Intelligent Supplies Replenishment Process

by
Merin Thomas
B Tech. & M.Tech in Chemical Engineering, Indian Institute of Technology Madras, 2014

Submitted to the MIT Sloan School of Management and the Operations Research Center in Partial Fulfillment of the Requirements for the Degrees of
Master of Business Administration
and
Master of Science in Operations Research

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

June 2019

Signature of Author ______________________________
Operations Research Center
MIT Sloan School of Management
May 10, 2019

Certified by ______________________________
David Simchi-Levi, Thesis Supervisor
Professor of Civil and Environmental Engineering

Certified by ______________________________
Jonas Jonasson, Thesis Supervisor
Assistant Professor of Operations Management

Accepted by ______________________________
Patrick Jaillet, Co-Director, Operations Research Center
Dugald C. Jackson Professor

Accepted by ______________________________
Maura Herson, Assistant Dean, MBA Program
MIT Sloan School of Management

This page intentionally left blank.

Intelligent Supplies Replenishment Process

by

Merin Thomas

Submitted to the MIT Sloan School of Management and the Operations Research Center on May 10, 2019 in Partial Fulfillment of the Requirements for the Degrees of Master of Business Administration and Master of Science in Operations Research

Abstract

Company X is facing high cost to serve customers such as hospitals and clinics, due to irregular ordering pattern. Currently, the customer ordering process is not well planned and leads to multiple orders in a month, thereby excessive shipping and increased cost to serve. The supplies provided to customers are used for specimen collection, and the collected specimen are sent to diagnostic laboratories for analysis. Historical data on order quantities of specimen collection items (SCIs) and specimen containers returned to lab are available. This project takes advantage of the closed loop nature of the system to predict order quantities of SCIs.

This project explores two replenishment strategies and compares it with the current method, through simulation. The simulation models the daily consumption of SCIs at a chosen Patient Service Center (PSC), and estimates average inventory levels and the number of occurrences of stockouts for each SCI at the PSC, for varying values of parameters such as review period and safety stock levels. The two replenishment strategies are (a) constant order quantity, in which fixed replenishment quantities of SCIs are supplied every review period, and (b) predictive modelling replenishment strategy, in which the order quantities of SCIs are predicted using the data on specimen containers returned to diagnostic lab for analysis. For the latter strategy, multiple models for prediction, such as penalized regression, Classification and Regression Trees (CART) and Random Forest are used.

Two parameters, the total replenishment costs and the number of occurrences of stockouts, are measured to evaluate the performance of the replenishment strategies. The total cost of replenishment for constant quantity strategy is comparable to that of baseline case, whereas predictive modelling strategies have much higher cost. The constant quantity strategy with increased levels of safety stock gives best results of reducing the total cost of replenishment and minimizing the number of occurrences of stockouts.

Thesis Supervisor: David Simchi-Levi,
Professor of Civil and Environmental Engineering

Thesis Supervisor: Jonas Jonasson,
Assistant Professor of Operations Management

This page intentionally left blank.

Acknowledgments

I would like to thank Company X for providing the financial and technical support for this research project. I thank Company X team for their assistance, as well as for their dedication to bettering the quality of healthcare in the United States.

I would like to thank my thesis advisors, Dr. David Simchi-Levi and Dr. Jonas Jonasson, for their invaluable guidance and support for my thesis. I thank the LGO program staff and the Operations Research Center staff for guiding and supporting me towards completing this research.

Finally, I would like to thank everyone who has contributed to my work in this two-year journey at MIT Sloan School of Management in the Leaders for Global Operations program, and my LGO and Sloan classmates who have made this journey a fantastic experience.

Table of Contents

This page intentionally left blank.

List of Figures

Glossary

- **Patient Service Center (PSC):** A Patient Service Center is a site for collection of specimens from patients for diagnostic testing. However, unlike customers, PSCs are owned and operated by Company X. Therefore, PSCs can be considered as an internal customer.
- **Specimen Collection Items (SCIs):** There are materials used to draw specimens, such as body fluids, from patients. They include all containers and consumables used for specimen draw. Some examples are needles, band-aids, alcohol wipes etc. used for drawing blood from a patient.
- **Specimen Containers:** These are collection tubes or containers that hold the specimens drawn from patients and are sent for diagnostic study at Company X's labs. Specimen containers are a subset of SCIs.
- **Container Code:** These are codes assigned to a class of specimen containers. It does not uniquely identify the SCI used. For example, a 4 mL and a 10 mL containers of the same kind may have the same container code, but different product codes.
- **Product Code:** These are codes used to uniquely identify a SCI. Unlike container codes which are only assigned to containers, product codes are assigned to all SCIs, including containers and other consumables.
- **Par Level:** The PSCs follow an order-up to policy for restocking SCIs. The order up-to level for each SCI have been fixed and is referred to the par level of inventory. The par level can also be understood as the sum of safety stock and average demand in the 2 weeks review period.
- **Classification and Regression Trees (CART):** A type of algorithm for predictive modelling.

Chapter 1

Introduction

Company X is a leading diagnostics services provider in the United States, that enables patients and doctors make better healthcare decisions. Company X provides specimen collection items (SCIs) to its customers such as hospitals, clinics and Patient Service Centers (PSCs). Company X faces high cost to serve its customers. Operational efficiency is key to Company X and reducing cost to serve customers is important. This thesis aims to identify an intelligent process for replenishment of SCIs at customer locations, to reduce cost to serve and provide competitive advantage. This thesis compares the outcomes of various replenishment strategies, as discussed in Chapter 4 and 5, on cost and quality of service at a chosen PSC.

1.1 Problem Statement

Company X provides SCIs to over 100k customers and ships over 1.1 million orders annually. These SCIs include needles, tubes, band-aids etc. for blood draw, urine containers, among other items used in hospitals and clinics. The cost of replenishment, including cost of SCIs, order processing costs and freight is fully borne by Company X and amounts to over $90 million annually. The customer ordering process is not well planned and leads to multiple orders to the same customer in a month, thereby excessive shipping and increased cost to serve.

The main problem addressed in this study is to reduce the cost of serving customers and improve the quality of service. The method used to address this problem is to develop a system that can remove the decision making of SCI orders from customers, thereby enabling more control over the orders by Company X. For the purpose of this study, the scope was limited to a chosen PSC. PSCs are specimen collection centers owned and operated by Company X, and therefore, can be considered as an internal customer. The chosen PSC follows an 'order up to' policy with a review period of 2 weeks. This thesis develops replenishment strategies for restocking the PSC's inventory of SCIs. The insights derived from the study on the PSC can be applied to other customers.

1.2 Project Objective

The primary objective of this project is to develop a process for replenishment of SCIs at Company X's PSC in a cost effective manner. The project aims to develop a model that predicts demands of SCIs at the PSC and generates order quantities for SCIs, thereby eliminating the need to place orders by the PSC staff.

There are two-fold benefits to this developed process, when extended to customers.

(1) This process will enable Company X to better predict demand from customers. This helps in better planning of logistics and reduce cost, as Company X will have more control on timing and quantities of SCI orders.
(2) The developed process provides competitive advantage, as customers do not require to place orders for SCIs anymore. It eliminates the decision making on SCI orders from customers.

1.3 Overview of Approach

Company X has historical information on the quantities of SCIs ordered by customers. Information of diagnostic tests ordered and the quantities of specimen containers sent to Company X's diagnostic laboratories by customers are also available. Exploring this historical data will provide an understanding of customers' ordering patterns.

Some of the SCIs supplied to customers, namely the specimen containers, are returned to Company X's lab for diagnostic analysis. Therefore, Company X has a closed loop nature in its supply chain. The product codes associated with SCIs can be linked to the container codes received in the diagnostic lab. This project aims to exploit the closed loop nature of the system to predict demand for SCIs at customer site. However, the problem become more challenging since the links between product codes of SCIs and container codes of specimen containers received in labs are not one-to-one. A container code can be associated with multiple product codes and vice versa. For example, if a blood draw was made and if a blood collection tube was received in the diagnostic lab, some information about the type of SCIs used for drawing the blood specimen can be derived from the container code of the blood collection tube received in the lab. From the container code, the kind of tube used to draw the blood can be derived, but the specific volume of the tube or other details cannot be obtained. Similarly, it can be concluded that a needle was used to draw the blood, but the type of needle used cannot be determined.

The SCIs used in the chosen PSC and the historical order data are available, and are used to determine the replenishment strategy for this PSC. The project develops replenishment strategies for SCIs at the chosen PSC and the effects on total cost to serve and quality of service are studied by simulating the inventory levels. The details of the approach are discussed further in Chapter 4.

After simulation of replenishment strategies, a pilot study was initiated at the chosen PSC. The pilot study keeps track of demands, inventory levels and occurrences of stock-outs at the PSC for each SCI. The pilot study has been initiated to get more accurate data on the demand for SCIs at the PSC.

Chapter 2

Project Scope at Company X

This chapter provides information about the background, business model and supply chain of Company X, that helps understand the relevance of the project and its scope in various stages of Company X's supply chain.

2.1 Company X Background

Company X is a multinational provider of diagnostics services such as testing and information services. Company X has laboratories that are consolidated regionally, to perform diagnostic testing. In addition to these facilities, Company X also operates more than 2,200 PSCs, for specimen collection from patients. Achieving operational efficiencies in the whole supply chain, involving customers, laboratories and PSCs is important to Company X.

2.1.1 Business Model

Company X offers a variety of services and diagnostic testing for its customers such as hospitals and clinics. Company X generates revenue on a per test basis from its customers. Customers collect specimens such as body fluids from patients and sends it Company X's laboratories for diagnostic tests. All the SCIs required for specimen draw are provided to customers by Company X and customers are charged on a per test basis. The total cost of replenishing SCIs to customers, including cost of SCIs, order processing costs, shipping and logistics is borne fully by Company X.

Each SCI is associated to one or more diagnostic tests. Customers are given 'credit' for each SCI by taking into consideration how much of each kind of diagnostic tests has been ordered. This SCI 'credit' can be considered as the maximum allowable limit on order quantities of SCIs. This is calculated based on the number of diagnostic tests ordered by the customer, and back calculating the consumption of SCIs for specimen draws associated with these tests.

The replenishment process start with customers placing orders for SCIs through various ordering channels such as fax, email etc. After reviewing the customer's maximum allowable limit for each SCI, the allowable limit or ordered quantities of each SCI, whichever is lesser, is sent to the customer sites.

2.2 Supply Chain

The supply chain for diagnostic testing and replenishment of SCIs to customers involve multiple stages. This section explains the various stages in the supply chain and the potential benefits of this project in each stage.

2.2.1 Overview

There are five main stages in the supply chain, and six connections between these stages that transfer either material or information, as shown in Figure 2-1 below.

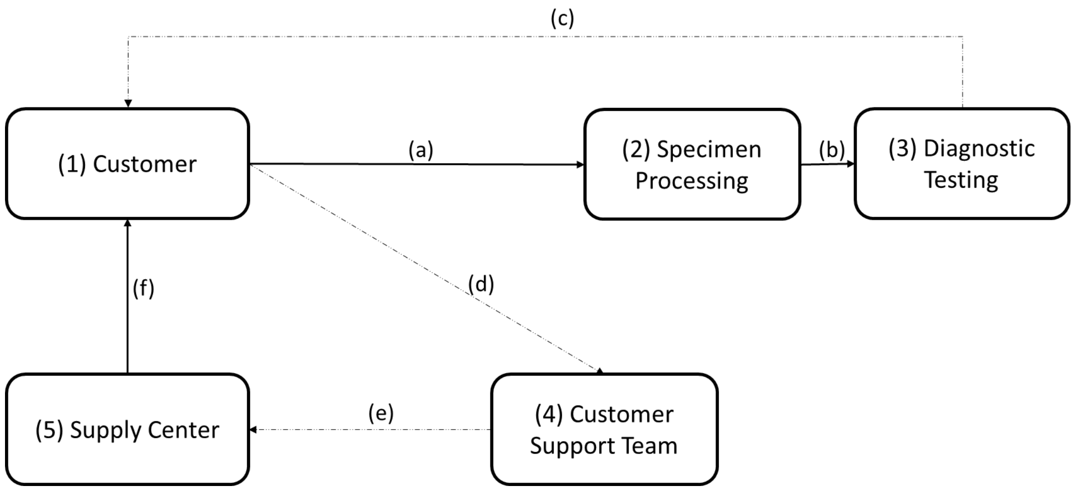

Figure 2-1: Multi-stage supply chain at Company X

Among the five stages, only the first stage, customer, is external to Company X. Customers are hospitals and clinics that collect specimens from patients for diagnostic testing at Company X. In addition to external customers, there are also internal customers or PSCs, which are owned and operated by Company X. The activities at external and internal customers are collection of specimens from patients, and are considered to be identical for the scope of this project.

After specimens are collected at customer sites, it is transferred to the diagnostic laboratory at Company X. This is depicted in Figure 2-1 as (a). This process is performed by Company X Logistics Team, that picks up specimen containers from customers and transfers them to diagnostic labs.

Prior to diagnostic testing, the specimen containers undergo processing in the laboratories, where information about the container code, the customer it came from and so on are recorded. This information is key to the project to understand the utilization patterns of each container type by customers.

After specimen processing, the specimens undergo diagnostic testing, as depicted in stage (3) of Figure 2-1. The results of diagnostic testing are sent to customers electronically or otherwise, as depicted by (c) in Figure 2-1.

As discussed in Section 2.1.1, the SCIs are provided to customers by Company X. Customers place order through various modes such as email, fax, phone call or online portal. This is depicted by (d) in Figure 2-1. The orders are processed by Customer Support Team at Company X, where the order quantity is compared with allowable limit. The allowable limit is the maximum order quantity of an SCI for a customer and is calculated based on the number of diagnostic tests ordered by the customer, as explained in Section 2.1.1.

The final order quantity is either the allowable limit of the SCI or the actual order placed by the customer, whichever is lesser. After the final order has been generated by the Customer Support Team, it is faxed to Supply Center. The Supply Center is a distribution center, that holds inventory of SCIs. At the Supply Center, the order quantities of each SCI is picked, packed and shipped to customers, as depicted by (f) in Figure 2-1.

2.2.2 Potential Contribution to Supply Chain

There are many benefits to this project at various stages of the supply chain. The main benefits for this project are increased convenience, competitive advantage and reduced cost to serve.

This project eliminates process (d) from the supply chain. Eliminating the process of placing orders by the customer reduces labor time and provides more convenience. This project also helps the customer in better inventory management through (a) receiving more accurate amount of SCIs at the right time and (b) minimizing occurrences of stock-outs at customer sites.

One of the problems Company X currently face is return of SCIs by the customer and the efforts associated with processing these returns. These returns usually occur due to incorrect order made by customer. This project estimates the customer utilization patterns for each SCIs and replenish them only when consumed, and hence can reduce the number of returns.

This project addresses the problem of excessive shipping (discussed in Section 1.1) faced by Company X. Currently, there are multiple orders placed by a customer in a month, causing excessive shipping. This project will standardize ordering period for customers and combine such multiple orders, thereby saving labor time and freight cost. Better prediction of demands for SCIs can help in reducing the number of expedited shipping. There can be potential savings by reducing the number of expedited shipments.

At the Supply Center, better prediction of orders can help in better inventory management. This project can minimize sporadic orders, thereby evening out the load and help in better planning of operations and labor at the Supply Center.

In addition to the potential benefits at various stages of the supply chain, this project also provides a competitive advantage to Company X. As discussed in Section 1.2, competitive advantage through providing this service to customers is one of the two-fold objectives of this project.

Chapter 3

Current State Analysis

This chapter discusses the current supply chain, ordering process and replenishment methods for a chosen PSC in more detail. A suitable mid-size PSC was chosen for the purpose of this project, based on the volume of specimens drawn at the PSC.

3.1 Patient Service Center

The scope of the project was limited to a chosen PSC in Boston, MA. This PSC is representative of an internal customer, owned and operated by Company X. Data on order quantities of SCIs are available for the past year.

The PSC has a standardized ordering process, following the base-stock model. There is a fixed review period of two weeks and fixed par level of inventory for each SCI. The par level of inventory is the order upto level for each SCI, and is a combination of safety stock and average demand in the two weeks review period. After every review period, a staff at the PSC reviews the inventory of each SCI and places an order to replenish the item up to the par level of that SCI. For example, if a particular SCI has a par level of inventory as 10 units, and if 2 units were consumed in the two weeks following the last order date, the staff places an order of 2 units for that SCI on the following order date. The order dates are spaced two weeks apart and at the chosen PSC, an order is made every other Friday, adhering to the review period duration of two weeks.

A study of the order data for the past year revealed that the chosen PSC used 41 SCIs. These SCIs include collection tubes, needles, gloves, lab coats etc. Each of these SCIs and other consumables are assigned a product code. Some of these items, such as collection tubes, needles etc. can be directly linked to a specimen draw. However, other consumables such as gloves, lab coats etc. cannot be directly linked to a specimen draw. Such items that cannot be linked to a specimen draw is excluded from the scope of this project. 32 out of 41 SCIs are in the scope of the project, and differ in their frequencies of orders and order quantities, as depicted in the Figure 3-1 below. The names and descriptions of the SCIs have been masked and are represented by product codes P1 through P32

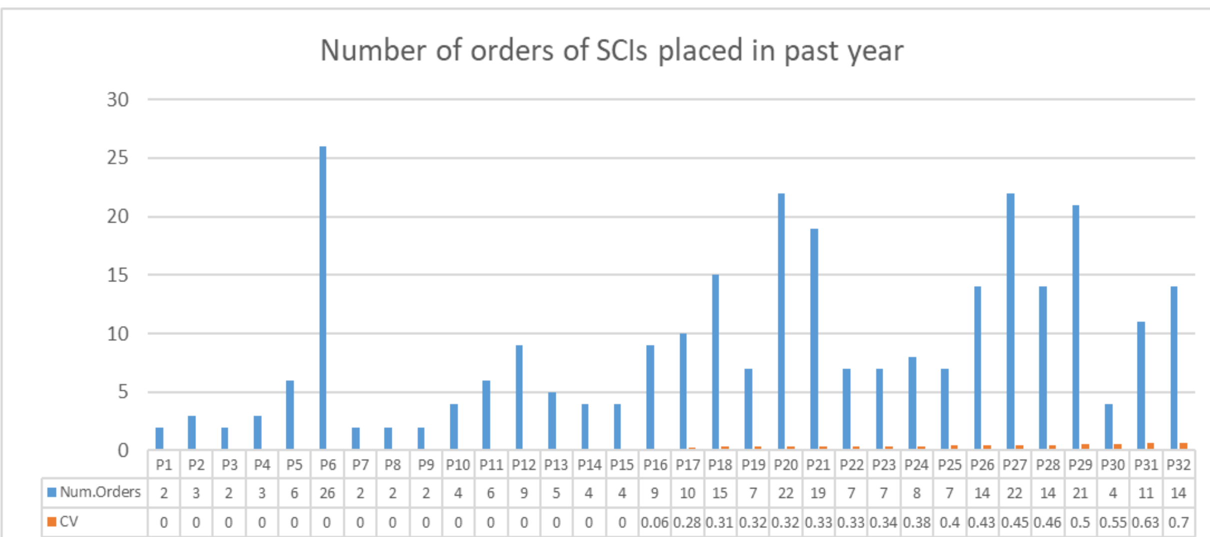

Figure 3-1: SCIs at Company X's PSC – order frequency and coefficient of variation

A study of the specimen containers collected in the Marlborough diagnostic lab of Company X showed that the chosen PSC used 38 different container codes. These containers codes are assigned to a specific class of specimen containers. As discussed in Section 1.3, container codes give indication of the type of containers used, but does not give finer details such as volume etc. and therefore, the container codes cannot be used to uniquely identify a SCI.

3.2 Demand for SCIs

The SCI orders made by the chosen PSC for the past year were studied. It was observed that some of the SCIs were ordered frequently, such as during every review period, whereas some others were ordered rarely, such as once or twice in the past year. These variations in the order frequencies and order quantities were studied in more detail and the items were grouped into three categories as shown in Figure 3-2.

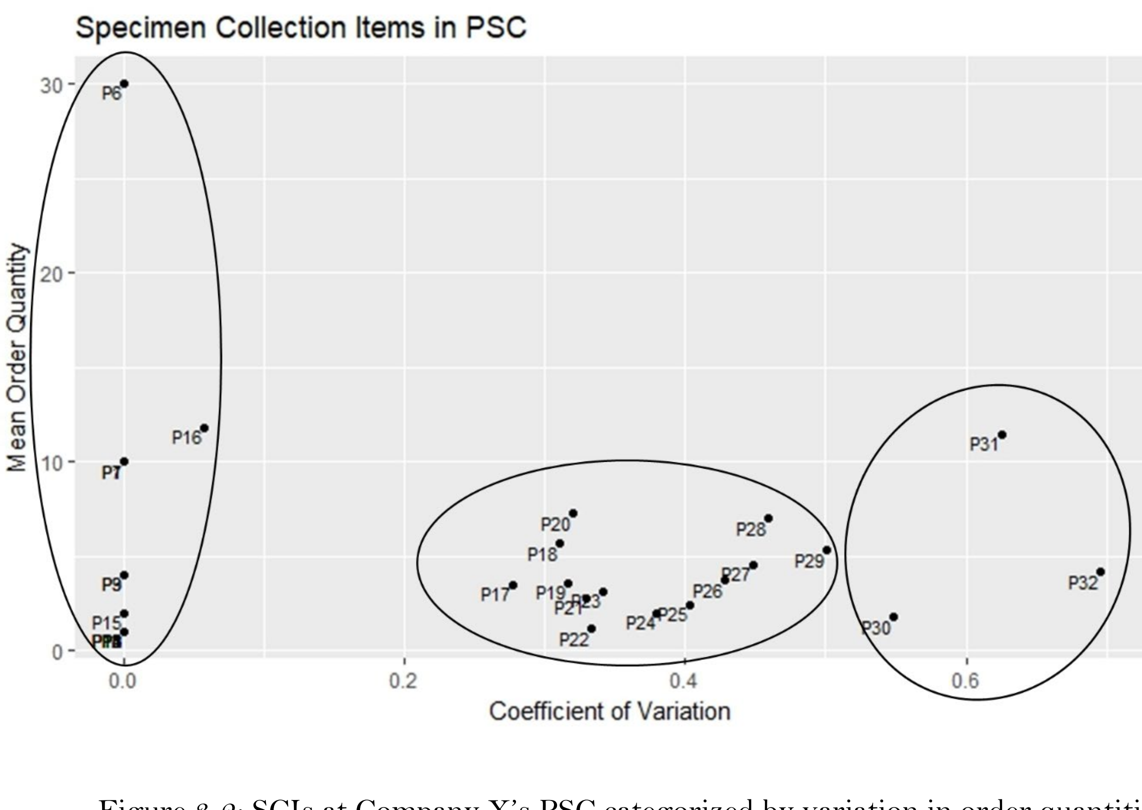

Figure 3-2: SCIs at Company X's PSC categorized by variation in order quantities

In Figure 3-2, some SCIs such as P1 through P16 does not vary much in their order quantities. Such items are categorized as ‘low variation’. The second category include the SCIs that have some variation in the order quantities. These are called ‘medium variation’ SCIs and are depicted by items P17-P29 in Figure 3-1. The third category include SCIs that show high variation in their order quantities. These are SCIs P30-P32 in the Figure 3-1 and are called ‘high variation’.

The demands for example SCIs from each of these three categories, P16, P17 and P31 are given in Figure 3-3 below. It can be noted from the Figure 3-3 below that the order quantities for P16 has lower variation, whereas P31 shows highest variation in order quantities placed.

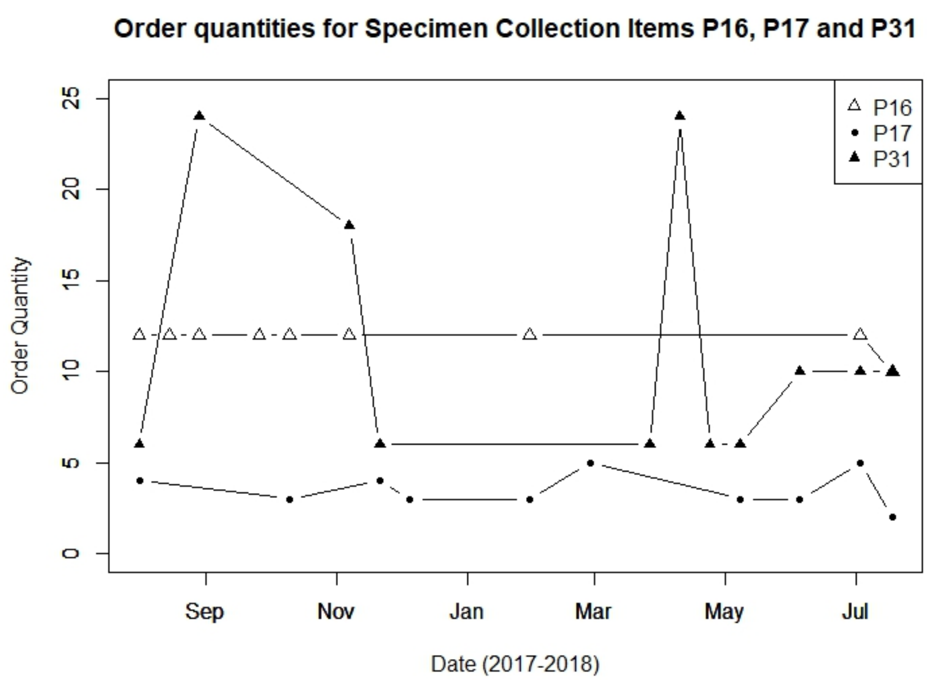

Figure 3-3: Annual demand of SCIs P16, P17 and P31 at Company X’s PSC

SCIs in the first group are expected to be more accurate in its demand predictions that those in the third group. Some of the SCIs, that are not frequently ordered, does not have sufficient data points and poses challenge to predictive modelling. In addition to insufficient data points, there are other noises in the available data due to unrecorded orders and shrinkage. The orders made for SCIs and other consumables may not accurately reflect its actual consumption at the PSC. This is because, sometimes the PSC receives SCIs from other PSCs or clinics, in an event of shortage or closure, and such procurement of SCIs are usually not recorded. Therefore, the quality of available order data is compromised. Also, the shrinkage of SCIs at the PSC due to breakage etc. are not estimated accurately.

Chapter 4

Simulation Methodology

The overview of approach has been discussed in Section 1.3. This chapter discusses the approach in further detail. The historical data of orders for SCIs made by the PSC and the quantity of specimen containers returned to Company X lab for diagnostic testing are available for the past year. The project develops two strategies for replenishment of SCIs and compares their performances to the baseline case. A pilot study has been initiated to better understand consumption of SCIs at the PSC.

4.1 Overview

As discussed in Section 1.3, historical data on orders for SCIs made by the chosen PSC are available. Some of these SCIs can be directly linked to a specimen draw, whereas some others are consumables, that cannot be directly linked to a specimen draw. Such consumables are excluded from the scope of this project. The data on quantities of specimen containers sent to labs for diagnostic testing, from the chosen PSC are also available. The consumption of SCIs is expected to be correlated to the quantity of specimen containers sent to labs. This project predicts the consumption of each SCIs from the quantities of specimen containers received in labs.

For the prediction of the consumption of SCIs, various techniques were adopted, such as penalized regression like Lasso, Classification and Regression Trees (CART) and Random Forest. These methods are further discussed in detail in Section 4.4.

Due to the compromise made on data quality as discussed in Section 3.2, the demand prediction using various techniques such as Lasso, CART and Random Forest, is not expected to be highly accurate. Therefore, predictive modelling alone is not a reliable approach. In addition to predictive modelling, replenishment strategies were developed and compared for performance through simulation, further detailed in Section 4.2. The performance of each replenishment strategy was studied by comparing the effects on overall cost of replenishment to Company X and number of occurrences of stockouts at the chosen PSC.

A pilot study was also initiated at the chosen PSC. During this pilot study, the daily consumption of each SCIs were recorded. The order quantities during every review period was compared with the order quantity generated by the predictive modelling approach.

4.2 Simulation

The chosen PSC currently follows the base-stock inventory model for replenishment of the inventory of SCIs and other consumables, as discussed in Section 3.1. There is a fixed review period of two weeks and a par level of inventory for each SCI. At the end of two weeks, a staff at the PSC reviews the inventory and places orders for SCIs. The order quantity is same as the consumption during the two weeks after the last order date, so that the inventories are replenished to the par level. There is a lead time of 5 days after which the ordered SCIs arrive at the PSC.

Some SCIs have a minimum order quantity. For example, tubes are received in packs of 100. Such SCIs are not accounted for on an individual basis, but on a stock keeping unit basis, such as pack. So during a replenishment period, if only half of a pack (50 tubes) were consumed, no order will be placed during that review period. This deficit of half a pack will be accounted for in the future review period. If another 75 tubes were consumed in the following review period, the total deficit is 1.25 packs, and an order for one pack will be placed. The order quantity is derived by rounding down the sum of total consumption during the review period and previous deficit.

The demand distributions for each SCIs at the PSC were approximated to be normal and daily demands were generated using various seed values.

$$D_i = N(\mu_i, \sigma_i)$$

where D_i is the daily demand of SCI i, μ_i and σ_i are the mean and standard deviation of daily demands of SCI i. There are 32 SCIs in scope for this project and therefore, i varies from 1 to 32.

Simulation was done in order to compare the various replenishment strategies. In the simulation, the demand distribution of each SCI at the PSC and the lead time used to deliver SCIs upon placing order are constant. The variables in the simulations, are the replenishment quantities and time of replenishment for each SCI. The decision of when to replenish and how much to replenish is based on the replenishment strategy adopted in the simulation. The time of replenishment is adjusted by varying the review period from 1 week to 4 weeks, and the effect of changing review period is studied for each of the replenishment strategies.

Through simulation, the performance of each replenishment strategy is studied and compared to each other. Two features used to compare the performance of replenishment strategies are overall cost of replenishment to Company X and occurrences of stockouts at the chosen PSC.

The total cost of replenishment is a sum of the cost of SCIs delivered to the PSC, cost of holding inventory and the cost of processing and shipping orders.

$$Total\ Cost = SCI\ Cost + Order\ Cost + \ Inventory\ Cost$$

$$SCI\ Cost = \sum_{i=1}^{32} \sum_{j=1}^{n} C_i * R_{ij}$$

where Ci is the cost of unit quantity of SCI i, Rij is the replenishment quantity of SCI i in review period j. The summation of SCIs vary from 1 to 32, as there are 32 SCIs in scope and the summation of review period vary from 1 to n, where n is the number of review periods in the one year simulation period, given by

$$n = \frac{365}{R}$$

where R is the duration of the review period.

$$Order\ Cost = \mathbf{C} * n$$

Where **C** is the average processing and shipping cost incurred by Company X, and has a constant value.

$$Inventory\ Cost = h * \sum_{i=1}^{32} C_i * \overline{I_i}$$

where h is inventory holding rate at Company X, $\overline{I_i}$ is the average inventory of SCI i at the PSC, calculated by averaging the simulated inventories.

The SCI orders made for the past year were studied. Though the orders vary from actual consumption, this order data was used to estimate the consumption of each SCI at the PSC and used to generate demand distributions for each SCI. The simulation generates random samples of daily demand for each SCI from the demand distribution, generates replenishment quantities based on the replenishment strategies and generates daily levels of inventory for each SCIs.

The replenishment quantities are reflected on the inventory levels five days following the review period, as there is a lead time of five days. For example, the inventory levels of each SCIs on Day 1 are at the par levels. On Day 2 - Day14, the inventory levels of each item reduce, depending on the consumption of each SCIs. On Day 14, the sums of daily consumptions of each SCI from Day 1- Day 14, rounded down to the stock keeping units are calculated as the replenishment quantities for each SCI. The inventory levels continue to reduce until Day 19. On Day 19, i.e. five days after the review period, the replenishment quantities are added to the inventory levels. At any day, if the inventory level is zero, it is marked as an occurrence of stockout.

4.2.1 Baseline Simulation

The chosen PSC currently follows an order up-to policy, and has a fixed review period of 2 weeks. The baseline simulation models the current replenishment strategy at the PSC, where replenishments of SCIs are made periodically, the orders being placed at the end of each review period. The baseline simulation replenishes the quantities of SCIs consumed in the review period, and it is reflected on the inventory levels after the 5 days lead time.

As discussed earlier, some SCIs have minimum order quantities. The replenishment quantities can be less than actual consumption for such SCIs and the difference between the consumptions and replenishment quantities are calculated as deficits for that review period, and are considered in future review periods.

This simulation is performed for various seed values of demand generation, for one year or 365 days. The total cost of SCIs, inventory holding cost and cost of processing and shipping order are calculated at the end of 365 days. The number of days where at least one of the SCI has zero inventory are recorded as occurrences of stockouts.

The baseline strategy is expected to perform the best in terms of reduced overall cost and number of occurrences of stockouts, since the actual demands of SCIs in each review period are correctly known. The other replenishment strategies are simulated, without knowledge of actual demands of SCIs, so that an automatic replenishment process can be developed, without manual order placement at the end of every review period.

4.2.2 Constant Quantity Replenishment

In this replenishment strategy, the replenishment quantities for each SCI are fixed to be the average demands, rounded to the nearest stock keeping units, in the chosen review period duration. The average demands for each SCIs are calculated from the historical order data for the past year.

As opposed to the baseline simulation, this method does not consider the actual demands of SCIs during the review period. The simulation method used is similar to the baseline simulation as described in Section 4.2.1, but the replenishment quantities added to the inventory in each replenishment period are constant, and equal to the average demands in that review period.

Rounding up the demands in a review period to the nearest stock keeping unit can cause excessive replenishment, whereas rounding down can cause increased stockouts. This strategy is expected to perform better than predictive modelling methods for those SCIs that are not frequently ordered, since predictive modelling requires good quality input data.

4.3 Predictive Modelling Replenishment

This section describes the various methods of predictive modelling used for predicting the demands of SCIs at the chosen PSC. As discussed in Section 3.1, the historical data on orders placed by the chosen PSC and the quantities of specimen containers sent to lab for diagnostic testing are available for the past year. For the purpose of predictive modelling, this data for the chosen PSC alone does not give sufficient data points. Therefore, data from other PSCs in the same geographical region are also used.

As discussed in Section 3.1, the quantities of specimen containers are expected to be correlated to the consumption of SCIs at the PSC. Predictive modeling is used to predict a variable, known as the dependent variable, based on the value of one or more independent variables. The dependent variable being predicted is the order quantities of each SCIs. The independent variable is the quantity of specimen containers, identified by their container codes, received in the lab between two order dates. For example, if an orders were placed on Day 1, Day 15 and Day 17 for the SCI P1, the dependent variable would be the order quantity placed on Day 1, Day 15 and Day 17. The independent variables would be the quantities of each kinds of specimen containers received in the lab prior to Day1, between Day 2 and Day 15, and between Day 16 and Day 17. For these three order dates, three data points will be generated for predictive modelling. For all the orders made for a particular SCI, corresponding data points for predictive modelling with the dependent and independent variables are generated. This method for data points generation was repeated for all PSCs in the available data.

For predictive modelling, different approaches were taken such as penalized regression, CART and Random Forests. Lasso is the method of penalized regression used for this project. In penalized regression, the statistically significant independent variables are identified and correlations between independent variables are taken into consideration. For example, two of the independent variables, such as quantity of needles consumed and quantity of band aids consumed in a time span may be correlated. The penalized regression eliminates the presence of highly correlated variables in the linear regression model.

CART is a method used to predict the dependent variable by classifying the data points into different buckets, based on criteria. For example, the entire data set may be split into two buckets based on the value of one of the dependent variable, say quantity of needles consumed. Further splitting of data set is done based on other criteria. The Random Forest approach is taking an aggregate of multiple 'trees' or CART models.

Chapter 5

Results and Discussions

This chapter discusses the results obtained from simulation of the two replenishment strategies, i.e. constant quantity and predictive modelling, and compares it with the baseline simulations. As expected, the baseline simulation performs better that the other two replenishment strategies. However, this baseline method requires knowledge of actual demands of SCIs. The two replenishment strategies do not need the knowledge of actual demands, but make decisions on order quantities of each SCIs based on their predicted consumption. The effect of these two replenishment strategies on overall cost and number of occurrences of stockouts are discussed in Section 5.1 - 5.3 below.

5.1 Effect of Review Period

Varying the review period can affect the cost of replenishment and the number of occurrences of stockouts. To study the effect of review period, the simulations using baseline, constant quantity replenishment strategy, and predictive modelling replenishment strategy using Lasso, CART and Random Forest were conducted for varying review periods of 1,2,3 and 4 weeks.

5.1.1 Effect on cost of replenishment

This section studies the effect of varying review period on the total cost of replenishment, and its components such as cost of SCIs and cost of holding inventory for varying review periods.

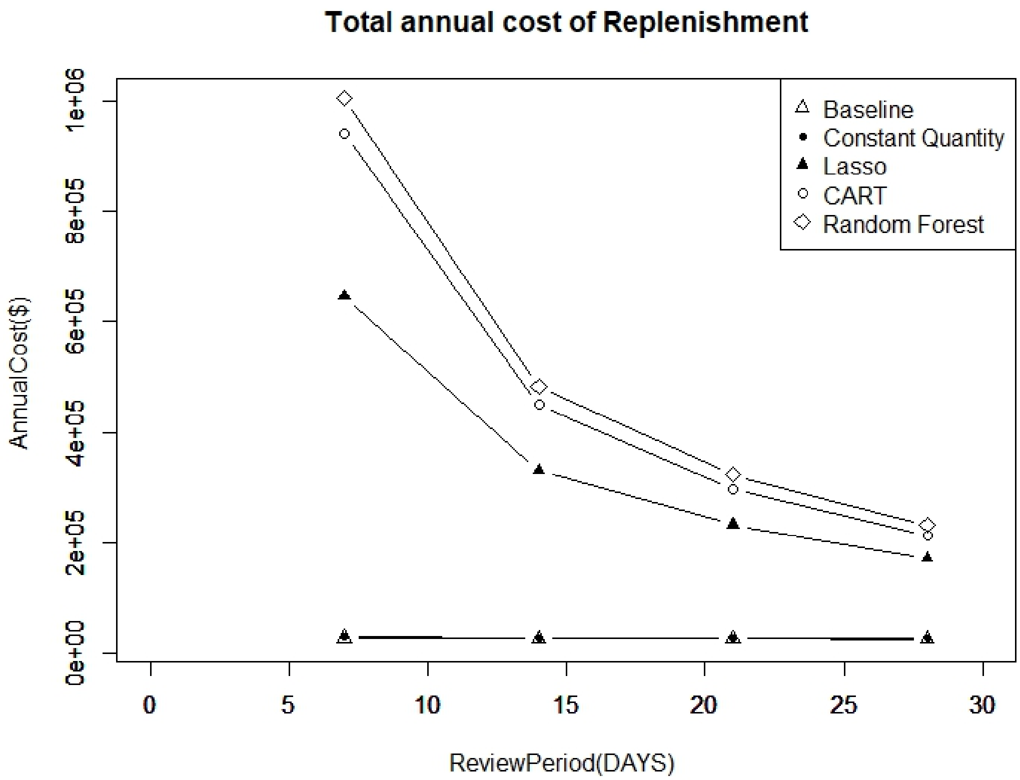

Figure 5-1(a): Comparison of the total cost of replenishment (baseline, constant quantity replenishment and predictive modelling strategies) for varying review periods

The total cost of replenishment is calculated as the sum of the cost of SCIs replenished, cost of holding inventory and cost of processing and shipping an order for a year, as discussed in Section 4.2. For the calculation of the total cost, the standard rate for holding inventory, and the standard fee for processing and shipping an order applicable to Company X are used. The exact value of these rates as well as the cost of each SCI is not revealed in this thesis to protect the confidentiality of this information.

It can be observed from Figure 5-1(a) that the total cost of replenishment for the constant quantity strategy is comparable to the baseline simulation. Figure 5-1(b) below shows the comparison of constant quantity replenishment strategy to the baseline simulation. There does not seem to be much variation in cost with respect to changing review periods.

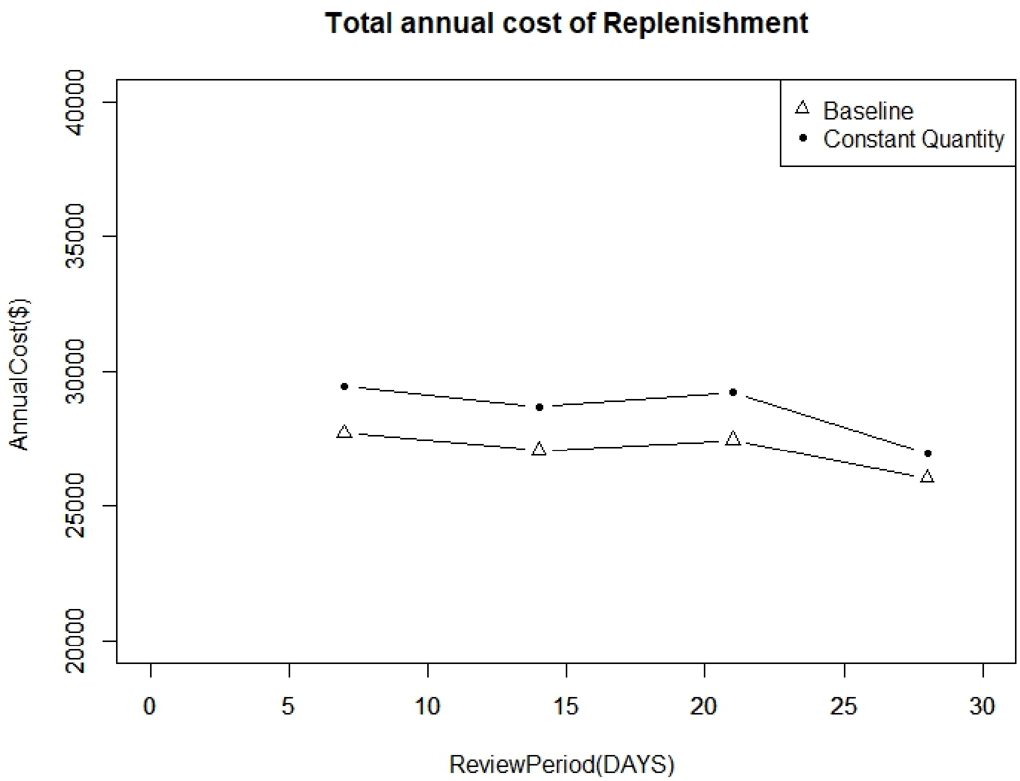

Figure 5-1(b): Comparison of the total cost of replenishment (baseline and constant quantity replenishment strategy) for varying review periods

Among the various methods used for predictive modelling, the penalized regression using Lasso method performs better than the other two, i.e. CART and Random Forest, in reducing the overall cost for replenishment. As can be seen from Figure 5-1(a), the total cost of replenishment is lower for Lasso than CART and Random Forest for all the review periods. As discussed in Section 3.2, the varying categories of products with respect to order frequency and order quantity, as well as unrecorded data on SCIs received by the PSC, pose challenges to predictive modelling approach.

Figure 5-1(a) shows that there is not much variation in total cost of replenishment for the constant quantity replenishment strategy with change in review periods. However, the cost of replenishment reduces drastically for all the predictive modelling strategies, as the length of review period increase. This could be attributed to better performance of predictive modelling for longer review periods, as there are some effects of longer time periods that reduce variation in demand of SCIs.

The Figure 5-2(a) and Figure 5-2(b) below shows the comparison of the cost of SCIs and cost of holding inventory separately, to understand if the trend is similar for both these cost components. It can be observed from the Figure 5-2(a) and Figure 5-2(b) below that the components of the total cost of replenishment follows the same trend as the total cost.

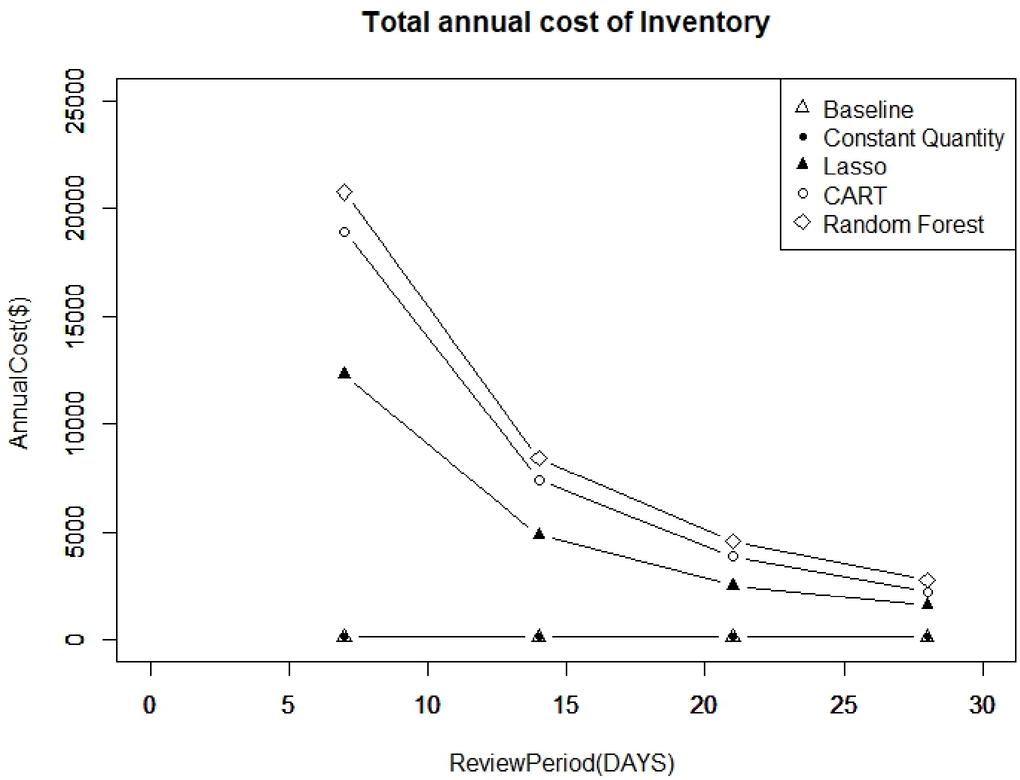

Figure 5-2(a): Comparison of the inventory holding cost (baseline, constant quantity and predictive modelling replenishment strategies) for varying review periods

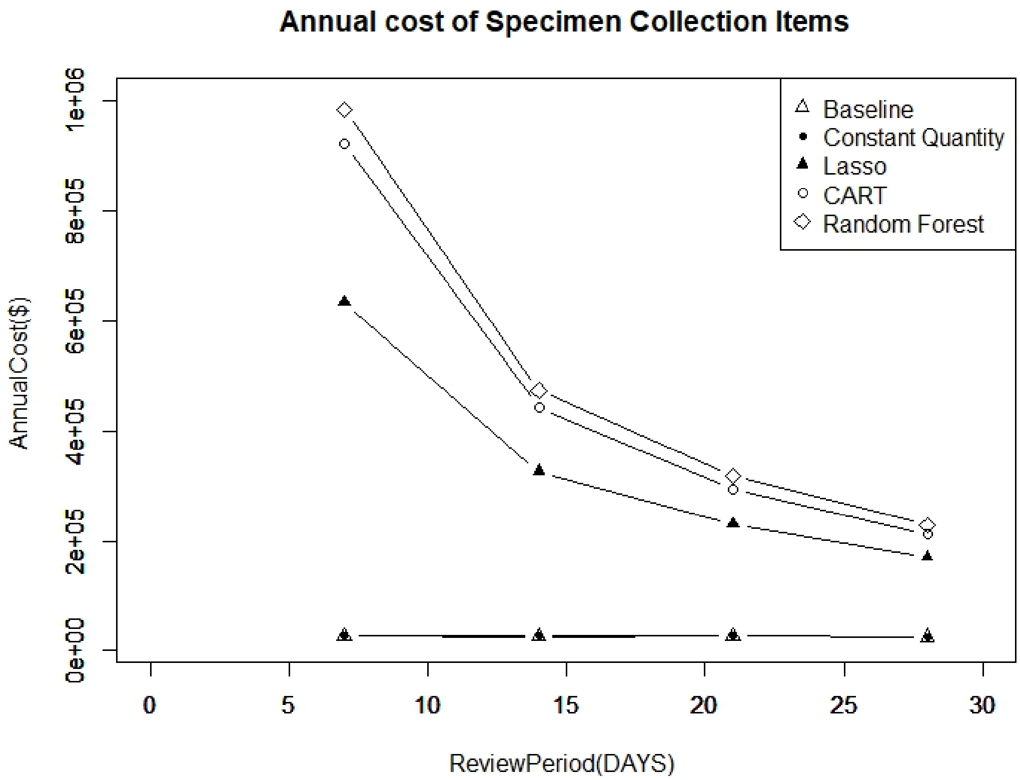

Figure 5-2(b): Comparison of the cost of SCIs (baseline, constant quantity and predictive modelling replenishment strategies) for varying review periods

5.1.2 Effect on stockouts

This section studies the effect of varying review period on the average number of occurrences of stockouts. The average days of stockouts is calculated as the average of the number of occurrences of stockouts for each SCI in a year.

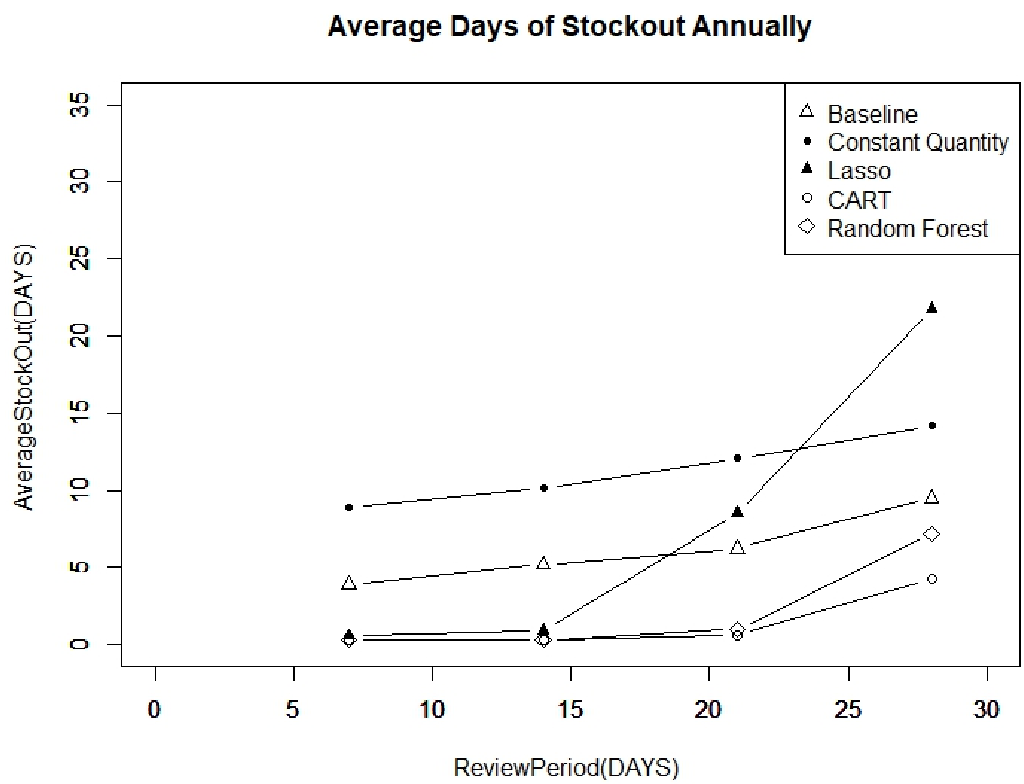

Figure 5-3: Comparison of average days of stockouts (baseline, constant quantity and predictive modelling replenishment strategies) for varying review periods

In the Figure 5-3, the average number of occurrences of stockouts increases for all replenishment strategies, as the review period becomes longer. This is because the par level for inventory is unchanged for all the review periods. Among the various replenishment strategies, the predictive modelling strategies perform better in terms of reducing the average number of occurrences of stockouts, compared to constant quantity replenishment strategy and baseline simulation.

From the study on effect of review periods on total cost of replenishment and occurrences of stockouts, it can be concluded that the predictive modelling strategies are oversupplying SCIs.

Therefore, the effect of safety stock levels at the PSC on the total replenishment cost and the number of occurrences of stockouts was studied, as discussed in the following sections.

5.2 Effect of Safety Stock

To study the effects of safety stock levels for each SCI at the PSC, the safety stock levels were varied from 0.25, 0.5, 0.75, 1 and 2 times that of the current par levels of inventories. Simulations were performed for the currently followed review period of 2 weeks and the effects on overall cost of replenishment and occurrences of stockouts were studied.

5.2.1 Effect on cost of replenishment

This section studies the effect of varying safety stocks on the total cost of replenishment, and its components such as cost of SCIs and cost of holding inventory.

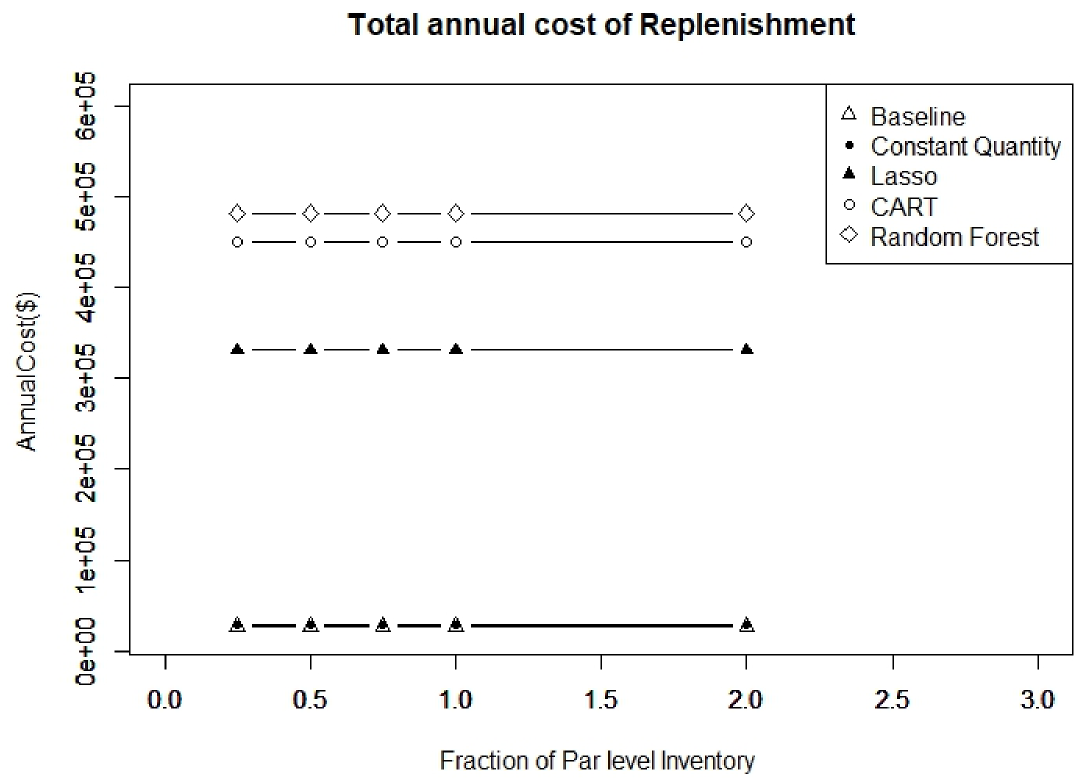

Figure 5-4: Comparison of the total cost of replenishment (baseline, constant quantity replenishment and predictive modelling strategies) for varying safety stock levels

From Figure 5-4, it can be observed that the total cost of replenishment for the constant quantity replenishment strategy is comparable to baseline simulations, whereas the cost is much higher for all the predictive modelling strategies such as Lasso regression, CART and Random Forest.

The cost of replenishment does not vary much with change in the safety stocks. One of the components of replenishment cost, the inventory holding cost, increases with the increase in safety stocks, as can been seen in Figure 5-5 below that compares the cost of holding inventory for constant replenishment strategy and the baseline simulation. However, the other two components of replenishment cost, i.e. cost of SCIs and cost of processing and shipping is not affected by the inventory levels at the PSC. Since the inventory holding cost is only a small fraction (exact rate not mentioned to protect confidentiality of Company X) of the total replenishment cost, the increase in cost of holding inventory does not have a significant impact on the total replenishment cost.

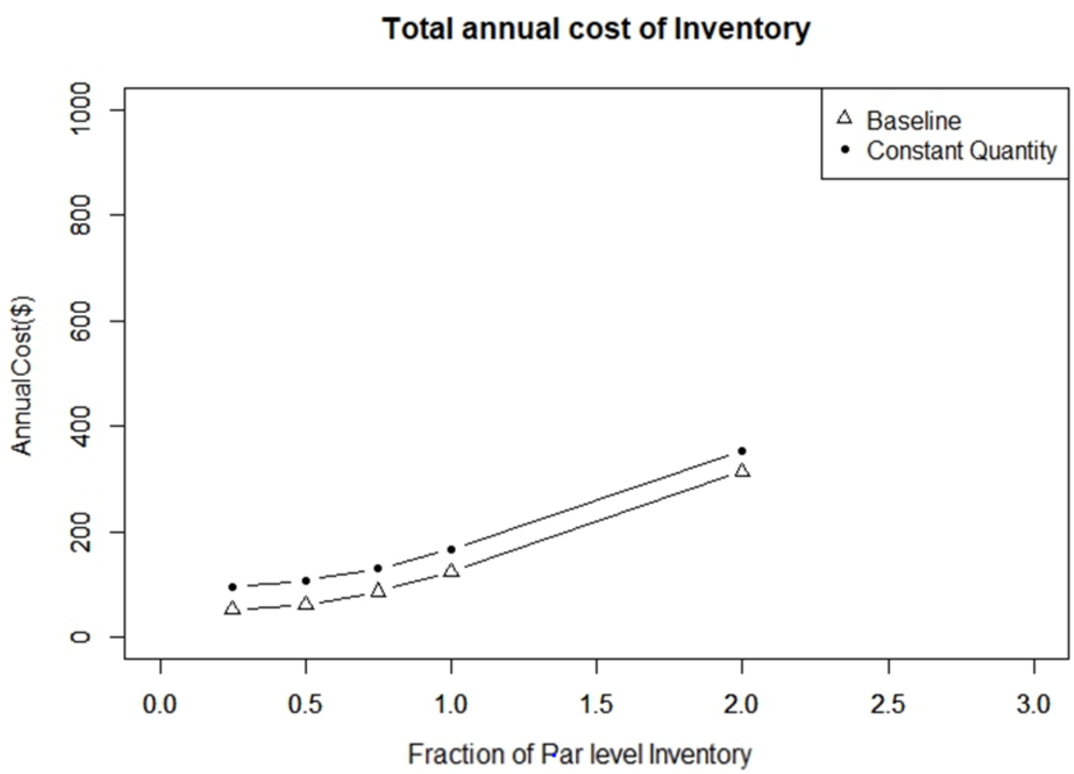

Figure 5-5: Comparison of the inventory holding cost (baseline, constant quantity replenishment strategy) for varying safety stock levels

5.2.2 Effect on stockouts

This section discusses the effect of safety stock levels of SCIs on the number of occurrences of stockouts. The Figure 5-6 below shows that the average number of occurrences of stockouts for all SCIs in a year reduces as the inventory levels of SCIs increase, for constant quantity strategy and baseline simulation. However, the predictive modelling strategy oversupplies SCIs, as discussed in Section 5.1.2, and hence the number of occurrences of stockouts is zero for those.

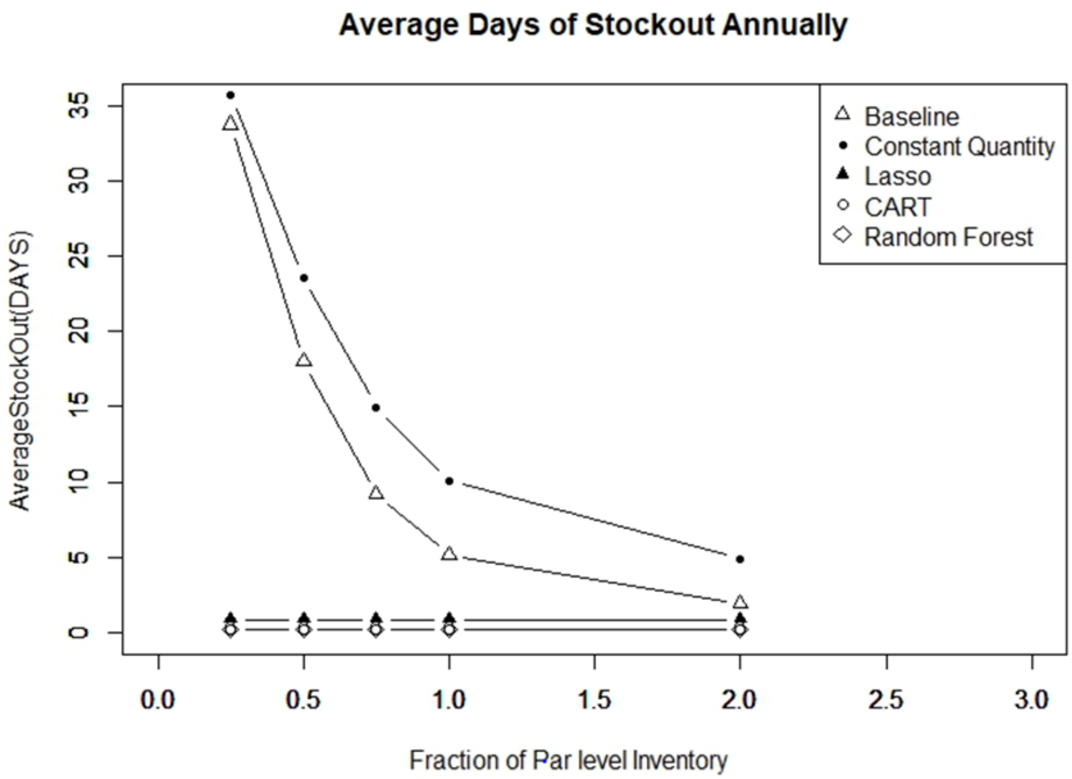

Figure 5-6: Comparison of the average days of stockouts (baseline, constant quantity replenishment and predictive modelling strategies) for varying safety stock levels

5.3 Effect of Product Category

As discussed in Section 3.2, the SCIs have been grouped into three categories based on the frequency of orders placed and the variations in order quantities. The studies on effects of review period and safety stocks at the PSC have indicated that the constant quantity replenishment strategy shows results similar to that of the baseline simulation. The predictive modelling replenishment strategies tend to oversupply items and therefore have excessive cost. To understand the performance of predictive modelling, a study based on the product category was conducted. The total cost of replenishment for review period of two weeks and safety stocks as the currently used par levels were plotted for each of the products in scope and the results have been summarized in Figure 5-7 below.

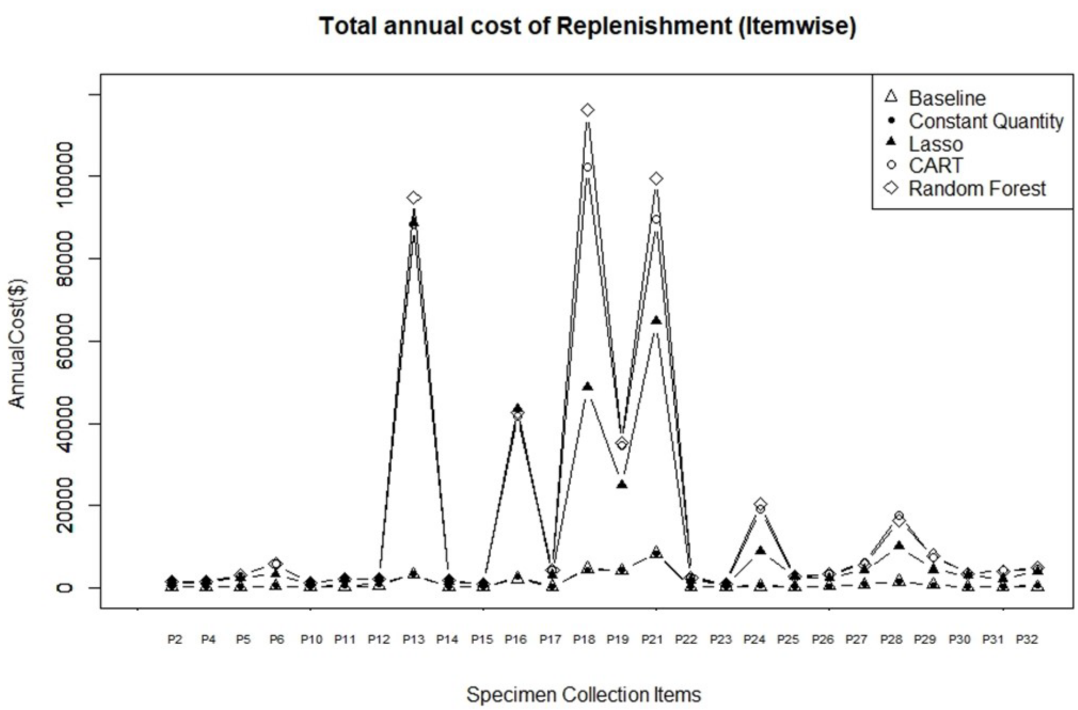

Figure 5-7: Comparison of the total cost of replenishment (baseline, constant quantity replenishment and predictive modelling strategies) for each SCI

It can be observed that the predictive modelling strategies such as Lasso, CART and Random Forest overestimates the replenishment quantities for all the SCIs. However, the predictions are vastly different only for a few SCIs, namely P13, P16, P18, P19, P21, P24 and P28. This can be attributed to the quality of the available data that has been used to develop the predictive models.

5.4 Preliminary Pilot Study Results

This section describes the pilot study conducted on the chosen PSC. After comparing the cost of replenishment and number of occurrences of stockouts for the various replenishment strategies, it was observed that the constant quantity replenishment strategy performs better for some SCIs, whereas predictive modelling replenishment strategy works well for other SCIs. Therefore, a combination of both the strategies were used to generate order quantities for each review period in the chosen PSC.

For each SCI, the first step is to use predictive modelling approach to generate demands. These predicted demands are then rounded down to the nearest stock keeping units, and recorded as the order quantities for each SCIs. The difference between predicted demand and order quantities are recorded as deficits and considered in future review periods. The rounded order quantities are then compared to the average demands for corresponding SCIs in the review period. If there is high difference between order quantity and the average demand for a SCI, the order quantity is changed to the average demand. This step serves as a sanity check for those SCIs that do not have a sufficiently accurate predictive model. The final order quantities generated by this method are compared to the actual order quantities placed by the PSC in every review period.

The actual consumptions of SCIs at the PSC are different from the orders placed for SCIs, as discussed in Section 3.2. The actual consumption at the PSC are recorded using tally sheets as shown in Figure 5-8. This tally sheet records daily consumptions of each SCIs and records the occurrences of stockouts.

Location : QBE Date: 10/1/2018

NEEDLE:

Product	Description	Consumption	Any stockout today?
141998	WINGSET SAFETY-LOK 23G 12IN TUBING W/ LUER 50/PK 4PK/CS	卌 卌 ǀǀ	
141999/ 193263	NEEDLE ECLIPSE 21G 1.25IN 48/PK 10PK/CS 126CS/PLT	卌 ǀǀǀ	X
141994/ 193291	NEEDLE ECLIPSE 22G 1.25IN 48/PK 10PK/CS 126CS/PLT	卌 ǀ	

TUBES:

141847	TUBE VAC PL HEMO 13X75 3ML STR TAN EDTA 100/PK 10PK/CS	卌 卌 ǀǀ	
53711	TUBE VACUTAINER PLN 13X100MM 6ML RED 100/PK 1000/CS	卌 ǀǀǀ	
159861	TUBE VACUTAINER EDTA 16X100MM 10ML LAV 100/PK 1000/CS	卌 卌	

Figure 5-8: Example of tally sheets used to record actual consumption of SCIs at Company X's PSC

The actual consumptions of SCIs were recorded at the PSC and the it has been observed that only few of the SCIs, P2, P10, P18, P19, P22, P26, P28 and P29 were consumed regularly at the PSC. The consumptions are shown in Figure 5-9 below.

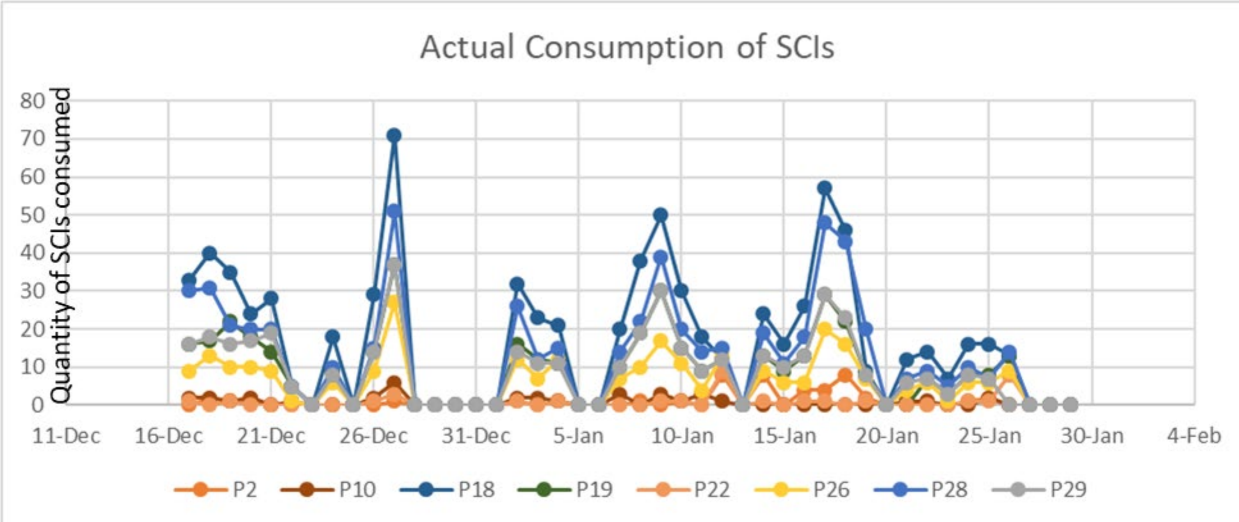

Figure 5-9: Actual consumption of SCIs at Company X's PSC

It can be observed that some of the SCIs are more frequently consumed than others. The consumption of some SCIs, such as P18, P28 and P29 are correlated to each other, and can be attributed to the fact that these SCIs are required for the same specimen draw. The correlation between consumption od SCIs is expected, however not fully explored in the regression model. There is considerable variation in daily consumption of SCIs, and some of it can be attributed to holiday season in December.

5.5 Accuracy of Data and Simulation

As discussed in Section 3.2, there are several factors that affect the quality of the available data and therefore the accuracy of the predictive modelling methods. These include insufficient data points in the historical order data for SCIs, unrecorded orders at the PSC and shrinkage.

In the simulations, the demand distributions for each SCIs were approximated to be normal. However, this approximation may not be accurate based on the number of historical order data points available and can be seen in the examples below. Examples for the demand distribution for three products P16, P17 and P31, that belong to the three categories as discussed in Section 4.2, is given in the Figure 5-10(a), 5-10(b) and 5-10(c) below.

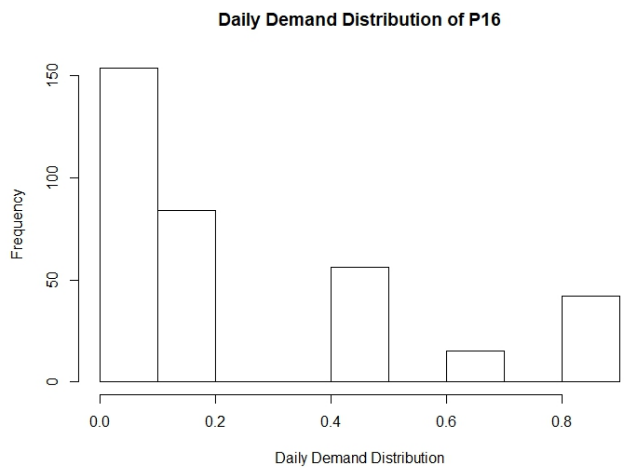

Figure 5-10 (a): Distribution of daily demand of SCI P16

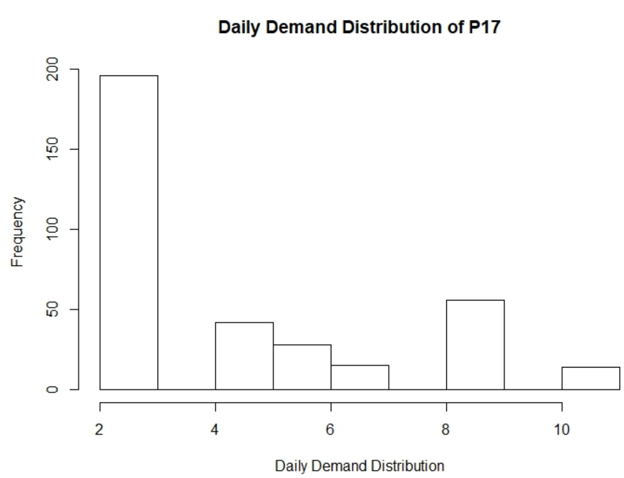

Figure 5-10 (b): Distribution of daily demand of SCI P17

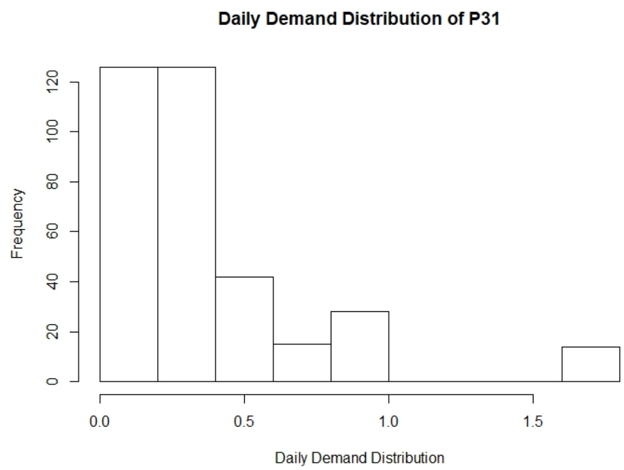

Figure 5-10 (c): Distribution of daily demand of SCI P31

As can be seen from the figures above, the approximation of demand distribution has some inaccuracies and for most cases, can be attributed to insufficient data points. The performance of the predictive modelling replenishment strategies is poorer than constant quantity replenishment strategy and can be associated with the poor quality data. Gathering more data points over time is expected to produce better demand prediction results.

Chapter 6

Conclusion

This chapter discusses the summary of findings, recommendations based on the findings and the areas that Company X can explore for further studies.

Two main replenishment strategies were studied and its effects on total cost of replenishment and occurrences of stockouts were compared to the baseline case through simulation. The two parameters used to evaluate the performance of the replenishment strategies, total cost of replenishment and number of occurrences of stockouts, vary with changing review periods and safety stock levels. The total cost of replenishment for constant quantity replenishment strategy is comparable to baseline simulation for all review periods, whereas the predictive modelling strategies such as Lasso, CART and Random Forest show higher cost of replenishment. The cost of replenishment for predictive modelling replenishment strategies reduces as the review period becomes longer, implying better demand prediction over longer review periods. The number of occurrences of stockouts is lower for predictive modelling strategy, which comes at the expense of replenishing higher quantities of SCIs every review period, and therefore higher replenishment cost.

The two parameters, total cost of replenishment and number of occurrences of stockouts, move in opposite directions. If the quantities of SCIs replenished every review period is higher, the cost of replenishment is also higher and the number of occurrences of stockouts is lower. To find a balance between the two, the effects of safety stock levels on total replenishment cost and occurrences of stockouts were studied. The cost of holding inventory increases with increased levels of initial inventory. However, since Company X has a low holding rate for inventory, the impact on overall cost of replenishment is insignificant. However, there is significant reduction in number of occurrences of stockouts. Therefore, increasing the safety stock levels is recommended.

The effect of replenishment strategies on the total cost of replenishment was studied product wise and it was observed that only some of the SCIs showed vast variation in cost of replenishment from the baseline simulation. The items P13, P16, P18, P19, P21, P24 and P28 need to be studied further. Company X could explore ways to improve the demand data collection in future.