total replenishment compared to the current model.

Table 17: The sensitivity analysis for different ordering cost and the number days of supply for Forth Smith

		Ordering Cost ($)									
		1	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**50**
# days of supply	**1**	-24%	-10%	6%	18%	25%	35%	37%	42%	45%	51%
	2	-9%	0%	12%	22%	29%	35%	39%	44%	47%	52%
	3	3%	8%	17%	25%	31%	37%	41%	45%	48%	53%
	4	13%	15%	22%	29%	34%	39%	43%	46%	49%	54%
	5	21%	21%	26%	32%	37%	41%	45%	48%	51%	55%
	6	27%	26%	30%	35%	39%	43%	46%	49%	52%	56%
	7	33%	30%	34%	38%	41%	45%	48%	50%	53%	56%
	8	38%	34%	37%	40%	43%	46%	49%	52%	54%	57%
	9	42%	38%	40%	42%	45%	48%	50%	53%	55%	58%
	10	45%	41%	42%	45%	47%	49%	52%	54%	56%	59%
	11	49%	44%	45%	46%	48%	51%	53%	55%	57%	60%
	12	51%	47%	47%	48%	50%	52%	54%	56%	58%	60%
	13	54%	49%	49%	50%	51%	53%	55%	57%	58%	61%
	14	54%	51%	51%	52%	53%	54%	56%	58%	59%	62%
	15	54%	53%	52%	53%	54%	56%	57%	59%	60%	62%
	16	60%	55%	54%	55%	55%	57%	58%	59%	61%	63%
	17	62%	57%	56%	56%	56%	58%	59%	60%	61%	63%
	18	64%	58%	57%	57%	58%	59%	60%	61%	62%	64%
	19	65%	60%	58%	58%	59%	60%	61%	62%	63%	65%
	20	66%	61%	60%	59%	60%	60%	61%	63%	63%	65%
	30	76%	71%	69%	68%	68%	68%	68%	68%	69%	70%
	60	87%	84%	82%	80%	80%	79%	79%	79%	78%	78%

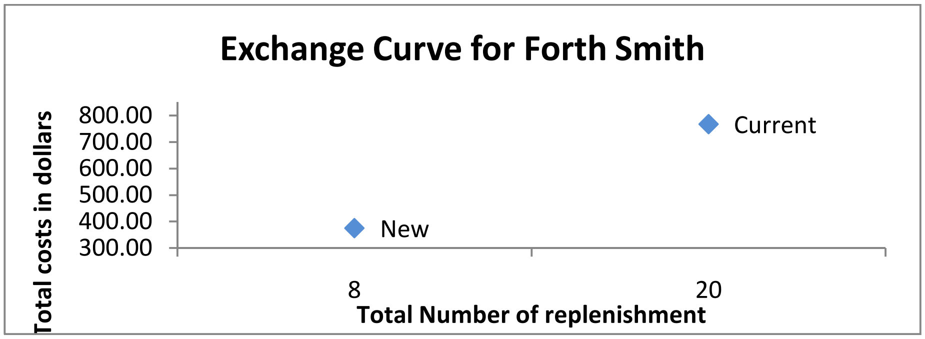

Figure 12: Exchange Curve for Forth Smith

Figure 13 provides an exchange curve that indicates the changes in total costs for different ordering cost values for new and current inventory models. As the ordering cost per order is increasing, the number of total replenishment is decreasing for the new inventory model. On the other hand, the number of total replenishment for the current model is constant. Table 18 presents the data used in Figure 13.

Table 18: Comparison of the new and Current Inventory Models for Different Ordering Costs

	Current Inventory Model				New Inventory Model				
Ordering Cost ($/order/ week)	Holding Cost ($/week)	Ordering Cost ($/week)	Total Cost ($/ week)	Total Number of Replenishment	Holding Cost ($/week)	Ordering Cost ($/week)	Total Cost ($/ week)	Total Number of Replenishment	Cost Saving (%)
1	490	20	510	20	204	21	225	21	56%
5	490	102	592	20	227	62	289	12	51%
10	490	205	695	20	248	95	343	10	51%
15	490	307	797	20	267	120	387	8	52%
20	490	410	900	20	278	147	425	7	53%
25	490	512	1002	20	307	149	456	6	54%
30	490	615	1105	20	323	161	484	5	56%
35	490	717	1207	20	332	177	509	5	58%
40	490	819	1309	20	340	195	535	5	59%
50	490	1024	1514	20	350	231	581	5	62%

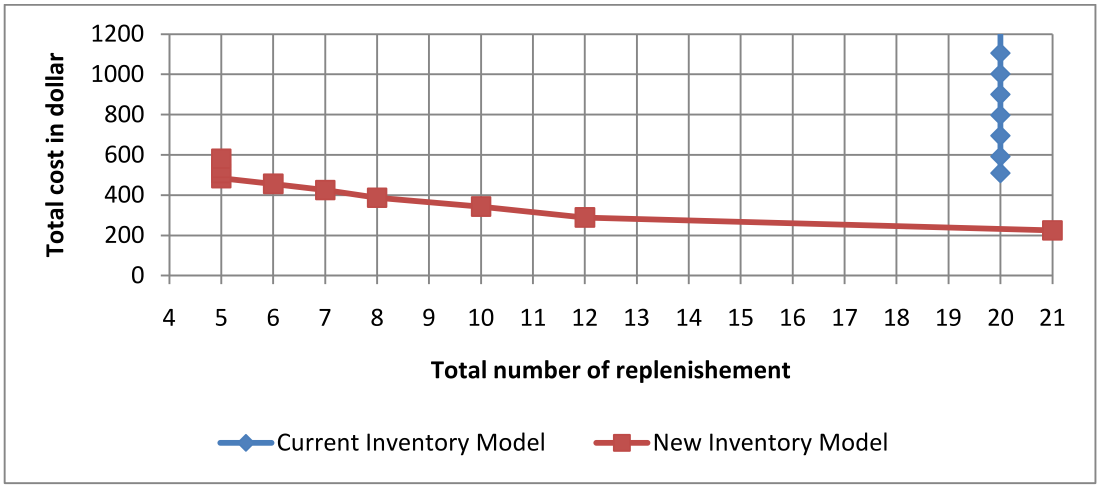

Figure 13: Comparison of the new and Current Inventory Model for Different Ordering Cost

The details of the total cost including holding and ordering cost and the percentage of each cost in the total cost are shown in Figure14-15 and Table 19-20 for the current inventory model and new inventory model, respectively.

Table 19: The details of total cost for 14 days of supply and different ordering cost for the current inventory model

	Current Inventory Model				
Ordering Cost ($/order/ week)	**Holding Cost ($/week)**	**Ordering Cost ($/week)**	**Total Cost ($/ week)**	**% HC**	**% OC**
1	490	20	510	96%	4%
5	490	102	592	83%	17%
10	490	205	695	71%	29%
15	490	307	797	61%	39%
20	490	410	900	54%	46%
25	490	512	1002	49%	51%
30	490	615	1105	44%	56%
35	490	717	1207	41%	59%
40	490	819	1309	37%	63%
50	490	1024	1514	32%	68%

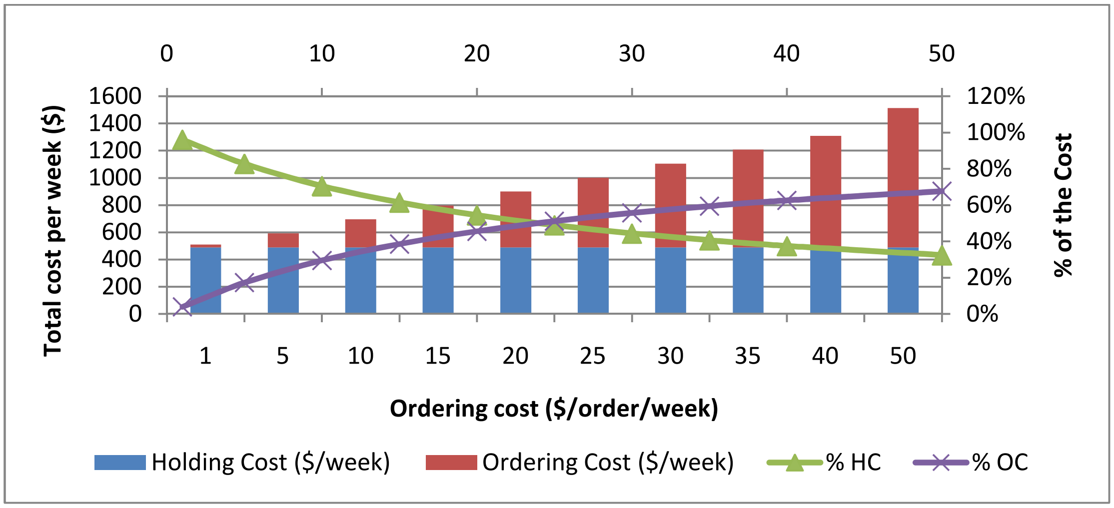

Figure 14: The details of total cost for 14 days of supply and different ordering cost for the current inventory model

Table 20: The details of total cost for different ordering costs for the new inventory model

	New Inventory Model					
Ordering Cost ($/order/ week)	**Holding Cost ($/week)**	**Ordering Cost ($/week)**	**Total Cost ($/ week)**	**Total Number of Replenishment**	**% HC**	**% OC**
1	204	21	225	21	91%	9%
5	227	62	289	12	79%	21%
10	248	95	343	10	72%	28%
15	267	120	387	8	69%	31%
20	278	147	425	7	65%	35%
25	307	149	456	6	67%	33%
30	323	161	484	5	67%	33%
35	332	177	509	5	65%	35%
40	340	195	535	5	64%	36%
50	350	231	581	5	60%	40%

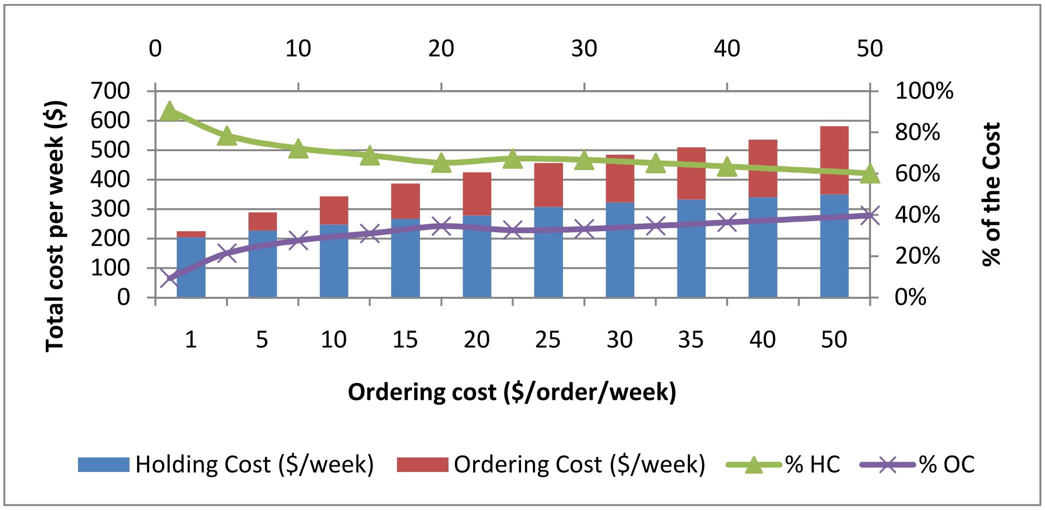

Figure 15: The details of total cost for different ordering cost for the new inventory model

Results similar for the CP in Rogers were obtained for the CP in Forth Smith. . The new model brings the cost saving, and the cost saving is going up as the ordering cost per order is increasing.

3. Sensitivity Analysis for Forecasting

Within the forecasting results, different forecasting models were applied for individual items. It is difficult to manage forecasting process with diverse forecasting models for each individual items, so a sensitivity analysis was performed by assuming that simple exponential smoothing (SES) is the best model for all items to make the forecasting process more general. Under this assumption, inventory control policies were applied for each item and location with the sensitivity analysis presenting the effects of different ordering cost and the number day of supply on the total cost. Appendix 8 and 9 show the different cost savings for different combination of the number days of supply and ordering cost for Rogers and Forth Smith under the assumption that SES is the best forecasting model for each item. The cost saving increases when the number days of supply and ordering cost increase. Consequently, under this new forecasting assumption, the new inventory policy brings cost saving to the system, as well. Essentially, using SES for the items doesn’t change the basic conclusions obtained when using the best forecasting techniques.

4. Results for Multi-echelon Analysis

In this section, the results from multi-echelon analysis are discussed. The model developed for multi-echelon structure is explained by giving numerical results of a specific item (item no:906872). At the end of this section, the general results, such as total cost, turnover and the number days of supply will be presented for CSC and overall multi-echelon structure.

Before the inventory control policy for CSC is applied, the demand process from CPs to CSC should be aggregated, since the demand process is not identical for CPs. In order to aggregate the ordering process, first the mean and variance of the order size and interarrival times for each CP is calculated. The expected value and variance of the time between arrivals and the demand size are shown in the Table 21.

Table 21: Parameters of Demand Process for Item no: 906872

	$E\{A\}$	$Var\ \{A\}$	CV	$E\{D\}$	$Var\ \{D\}$	CV	q	r
CP_1	0.766	0.587	1	2.823	9.537	1.084	43	0
CP_2	0.683	0.467	1	1.632	0.475	0.417	7	0

The moments of actual order quantities are calculated via the equation (V.20) and (V.21), where due to the sufficiently large order size q.

$E\{M_1\} = 43$ $E\{{M_1}^2\} = 1849$

$E\{M_2\} = 7$ $E\{{M_2}^2\} = 49$

The first moment of the order cycles in CPs are computed by (V.22).

$E\{R_1\} = 15.232$ $E\{R_2\} = 4.288$

The moments of the total order cycles in CPs are as follows:

$E\{T_1\} = 11.67$ $E\{{T_1}^2\} = 24.18$

$E\{T_2\} = 2.93$ $E\{{T_2}^2\} = 14.33$

All parameters, $E\{M_i\}$, $E\{{M_i}^2\}$, $E\{R_i\}$, $E\{T_i\}$, and $E\{{T_i}^2\}$, are calculated, so the aggregation of the demand process for CSC will be the next step. First, the time between two consecutive orders arriving, A_z, to CSC is calculated via the equation (V.26). For the item considered,

$$E\{A_z\} = \frac{1}{\frac{1}{11.67} + \frac{1}{2.93}} = 2.34$$

The moment of the demand sizes in CSC, D_z, are calculated by using the equation (V.28) and (V.29). $E\{D_z\} = 14.22$ and $E\{{D_z}^2\} = 14.22$.

The mean rate of arrivals at CSC can be calculated via the equation (V.30), and

$\lambda_w = 1/2.34 = 0.43$

The last step before inventory optimization is to calculate the mean and variance of the demand during lead time by using the equation (V.31) and (V.32).

$E[D_w(L)] = \lambda_w L\, E(D_z) = 2.62$

$Var[D_w(L)] = \lambda_w tLE(D_z{}^2) = 75.14$

It is assumed that the demand during the lead time has a Gamma distribution, so that the parameters of Gamma distributions are computed via equations (V.33) and (V.34). After the shape and scale parameters are calculated, the expected value of the demand during lead time and the variance of the demand during lead time is obtained by using the equation (V.35) and (V.36).

$E[D_w(L)] = \gamma\beta = 2.604$

$Var[D_w(L)] = \gamma\beta^2$=75.136

After this point, the optimal (r, Q) will be calculated for the performance metrics, such as the inventory level, the number of backorder, order frequency, and fill rate.

The results were obtained from the multi-echelon analysis for 24 items. The inventory model was run for each item individually to calculate the order point (r), the order quantity (Q), and the total cost by using a spreadsheet model. Appendix 7 shows the spreadsheet model for inventory control. The left and top sides of the spreadsheet shows the inputs of the inventory model, such as the mean of demand, MAE, the mean demand during lead time, the variance of demand during the lead time, and the calculation of the Gamma distribution parameters. The right and top sides of the spreadsheet present the new model to optimize the reorder point and order quantity based on the optimization model by using Excel Solver and VBA. Also, right sides presents the calculation of the performance parameters, such as average inventory level, the number of backorder, the stock-out, order frequency, and turnover, and the total cost calculations. The left and bottom sides of the spreadsheet represents the current inventory model showing the calculations of the reorder point, inventory level, all costs associated with keeping and getting inventory. The formulas behind of the spreadsheet (the equations from (V.12) to (V.15)) are created by using VBA, and the optimization model minimizing the total cost with the fill rate constraint is set up using Excel's Solver.

The multi-echelon model provides 24% of cost saving for all 24 items, and total cost per week including ordering and holding costs will decrease from $551 to $394 for the fill rate of 98.5% as shown in Table 22 and Figure 16.

The average waiting time at CSC is 0.0549 week (=9 hours), and this waiting time was added to lead time from CSC to CP to obtain the actual lead time for multi-echelon analysis.

Table 22: Total Costs of New and Current Models for Fill Rate of 98.5%

# of items	Total Cost for New Model	Total Cost for the Current Model	Improvement (Cost Reduction)
24	$394	$551	24%

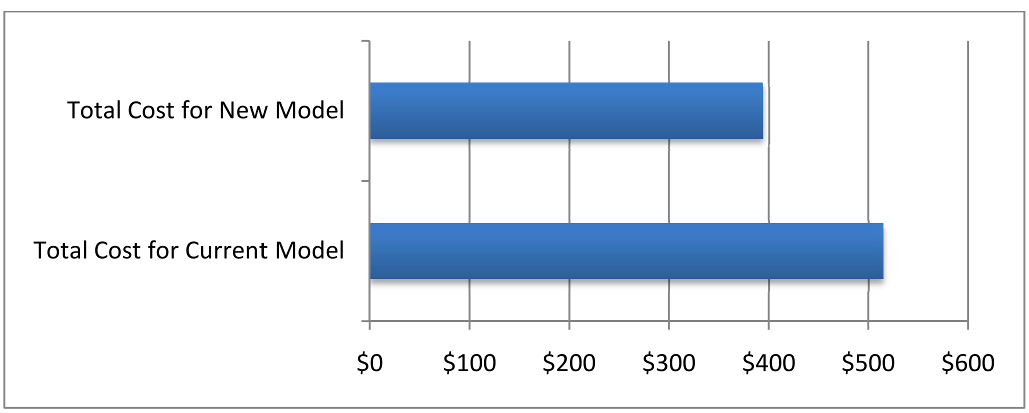

Figure 16: Comparison of Total Costs for New and Current Model

The average days of supply and inventory turnovers of individual items for new model are shown in Table 23. Turnover is decreasing from category A to C. The new model tends to have more inventory, since the fixed ordering cost per order is higher than holding cost per item for most items. At this point, the space and expiration date are concerns.

Table 23: Inventory Turnover and Average Days of Supply of Individual Items for Multi-echelon Model

No	Turnover per week	Turnover per year	# of days of supply	No	Turnover per week	Turnover per year	# of days of supply
1	0.37	19.10	19	13	0.07	3.79	96
2	0.22	11.25	32	14	0.07	3.44	106
3	0.21	11.14	33	15	0.06	3.25	112
4	0.13	6.99	52	16	0.06	3.14	116
5	0.13	6.93	53	17	0.05	2.53	144
6	0.12	6.27	58	18	0.05	2.50	146
7	0.12	6.22	59	19	0.05	2.43	150
8	0.10	5.33	69	20	0.04	2.33	156
9	0.09	4.86	75	21	0.04	1.99	183
10	0.09	4.58	80	22	0.03	1.70	215
11	0.09	4.53	81	23	0.01	0.63	583
12	0.08	4.27	86	24	0.01	0.60	610

A sensitivity analysis indicating the percentage of the cost savings for different ordering cost and the number of days of supply was conducted for the CSC, and the results are available in Table 24. In this table, the ordering cost range is from $1 to $50, and the range for the number days of supply is from 1 to 60 days. For the value of $1 for the average ordering cost, a cost savings becomes available if the number of days of supply is greater than 16. If the ordering cost is $5 per order, a cost savings becomes available if the average number of days of supply is greater than 10 days. An exchange curve is presented in Figure 17 and Table 25.

Table 24: The sensitivity analysis for the ordering cost assumption for CSC

		Ordering Cost ($)									
		1	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**50**
# days of supply	**1**	-175%	-59%	-10%	15%	29%	39%	46%	52%	56%	62%
	2	-148%	-51%	-6%	17%	31%	40%	47%	52%	56%	62%
	3	-125%	-42%	-2%	19%	32%	41%	48%	53%	57%	63%
	4	-106%	-35%	1%	21%	34%	42%	49%	54%	57%	63%
	5	-89%	-28%	5%	23%	35%	43%	50%	54%	58%	63%
	6	-75%	-22%	8%	25%	36%	44%	50%	55%	58%	64%
	7	-63%	-17%	11%	27%	38%	45%	51%	55%	59%	64%
	8	-52%	-11%	14%	29%	39%	46%	52%	56%	59%	64%
	9	-43%	-7%	16%	31%	40%	47%	52%	57%	60%	65%
	10	-34%	-2%	19%	32%	41%	48%	53%	57%	60%	65%
	11	-27%	2%	21%	34%	42%	49%	54%	58%	61%	65%
	12	-20%	5%	23%	35%	43%	50%	54%	58%	61%	66%
	13	-14%	9%	25%	37%	44%	50%	55%	59%	61%	66%
	14	-9%	12%	27%	38%	45%	51%	56%	59%	62%	66%
	15	-4%	15%	29%	39%	46%	52%	56%	60%	62%	67%
	16	1%	18%	31%	41%	47%	53%	57%	60%	63%	67%
	17	5%	21%	33%	42%	48%	53%	57%	61%	63%	67%
	18	9%	23%	35%	43%	49%	54%	58%	61%	64%	68%
	19	13%	25%	36%	44%	50%	55%	58%	61%	64%	68%
	20	16%	28%	38%	45%	51%	55%	59%	62%	64%	68%
	30	39%	44%	49%	54%	58%	61%	64%	66%	68%	71%
	60	66%	67%	68%	69%	70%	72%	73%	74%	75%	76%

Table 25: Comparison of the new and Current Inventory Model for Different Ordering Cost for CSC

	Current Inventory Model				Multi-Echelon Inventory Model				
Ordering Cost ($/order/ week)	Holding Cost ($/week)	Ordering Cost ($/week)	Total Cost ($/ week)	Total Number of Replenishment	Holding Cost ($/week)	Ordering Cost ($/week)	Total Cost ($/ week)	Total Number of Replenishment	Cost Saving (%)
1	219	27	246	27	320	10	330	10	-9%
5	219	134	353	27	330	34	364	7	12%
10	219	269	488	27	340	56	396	6	28%
15	219	403	622	27	349	73	422	5	38%
20	219	537	756	27	363	82	445	4	45%
25	219	671	890	27	371	92	463	4	51%
30	219	806	1025	27	378	102	480	3	56%
35	219	940	1159	27	386	114	500	3	59%
40	219	1074	1293	27	391	124	515	3	62%
50	219	1343	1562	27	398	145	543	3	66%

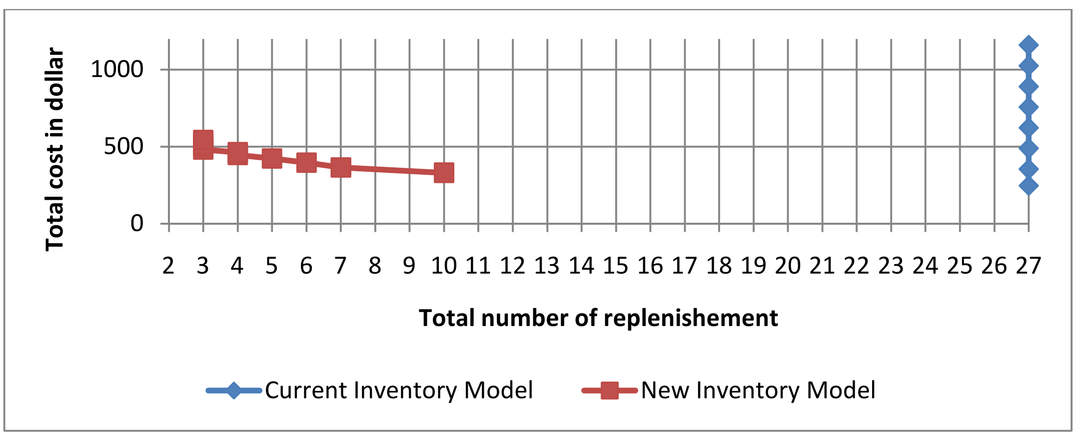

Figure 17: Comparison of the new and Current Inventory Model for Different Ordering Cost for CSC

The details of the total cost including holding and ordering cost and the percentage of each cost in the total cost are shown in Figure18-19 and Table 25-26 for the current inventory model and multi-echelon inventory model, respectively. In the new inventory model for CSC, the increment in the ordering cost affects the number of total replenishments. The number of the total replenishments is changing from 10 to 3 times. Holding cost has the biggest portion of the total cost for any ordering cost per order. For the current model, total cost is increasing due to the ordering cost, since the holding cost depending on the average number days of supply is constant.

Table 26: The details of total cost for 14 days of supply and different ordering cost for the current inventory model

	Current Inventory Model				
Ordering Cost ($/order/ week)	**Holding Cost ($/week)**	**Ordering Cost ($/week)**	**Total Cost ($/ week)**	**% HC**	**% OC**
1	219	27	246	89%	11%
5	219	134	353	62%	38%
10	219	269	488	45%	55%
15	219	403	622	35%	65%
20	219	537	756	29%	71%
25	219	671	890	25%	75%
30	219	806	1025	21%	79%
35	219	940	1159	19%	81%
40	219	1074	1293	17%	83%
50	219	1343	1562	14%	86%

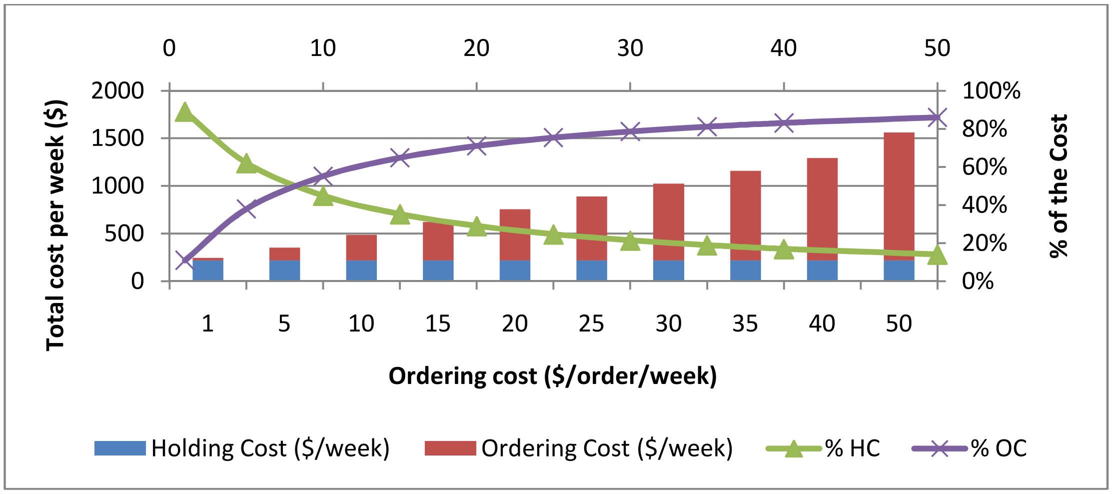

Figure 18: The details of total cost for 14 days of supply and different ordering cost for the current inventory model

Table 27: The details of total cost for different ordering costs for the new inventory model

	New Inventory Model					
Ordering Cost ($/order/ week)	**Holding Cost ($/week)**	**Ordering Cost ($/week)**	**Total Cost ($/ week)**	**Total Number of Replenishment**	**% HC**	**% OC**
1	320	10	330	10	97%	3%
5	330	34	364	7	91%	9%
10	340	56	396	6	86%	14%
15	349	73	422	5	83%	17%
20	363	82	445	4	82%	18%
25	371	92	463	4	80%	20%
30	378	102	480	3	79%	21%
35	386	114	500	3	77%	23%
40	391	124	515	3	76%	24%
50	398	145	543	3	73%	27%

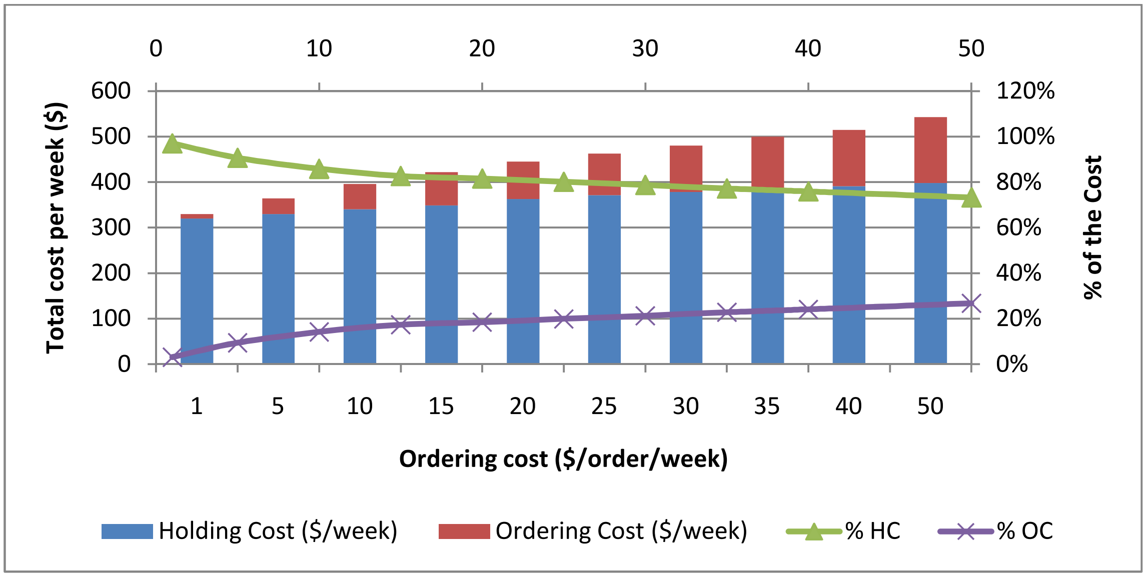

Figure 19: The details of total cost for different ordering costs for the new inventory model

Similar results are obtained for the CSC with smaller cost savings. The possible reason of having smaller cost saving is investigated even though 24% of cost saving is pretty good. The variance of demand during the lead time is high because of aggregated demand process for CSC. The variance of demand during lead time for the item: 906872 is 0.714, 0.695, and 75 for Rogers, Forth Smith, and CSC, respectively. Because of the high variance, the inventory level is high while keeping 98.5% of fill rate.

5. General Conclusions

For the CPs in Forth Smith and Rogers and the CSC, the cost savings have been obtained. The current practice is based on an assumption of an average of 14 days of supply, on the other hand the multi-echelon model is optimal model for (r, Q) model, and it provides 48% cost saving with the average fixed ordering cost (implied ordering cost) for all 24 items, and total cost per week will decrease from $1,402 to $720 for the fill rate of 98.5% as shown in Table 28.

Table 28: The results for multi-echelon analysis

	Total Cost for CSC	Total Cost for Rogers	Total Cost for Forth Smith	Overall Cost
Multi-echelon Model	$354.07	$259.48	$106.75	$720.31
Current Model	$515.05	$610.45	$276.72	$1,402.22
% Cost Saving	31.25%	57.49%	61.42%	48.63%

Overall the results for the multi-echelon analysis are more realistic, since the multi-echelon structure considers the average backorder waiting time (ABWT) at the CSC. ABWT is added to lead time to obtain the actual lead time from CSC to CPs. Table 29 shows the inventory level with and without actual lead time for each location. Because of the ABWT, the inventory level and the cost associated with inventory level are increasing. The holding costs for Rogers are increasing from $161 to $176, and the holding cost for Fort Smith is increasing from $101 to $102.

Table 29: Inventory level for each location

	CSC	Rogers	Forth Smith
Inventory level with actual lead time	9,770	6,358	3,792
Inventory level without actual lead time	9,770	5,551	3,750

VI. Summary and Future Research

The motivation for this research are (1) growing costs associated with inventory management which has the biggest impact on the supply chain costs after the labor cost, and (2) insufficient research in the healthcare supply chain compared to non-healthcare supply chains. With these motivations, a case study was selected as a research methodology for this thesis in order to provide practical information and real results for the Mercy Medical supply chain. The purposes of the case study are (1) to indicate the importance of applying inventory control model for the healthcare supply chain, and (2) examination of multi-echelon inventory control within the health care supply chain with the objective of cost reduction and supporting good inventory management. The results from CPs, CSC, and multi-echelon analysis indicate the importance of using analytical inventory models to get cost savings. In other words, inventory management in a scientific way is crucial for healthcare providers including Mercy Medical which has a well-organized supply chain structure, because the right inventory control policy brings more systematic inventory management and cost savings associated with getting and keeping inventory.

The biggest strength and weakness of this thesis comes from the real data set, because all analysis are conducted by using real data which presents more practical and realistic results. Also using the real data is a weakness, since (1) the difficulties of accessing correct data on time, (2) the difficulties in understanding the data and calculating cost related to inventory control.

Consequently, this thesis is a good starting point for improving the efficiency of inventory management in healthcare supply chain. More accuracy and details in the data set provide further the analysis bringing more realistic results into the healthcare supply chain.

For the future work, the following should be considered:

- The better ways to calculate the ordering cost per order and holding cost: The calculation of ordering cost which is total expenses associated with placing an order is a complex process, so healthcare providers and companies in the industry ignore this cost. Actually, the ordering cost is not negligible and cannot simply be ignored, since it has an impact on the total inventory cost. Holding cost is another cost associated with keeping inventory, and the calculation of holding cost depends on unit cost and inventory carrying rate. The paper presented by Holsenback and McGill (2007) gives a general model to calculate the holding cost, and this study could be applied for the calculation of holding cost.
- Estimate the individual number days of supply (by SKU): In this thesis, it is assumed that the same number days of supply is valid for all items. In the reality, it is not true, since each item has a different condition. In order to make a better comparison between the current inventory model and the new inventory model developed by using analytical model, it is important to figure out a way to estimate the individual number days of supply for each item.
- Investigate both practical and modeling methods to better handle the discrepancies' in unit of measure: The further analysis on the unit of measure is required to understand the causes of the discrepancies' in unit of measure. After these causes are taken away, the actual total demand can be obtained. It is crucial to complete analysis based on the actual total demand. This future work could be

a system analysis project by using some business management tools, such as cause and effect diagram, flow diagram, and etc. The master's thesis written by Paalman (2010) is a good reference to understand the scope and importance of the errors including unit of measures in healthcare supply chain. This issue can be improved by data standardization.

- Additional analytical model including space constraint and backordering cost could be utilized. The inventory model developed for this thesis does not consider space and backordering cost constraints, so the inventory level is high for some items, which means the number days of supply is high. This is a problem since we are dealing with pharmaceutical items, which can be perishable. Woosley (2009) describes inventory models for hospital pharmaceuticals, some of which apply space constraints. This would be a starting point for future investigation.

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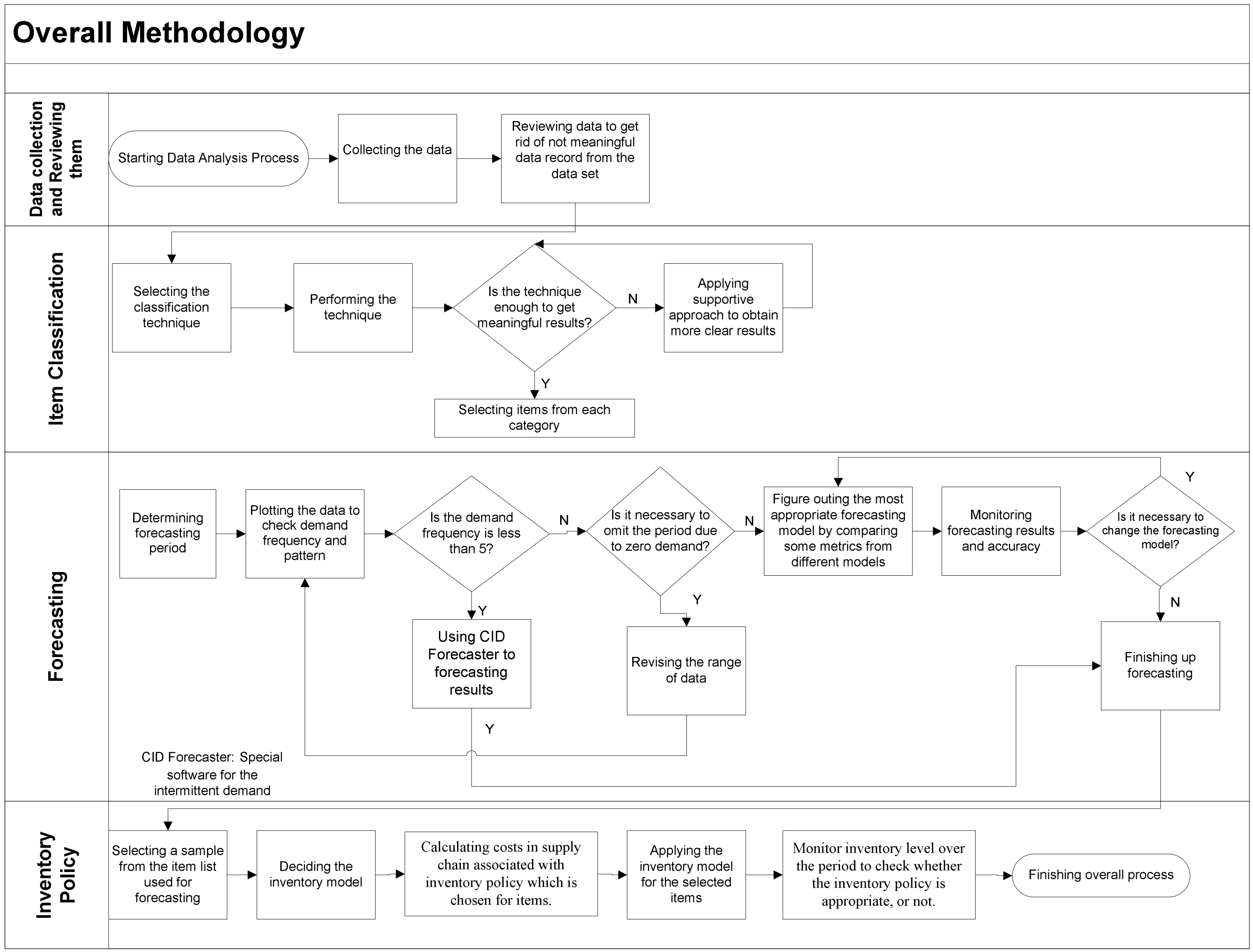
Appendix 1: Overall Methodology



Appendix 2: Unit of Measures

UOM-1		UOM-2	UOM-3	UOM-4
AM	FG	BX	CA	LUOM
AP	GM	CA	CS	
AR	IH	CN	EA	
AV	KT	CS	LOUM	
BG	PK	CS`	PK	
BO	S1	CS2		
BX	SC	CS4		
CA	SO	CX		
CI	SR	EA		
CJ	SS	LUOM		
CL	TB	PK		
CN	U2	TY		
CU	VI	VI		
EA				

Appendix 3: Details of ABC Analysis for CP in Rogers

1. Some Statistics for ABC Analysis based on usage value

	Demand Class				
	E	I	L	S	Total
A	1	50	7	10	68
B	5	292	74	24	395
C	5	260	166	33	464
Total	11	602	247	67	927

	A	B	C
N	68	395	464
Mean	19,952.72	837.00	24.98
Std Dev	29,462.13	916.90	24.97
Min	3,845.44	92.98	0.08
Max	175,945.05	3,777.58	92.89
Range	172,099.61	3,684.60	92.81
% of Total	0.80	0.19	0.01
Sum	1,356,784.84	330,616.54	11,589.12
Sum Wgt	68.00	395.00	464.00
Variance	868,016,924.00	840,701.63	623.52
Std Err	3,572.81	46.13	1.16
CV	147.66	109.55	99.98
Quantiles25	5,478.85	195.30	5.30
Median	9,714.30	440.46	14.87
Quantiles75	19,660.17	1,109.37	37.92

2. Some Statistics for ABC Analysis based on average weekly demand

	Demand Class				
	E	I	L	S	Total
A	5	52	19	44	120
B	5	215	105	19	344
C	1	335	123	4	463
Total	11	602	247	67	927

	A	B	C
N	120	344	463
Mean	9.79	0.67	0.14
Std Dev	18.58	0.65	0.23
Min	2.40	0.03	0.01
Max	188.29	2.40	1.80
Range	185.89	2.37	1.79
% of Total	0.80	0.16	0.04
N Missing	0.00	0.00	0.00
Sum	1,175.30	231.50	62.64
Sum Wgt	120.00	344.00	463.00
Variance	345.12	0.42	0.05
Std Err	1.70	0.04	0.01
CV	189.68	96.64	169.92
Median	5.46	0.42	0.05
Quantiles25	3.27	0.14	0.02
Quantiles75	9.50	1.10	0.10

3. Some Statistical Results of Each Category for ABC Analysis Based on Average Unit Cost

	Demand Class				
Category	**E**	**I**	**L**	**S**	**Grand Total**
A	1	76	32		109
B	9	367	155	64	595
C	1	158	60	3	222
Grand Total	11	601	247	67	926

	A	B	C
N	120	344	463
Mean	9.79	0.67	0.14
Std Dev	18.58	0.65	0.23
Min	2.40	0.03	0.01
Max	188.29	2.40	1.80
Range	185.89	2.37	1.79
% of Total	0.80	0.16	0.04
N Missing	0.00	0.00	0.00
Sum	1,175.30	231.50	62.64
Sum Wgt	120.00	344.00	463.00
Variance	345.12	0.42	0.05
Std Err	1.70	0.04	0.01
CV	189.68	96.64	169.92
Median	5.46	0.42	0.05
Quantiles25	3.27	0.14	0.02
Quantiles75	9.50	1.10	0.10

Appendix 4: Details of ABC Analysis for CP in Forth Smith

1. Some Statistics for ABC Analysis based on usage value

	Demand Class				
Category	**E**	**I**	**L**	**S**	**Total**
A	8	74	14	58	154
B	68	471	167	100	806
C	74	451	391	44	960
Total	150	996	572	202	1920

	A	**B**	**C**
N	154	806	960
Mean	41,494	1,905	68
Std Dev	58,593	1,925	67
Min	8,249	251	0
Max	476,653	8,246	250
Range	468,405	7,995	250
% of Total	1	0	0
N Missing	0	0	0
Sum	6,390,046	1,535,176	65,688
Sum Wgt	154	806	960
Variance	3,433,167,638	3,706,488	4,556
Std Err	4,722	68	2
CV	141	101	99
Median	21,850	1,112	45
Quantiles25	12,526	458	13
Quantiles75	39,884	2,687	106

2. Some Statistics for ABC Analysis based on average weekly demand

	Demand Class				
Category	**E**	**I**	**L**	**S**	**Total**
A	70	24	28	90	212
B	75	306	275	92	748
C	5	666	269	20	960
Total	150	996	572	202	1920

	A	B	C
N	212	748	960
Mean	94	6	0.15
Std Dev	117	7	0.15
Min	29	1	0.01
Max	1,258	29	1
Range	1,230	28	1
% of Total	0.400	0.097	0.003
N Missing	0.000	0.000	0.000
Sum	19,940	4,838	147
Sum Wgt	212	748	960
Variance	13,729	47	0
Std Err	8	0.251	0.005
CV	125	106	99
Median	63	4	0.09
Quantiles25	40	1	0.04
Quantiles75	105	9	0.20

3. Some Statistical Results of Each Category for ABC Analysis Based on Average Unit Cost

	Demand Class				
Category	**E**	**I**	**L**	**S**	**Total**
A	-	148	44	13	212
B	10	527	164	54	748
C	140	321	364	135	960
Total	150	996	572	202	1920

	A	B	C
N	205	755	960
Mean	741	48	1.88
Std Dev	709	44	1.97
Min	180	7	0.01
Max	3,497	178	7
Range	3,317	171	7
% of Total	0.400	0.095	0.005
N Missing	0.000	0.000	0.000
Sum	151,911	36,208	1,804
Sum Wgt	205	755	960
Variance	503,173	1,950	4
Std Err	50	1.607	0.064
CV	96	92	105
Median	470	30	1.25
Quantiles25	278	14	0.15
Quantiles75	893	73	3.10

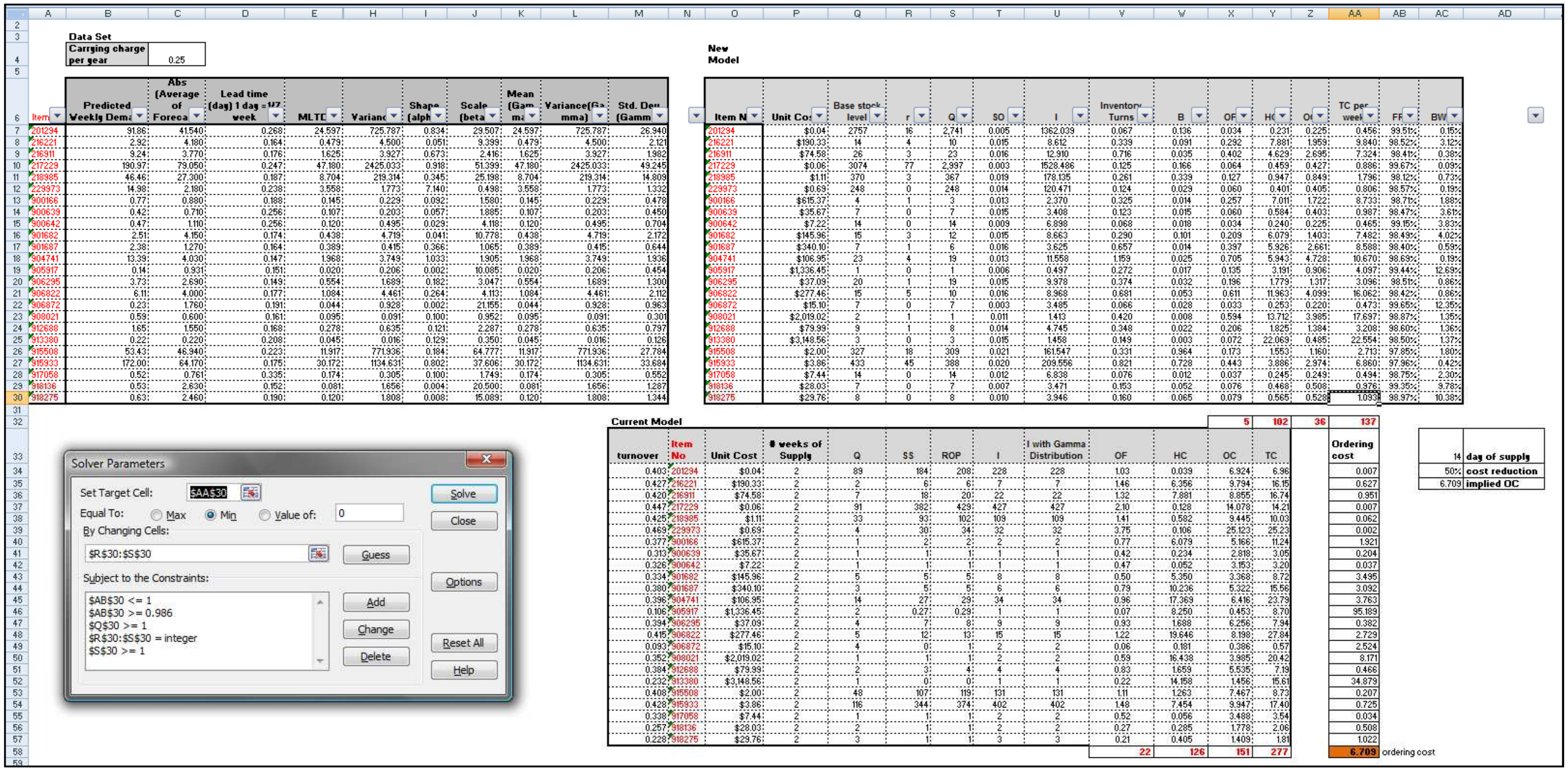
Appendix 5: Summary of Forecasting for CP in Rogers

Item No	Forecasting Model	Estimation	MAE	Total Weekly Demand	Average Weekly Demand	Std. Dev. Weekly Demand	Frequency	ABC Designation	Demand Class
216221	ARMA (1,1)	19.82	13.54	713	6.33	14.12	36	A	E
906822	ARMA(6,6)	3.40	3.83	400	3.60	4.82	45	A	I
900166	MA(1)	1.32	1.94	173	1.54	2.40	41	A	I
908021	ARMA(5,5)	0.23	0.42	33	0.30	0.58	26	A	I
901682	MA(2)	5.26	6.91	573	5.16	10.98	46	A	L
901687	AR(3)	1.62	1.42	212	1.89	2.30	67	A	L
913380	AR(1)	0.11	0.26	15	0.14	0.99	4	A	L
912688	ARMA (1,1)	7.69	2.29	940	8.34	3.06	109	A	S
904741	ARMA (1,1)	6.67	3.45	703	6.29	4.43	87	A	S
216911	ARMA (3,3)	7.76	2.10	651	5.71	4.53	80	A	S
906872	AR(2)	1.51	1.36	273	2.45	3.02	97	B	E
918142	MA(4)	3.66	2.01	117	1.04	2.33	29	B	E
915508	ARMA(6,6)	6.81	5.69	914	8.16	8.16	85	B	E
905917	ARMA (2,2)	0.90	0.10	6	0.05	0.23	6	B	I
910248	ARMA (1,1)	0.11	0.19	12	0.11	0.37	10	B	I
210852	AR(7)	1.19	7.88	972	8.76	14.61	33	B	I
900642	Simple Exponential Smoothing	27.65	4.96	1056	8.69	12.73	55	B	L
900639	ARMA(9,9)	2.71	1.89	206	1.86	3.45	44	B	L
918275	ARMA(1,1)	2.30	3.09	245	2.21	4.78	33	B	L
206378	AR(1)	11.15	10.55	840	7.39	13.29	31	B	S
915933	AR(1)	11.20	10.77	1989	18.08	13.87	92	B	S
916895	ARMA(3,3)	11.37	7.44	1221	10.75	9.82	85	B	S
918136	Cumulative Average	0.09	0.16	5	0.05	0.39	2	C	E
907566	Naïve Forecasting	7.00	0.17	7	0.06	0.58	2	C	E
229973	ARMA(2,2)	7.84	3.99	135	1.19	3.40	18	C	E
218985	ARMA(2,2)	1.12	2.87	179	1.60	3.34	29	C	I
904245	Cumulative Average	0.14	0.24	8	0.07	0.38	4	C	I
910755	Moving Average	2.00	0.04	2	0.02	0.13	2	C	I
917058	Cumulative Average	0.50	0.63	28	0.25	2.39	3	C	L
906295	Cumulative Average	0.11	0.13	6	0.05	0.48	2	C	L
229084	ARMA(2,2)	5.96	7.49	155	1.41	6.21	13	C	L
915094	Cumulative Average	3.50	4.21	196	1.78	5.31	16	C	S
217229	MA(3)	40.07	18.40	2742	23.90	27.70	63	C	S
201294	MA(1)	40.35	20.89	4551	40.10	26.38	107	C	S

Appendix 6: Summary of Forecasting for CP in Forth Smith

Item No	Forecasting Model	Estimation	MAE	Total Weekly Demand	Average Weekly Demand	Std. Dev. Weekly Demand	Frequency	ABC Designation	Demand Class
201467	ARMA(3,4)	17.14	14.33	2,836	24.88	20.02	105	A	E
917176	MA(4)	34.45	27.33	4,364	38.28	36.81	90	A	E
910725	ARMA (2,2)	5.59	3.03	522	4.58	3.98	98	A	E
905301	ARMA (1,1)	1.76	1.41	195	1.71	1.76	69	A	I
900725	AR(3)	1.70	1.32	195	1.71	1.71	77	A	I
903030	ARMA(2,2)	15.05	8.88	1,961	17.20	12.41	86	A	I
918267	AR(6)	1.22	1.08	125	1.10	2.14	41	A	L
914175	Damped-Trend Linear Exponential Smoothing	8.00	53.56	5,998	52.61	103.51	50	A	L
918034	ARMA(6,6)	1.40	1.31	184	1.61	1.84	74	A	L
900331	ARMA(3,3)	36.67	10.87	3,545	31.10	14.40	110	A	S
914418	MA(3)	268.78	45.86	31,110	272.89	68.70	113	A	S
918135	Damped-Trend Linear Exponential Smoothing	1.34	1.25	215	1.89	1.70	88	A	S
915556	AR(2)	74.93	59.21	7,463	65.46	73.43	93	B	E
914940	AR(3)	82.16	28.72	4,708	41.30	38.62	102	B	E
917099	ARMA(5,5)	43.32	26.33	6,601	57.90	44.24	111	B	E
918194	ARMA(1,1)	1.03	1.14	106	0.93	1.40	44	B	I
908995	AR(3)	3.15	1.88	288	2.53	2.31	82	B	I
202780	AR(3)	1.57	0.89	115	1.01	1.28	62	B	I
914995	AR(1)	62.40	85.14	8,585	75.31	118.49	63	B	L
914184	ARMA(3,3)	15.69	51.61	5,121	44.92	89.66	44	B	L
914939	Linear (Holt) Exponential Smoothing	3.58	25.83	2,292	20.11	44.78	47	B	L
909366	AR(1)	1.66	1.17	215	1.89	1.63	87	B	S
918263	ARMA(1,1)	12.78	6.17	1,325	11.62	9.00	97	B	S
914733	AR(1)	157.50	47.10	11,905	104.43	66.49	113	B	S
915813	ARMA(1,1)	99.19	106.93	6,753	59.24	118.56	41	C	E
915637	AR(1)	30.43	49.55	6,470	56.75	52.11	113	C	E
914237	MA(6)	19.36	27.19	3,270	28.68	64.10	72	C	E
915579	ARMA(1,1)	1.50	2.94	203	1.78	4.46	19	C	I
900408	Average Demand	0.08	0.08	5	0.04	0.28	3	C	I
220665	Simple Exponential Smoothing	0.04	0.16	10	0.09	0.47	5	C	I
914223	Simple Exponential Smoothing	3.75	5.08	428	3.75	10.61	35	C	L
905337	Simple Exponential Smoothing	0.27	0.44	31	0.27	0.91	14	C	L
904687	Cumulative Average	0.01	0.01	1	0.01	0.09	1	C	L
918595	Cumulative Average	0.13	0.39	15	0.13	1.04	2	C	S
917028	ARMA(2,2)	1.83	10.65	2,007	17.61	14.05	101	C	S
237373	Cumulative Average	4.19	4.28	478	4.19	19.42	6	C	S

Appendix 7: The Screen shot showing calculation in Excel



Appendix 8: The sensitivity analysis for the new forecasting assumption for Rogers

		Ordering Cost ($)										
		1	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**50**	**60**
# days of supply	**1**	-1%	17%	33%	42%	49%	54%	57%	60%	63%	67%	69%
	2	5%	20%	35%	44%	50%	54%	58%	61%	63%	67%	69%
	3	10%	23%	37%	45%	51%	55%	58%	61%	64%	67%	70%
	4	15%	26%	38%	46%	51%	55%	59%	62%	64%	67%	70%
	5	19%	28%	40%	47%	52%	56%	59%	62%	64%	68%	70%
	6	23%	31%	41%	48%	53%	57%	60%	62%	65%	68%	70%
	7	26%	33%	43%	49%	54%	57%	60%	63%	65%	68%	70%
	8	30%	35%	44%	50%	54%	58%	61%	63%	65%	68%	71%
	9	33%	37%	45%	51%	55%	58%	61%	63%	65%	69%	71%
	10	35%	39%	46%	52%	56%	59%	62%	64%	66%	69%	71%
	11	38%	41%	48%	52%	56%	59%	62%	64%	66%	69%	71%
	12	40%	42%	49%	53%	57%	60%	62%	65%	66%	69%	71%
	13	42%	44%	50%	54%	58%	60%	63%	65%	67%	70%	72%
	14	44%	45%	51%	55%	58%	61%	63%	65%	67%	70%	72%
	15	46%	47%	52%	56%	59%	61%	64%	66%	67%	70%	72%
	16	48%	48%	53%	56%	59%	62%	64%	66%	68%	70%	72%
	17	49%	49%	54%	57%	60%	62%	64%	66%	68%	70%	72%
	18	51%	51%	54%	58%	60%	63%	65%	67%	68%	71%	72%
	19	52%	52%	55%	58%	61%	63%	65%	67%	68%	71%	73%
	20	54%	53%	56%	59%	61%	64%	65%	67%	69%	71%	73%
	30	64%	62%	63%	64%	66%	67%	69%	70%	71%	73%	74%
	60	79%	75%	75%	74%	75%	75%	75%	86%	76%	77%	78%

Appendix 9: The sensitivity analysis for the new forecasting assumption for Forth Smith

		Ordering Cost ($)										
		1	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**50**	**60**
# days of supply	**1**	-35%	-16%	-14%	14%	22%	30%	35%	39%	43%	49%	53%
	2	-21%	-7%	-7%	18%	25%	32%	37%	41%	44%	50%	54%
	3	-8%	1%	-1%	22%	28%	34%	39%	43%	46%	51%	54%
	4	1%	8%	4%	25%	31%	36%	40%	44%	47%	52%	55%
	5	10%	14%	9%	28%	33%	38%	42%	45%	48%	53%	56%
	6	17%	19%	14%	31%	36%	40%	44%	47%	49%	53%	57%
	7	23%	24%	18%	34%	38%	42%	45%	48%	50%	54%	57%
	8	28%	28%	21%	36%	40%	44%	47%	49%	51%	55%	58%
	9	32%	32%	25%	39%	42%	45%	48%	50%	52%	56%	59%
	10	36%	35%	28%	41%	44%	47%	49%	51%	53%	57%	59%
	11	40%	38%	31%	43%	45%	48%	50%	52%	54%	57%	60%
	12	43%	41%	33%	45%	47%	50%	52%	53%	55%	58%	61%
	13	46%	44%	36%	46%	48%	51%	53%	54%	56%	59%	61%
	14	49%	46%	38%	48%	50%	52%	54%	55%	57%	59%	62%
	15	51%	48%	40%	50%	51%	53%	55%	56%	58%	60%	62%
	16	53%	50%	42%	51%	52%	54%	56%	57%	58%	61%	63%
	17	55%	52%	44%	52%	54%	55%	57%	58%	59%	61%	63%
	18	57%	54%	46%	54%	55%	56%	58%	59%	60%	62%	64%
	19	59%	55%	47%	55%	56%	57%	58%	60%	61%	63%	64%
	20	60%	57%	49%	56%	57%	58%	59%	60%	61%	63%	65%
	30	71%	68%	61%	65%	65%	66%	66%	66%	67%	68%	69%
	60	84%	81%	77%	79%	78%	77%	77%	77%	77%	77%	77%