Planning for Peak Demand in Reverse Logistics

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ABSTRACT

The project sponsor is a reverse logistics company that provides Returnable Transport Items (RTIs) to large manufacturing companies, distributors and retailers. Its business model is characterized by a unique closed-loop supply chain. The seasonal peak demand for RTIs from June to September negatively impacts service levels and costs. The sponsor company seeks an opportunity to level load production and build inventory position, while optimizing the service levels and annual supply chain costs. This capstone project proposes an optimal supply chain plan by analyzing historical data, identifying key cost-service drivers and creating a Scenario Planning Tool (SPT) that demonstrates tangible benefits in terms of cost and service level improvements. The data analysis quantifies the correlation between serviceability (days of coverage), inventory position and supply chain component costs (cost to serve). This correlation is used to model a Scenario Planning Tool (SPT) that recommends the optimal supply plan and directs the inventory policy decisions in order to maximize serviceability, while minimizing the total annual supply chain costs. A key takeaway is that the correlation between inventory policies and supply chain costs provides an opportunity to optimally plan inventory coverage in order to minimize supply chain costs while meeting service level targets.

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1. Introduction

Returnable Transport Items (RTIs) are defined as objects used for the purpose of “transportation, storage, handling, and product protection in the supply chain, which are returned for further usage” (ISO, 2016). Examples of RTIs include bins, kegs, pallets, and racks (Carrasco-Gallego, et. al, 2012). They are used across various industries for internal and external movement of raw materials, semi-finished products, and finished goods (Valerio & Maria, 2015). Current estimates place the number of active RTIs in the United States at more than 2 billion units, utilized to transport 80% of the country’s trade (Roy, Carrano, Pazour, & Gupta, 2016). With such a significant number of companies depending on the RTI platform to move their materials, a ready supply of empty RTIs is vital to ensuring users’ operational readiness.

1.1 Background

Our project sponsor is a reverse logistics company that provides RTIs to large manufacturing companies, distributors, and retailers. Its business model is characterized by a unique closed-loop supply chain.

They issue ready-to-use empty RTIs to customers. As seen in the flow of Figure 1, the customers load their products onto these RTIs and ship them through their supply chain. The RTIs are then emptied and offloaded, and returned to the sponsor company, typically to the nearest service center. At the service center, the sponsor company first inspects the condition of all returned RTIs. It then separates the damaged RTIs which need to undergo repair. Damaged RTIs are cleaned, repaired, and certified for use before being shipped out again.
Figure 1. Illustration of sponsor company's closed-loop supply chain

The company operates by maintaining target inventory levels of ready-to-use RTIs to ensure customer demand is met on time. As ready-to-use RTI inventory levels decrease, the company procures additional units or increase the repair rate of damaged RTIs to ensure supply meets customer demand.

The two main sources of RTIs in this closed-loop supply chain are:
1. Collect used containers for repair and reuse (95%)
2. Inject new containers into supply chain (5%)

Closed-loop supply chains are characterized by Jayaraman (1999) as “taking back products from customers and recovering added value by reusing the entire product, and/or some of its modules, components, and parts”. Thierry, et al. (1995) proposed a reverse logistics flows typology where returned products and components can be reused directly, recovered or disposed. In the case of RTIs, the entire product can be reused with only slight repairs taking place when needed. Typically, businesses operating in a closed-loop supply chain depend on maintaining a high utilization rate of their assets to reduce the need to inject new assets (which tend to cost much more relatively). Therefore, managing the corresponding supply chain network is more complicated than that of a unidirectional
supply chain. The main challenge would be in forecasting as visibility of the product is lost until time of return or collection. According to Guide (2003), “closed-loop supply chains include traditional forward supply chain activities and the additional activities of the reverse supply chain”. Also, the lack of visibility makes it much more complicated to foresee the number of used containers that can be repaired and reused.

1.2 Problem Description
The demand and supply of RTIs follows a seasonal pattern. The demand peaks prior to the holiday season, when manufacturers and retailers stock up products to sell during the holiday season. This causes a spike in demand for RTIs during June to September, leading to depleting inventory levels and lower service levels. The manufacturing and production of new RTIs need to be ramped up to inject new RTIs into the system, thus straining capacity and increasing cost. Returning the used RTIs is largely the responsibility of customers and the sponsor company cannot dictate the timing of these returns. Hence, supply is dependent on the RTIs that come back from retailers. This lack of visibility makes demand and supply planning even more complex. Post peak demand season tends to experience an enormous supply of returning RTIs to the service centers of the sponsor company, putting a strain on repair and storage capabilities and increasing ramp up relocation and repair costs.

The sponsor company has seen five consecutive years of year-on-year growth. Consequently, it is consistently getting challenged with inventory position between June and September, negatively impacting service and cost. It is becoming extremely challenging for the business to ramp up production, secure adequate storage and transportation capacities on time, resulting in unexpected service (1% - 2% on-time delivery impact) and cost ($2 million - $5 million) issues.

Figure 2. Demand Seasonality
Figure 3. Replenishment Cycle
The above graphs are representative of the monthly fluctuations and seasonality in the demand cycle, replenishment cycle, inventory position and serviceability. Figure 2 depicts the seasonality in demand over the year. As seen in Figure 2, demand peaks in the pre-holiday seasons, especially from May to September. Post the peak season, we see a dip in the monthly demand for RTIs. This indicates that inventory policies will need to cater for peak demand before the entering the peak period, so as to avoid production ramp up and procurement constraints.

Figure 3 captures the fluctuations in the replenishment cycle. As seen, replenishment cycle follows the seasonality pattern of the demand, however in a lagged fashion. During the peak season, from June to September, demand is replenished by injecting new RTIs into the system and shipping them to customers. After the peak season, all these RTIs shipped to the customers, make their way back to the sponsor company’s distribution centers. This results in a spike in the replenishment quantities, especially during the months of November to February.

Figure 4 captures the number of days of demand that can be satisfied by the existing inventory in the system. As evident from the graph, the inventory days of coverage is lowest during the peak demand season, depicting that more inventory is needed to meet the incoming demand. The opposite is observed during the lull season, when there is excess inventory, especially due to returned RTIs coming in from customers. The effect of seasonality on the weekly On-Time Delivery (service level) can be seen in Figure 5. As evident from the graph, the seasonality has a profound effect on the sponsor company’s service levels, causing large fluctuations on a weekly basis.

Optimizing service levels, cost and inventory becomes significantly challenging due to the huge variation in demand and supply coupled with the lack of product visibility in the closed-loop supply chain. Hence, the sponsor company seeks an opportunity to level load production throughout the year and build inventory ahead of time, while holistically considering annual supply chain costs. A series of factors (timing of demand, supply, production, storage, inventory position and other relevant parameters) need to be
considered and decisions need to be made in the prior eight months to manage the critical four months, from June to September. To address the projected growing demand, it is also imperative to facilitate long-term planning across fiscal years to prepare the supply chain to manage peak demand during critical months.

1.3 Project Scope and Objectives
The scope of this project includes leveraging on the sponsor company’s historical data to develop correlation and prediction models. These prediction models will be incorporated in a scenario-planning tool which will forecast supply chain costs and service levels based on a combination of inventory policies.

This project is aimed at addressing the sponsor company’s business challenges. It aims to:
- Analyze historical key performance indicators and identify statistically significant key drivers that impact service and cost
- Recommend an optimal supply chain plan - in terms of adjusting inventory days of coverage to optimize supply chain costs and service levels
- Quantify impact on cost and service levels through changes in inventory policy
2. Literature Review

This section will review existing literature applicable to developing predictive models capable of identifying the correlation between different factors, parameters and data points within a supply chain. Given abundant historical data, regression analysis appears to be the most effective and applicable for this project. Both linear and non-linear regression models explore correlational effect between days of coverage and the various supply chain costs. These models can also be used to test our initial hypothesis of the correlations between sales and operations data attributes. From the models developed, we would then be able to (a) check up on the validity of our hypothesis and assumptions, (b) test whether a parameter has the value predicted from the theory, under the assumption that the model is true, and (c) estimate the unknown constants, under the assumption of a valid model and (e) use the model for prediction purposes.

2.1 Regression Models

2.1.1 Linear Regression Model

Seber (2003) describes how a major activity in statistics is to identify and model the relationship of two different elements and any correlational behavior. Regression analysis constructs mathematical models to describe or explain relationships that may exist between variables. The simplest case would be a model of two variables. As long as a pair of observations exist, a scatter diagram can be plotted. A straight-line regression would be the most basic method. In our case, we will be using the days of coverage variable as the explanatory (independent) variable and study the various cost factors as response variables. Cost factors include: A-Stock relocation cost, B-Block relocation cost, C-Stock relocation cost, Issue cost and Collection cost.

2.1.2 Non-Linear Model

Cameron (1996) describes another method to model the relationship between the different variables, through a R-squared type goodness-of-fit summary statistic. There are a variety of methods to measure goodness of fit. These methods include logit, probit, Poisson, geometric, gamma and exponential. Given the large variety of methods to understand the response and explanatory variables, it is important to assess results in a formalized and standard manner.

The first and most interpretable measurement would the R-Square Ordinary Least Squares (OLS). This is the residual sum of squares between the generalized model and the actual data points. In the case of nonlinear models, two measures may fall outside the unit interval and decrease as explanatory variables are added.
Another method would be the likelihood ratio test (LRT) statistic. This general measure proposed by Vuong (1989) estimates the expected Kullback-Leibler information gain. The transformation of LRT guarantees to lie within the unit interval and it equals the usual multiple correlation coefficient in regression models under normality.
3. Data and Methodology

Our capstone project develops an approach to quantify and visualize the combination of various components of the supply chain costs for the sponsor company. It also proposes a series of combinations enumerating the optimal cost-serviceability scenarios. We first focus on listing the component costs by evaluating the cost drivers in the interconnected structure of the supply chain network. In the next stage, we deep dive into each component cost and study its correlation with serviceability metrics and other performance indicators. In the third stage, we integrate the component results to build a scenario-planning tool that optimizes the combined cost and proposes scenarios to maximize serviceability while adhering to relevant system constraints.

3.1 Quantification of Supply Chain Cost Drivers

3.1.1 Business context

The sponsor company has a unique closed-loop supply chain. Their business model primarily involves receiving and collecting used RTIs from down-stream supply chain partners, mainly retailers, and selling these used RTIs again to customers. The demand for RTIs is highly seasonal and peaks from June to September, when retailers begin to stock up inventory and hence require more RTIs. Furthermore, supply is dependent on the RTIs that come back from retailers and the company cannot dictate the timing of these returns. These challenges reflect in the supply chain in terms of higher volatilities, seasonal fluctuations and variability across time and location. These conditions drive up supply costs and cost variations as well as severely impact the demand serviceability. It becomes extremely challenging for the business to ramp up production, secure adequate storage and transportation capacities on time, resulting in unexpected service (1% - 2% on-time delivery impact) and cost ($2 million - $5 million) issues.

3.1.2 Key Definitions

The sponsor company segments its inventory stock into three key components: A stock, B stock and C stock. The P stock is defined as the total stock in any plant or distribution center. Table 1 below illustrates the key definitions related to the inventory stock segments and their nomenclature. Figure 6 shows the different categories of stock and how A stock is converted to B stock or C stock after inspection. Upon inspection, if no repair is needed for an A-stock RTI, it will directly be converted into C stock. If an A-stock RTI requires repair, it will then be categorized as B-stock. Once a RTI is categorized as B stock, these RTIs undergo repair and are converted to C-stock. C-stock RTIs are ready to be sold.

Table 1: Key definitions of inventory stock segments
Table 1. Key definitions of inventory stock segments

<table>
<thead>
<tr>
<th>Glossary</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Stock</td>
<td>All incoming RTIs from customers, other distribution centers. These RTIs are then sent for inspection to select the RTIs that are ready to use, need to be repaired or need to be discarded.</td>
</tr>
<tr>
<td>B Stock</td>
<td>RTIs that have been selected to be repaired, are referred to as B stock. B-stock RTIs are post inspection of A stock.</td>
</tr>
<tr>
<td>C Stock</td>
<td>C Stock comprises of ready-to-use RTIs, which can be shipped directly to customers. The C stock can be comprised of new and incoming ready-to-use RTIs, repaired B stock or inspected (selected) A stock.</td>
</tr>
<tr>
<td>P Stock</td>
<td>The total stock of all RTIs throughout all plant/distribution center at any point in time is referred to as the P stock.</td>
</tr>
</tbody>
</table>

Figure 6. Illustration of A, B, C stock and their relationship

3.1.3 Evaluation of supply chain cost components

The sponsor company’s supply chain is primarily governed by the following costs:

- a) New RTI costs: The total landed cost of manufacturing each RTI
- b) Holding costs: The cost of holding inventory, subject to total stock holding
- c) Repair costs: Cost for repairing B stock.
- d) Relocation or Transaction costs: Costs for transporting RTIs between plants and distribution centers
  - Issue costs: Costs involved in transporting conditioned RTI to customers
  - Return costs: Costs involved in transporting A stock RTI from customers to distribution centers. This cost is borne by customers who are external to the sponsoring reverse logistics company.
- Collection costs: Costs involved in transporting A stock RTI from customers to distribution centers. This cost is borne by the sponsoring reverse logistics company.
- A-Stock relocation costs: Cost of transporting A stock RTI between distribution centers
- B-Stock relocation costs: Cost of transporting B stock RTI between distribution centers
- C-Stock relocation costs: Cost of transporting C stock RTI between distribution centers

Figure 7 below depicts the inventory inflows and outflows in a typical distribution center. Each flow is associated with the relevant cost described above.

3.1.4 Observations about cost drivers

The cost drivers were quantified and analyzed by segmenting the data according to category (components), year-on-year and monthly ranges.

  a) Transaction-wise Cost Drivers

Each component of transaction costs was evaluated for its representation in total transportation costs. Transaction cost drivers are reported in weekly intervals and are aggregated from monthly and yearly analysis.

  b) Year-on-year Cost Increase

The total costs of each component were evaluated on a year-on-year basis to evaluate fluctuations in volume and contribution every year. This was done to detect whether one category cost was increasing more than the rest. The quantitative observations were concurred through subjective evaluation and business logic.
c) Monthly Seasonality

The effect of seasonality was evaluated for each cost component. The consistent monthly peaks and troughs of demand translated to similar seasonality in supply chain costs. Month-wise analysis proved to provide best regression results for supply chain cost components with consistent seasonality across the years.

As there were 7 years of weekly historical data from 2010 to 2017, month-wise segmentation for regression gave better results over annual segmentation or weekly segmentation. Annual segmentation did not provide enough granularity for insights to account for monthly seasonality. Weekly segmentation was too granular and resulted in too few data points for regression due to over segmentation (only 7 data points for every week in a year).

### 3.2 Evaluation of Cost-Serviceability Correlation

#### 3.2.1 Understanding Serviceability Key Performance Indicators

In order to consolidate the output parameters of the proposed model, it was imperative to identify serviceability criteria which best measured and quantified supply chain performance.

The sponsor company evaluates its serviceability using the metrics and Key Performance Indicators (KPIs) as illustrated in Table 2. These metrics would be the baseline for analyzing correlation with costs and for sensitivity analysis of input cost drivers.

<table>
<thead>
<tr>
<th>Key Performance Indicators</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C Stock Days of Coverage</strong></td>
<td>Number of days of forecasted demand that can be fulfilled with the existing ready-to-use RTI inventory (C stock).</td>
</tr>
<tr>
<td><strong>B Stock Days of Coverage</strong></td>
<td>Number of days of forecasted demand that can be fulfilled with the existing to-be-repaired RTI inventory (B stock).</td>
</tr>
<tr>
<td><strong>OTP (On Time Performance)</strong></td>
<td>The ratio of acceptable RTI stock to total RTI stock. It is the measure of on-time service levels for the sponsor company.</td>
</tr>
<tr>
<td></td>
<td>1. Issue OTP- The ratio of RTIs delivered to customers on time, to the total number of RTIs shipped to customers.</td>
</tr>
<tr>
<td></td>
<td>2. Collection OTP- The ratio of RTIs collected from customers on time, to the total number of RTIs collected from customers.</td>
</tr>
</tbody>
</table>

#### 3.2.2 Analysis of S&OP (Sales and Operations Planning) data

The sponsor company’s S&OP (Sales and Operations Planning) data was analyzed to understand historical trends and patterns in the demand, supply and inventory data points.
S&OP data such as number of BDays (business days) was crucial in ensuring that weekly cost aggregations were normalized across number of business days.

3.2.3 Evaluation of correlations through regression

The S&OP data points were concurred with the cost components to evaluate the correlation between cost and serviceability metrics. Key observations were flagged and the correlation framework was developed. One key observation was that the C Relocation cost per BDay (business day) has a statistically significant correlation with the Days of Coverage (DoC), as illustrated in Figure 8.

Figure 8. C Relocation cost per unit vs. Days of Coverage (per BDay).

Exponential trendline has correlation has p-value of <0.0001 and R-square of 0.214969. This means that there is a statistically acceptable correlation between the C-stock days of coverage and the C-stock relocation costs.

It is observed that there is an inverse relation between the ready-to-use RTI inventory and the costs associated with moving ready-to-use RTIs between distribution centers. This implies that as the ready-to-use RTI inventory across distribution centers increases, the relocation of RTIs between distribution centers reduces, and vice versa. This is because more distribution centers have enough ready-to-use RTIs to satisfy demand from the nearest location. As a result, there is a lower need to relocate inventory from other distribution centers, reducing the amount of relocations needed. Hence, by maintaining a healthy level of ready-to-use RTI inventory at each distribution center, the internal relocation and transportation requirements can be minimized, thus reducing the associated relocation costs.
3.3 Modeling of Optimal Cost-Serviceability Scenarios

3.3.1 Key Definitions
The sponsor company calculates key ratios for inventory monitoring and reporting. These ratios, along with their definitions, are illustrated in Table 3. These definitions are relevant to the inventory levels for the different categories of RTIs and affect the available stock.

| **Table 3. Key definitions of ratios that govern inventory calculations and reporting** |
| --- | --- |
| **B-stock Days of Repair** | Number of days before deplete existing B Stock without needing to generate additional B Stock, given current rate of repair |
| **Control Ratio** | Inventory returned/collected vs. inventory issued to customers |
| **Damage Ratio** | % of incoming RTIs that need repair |
| **Conditioning Ratio** | % of actual repairs out of all reparable stock |

3.3.2 Understanding Constraints
The underlying constraints in cost, space and time affects the various components of manufacturing, storage, purchase, transportation and repairs. These constraints include:

1. Facility holding space
2. Labor ramp up limit
3. New RTIs procurement lead time
4. Minimum safety stock

These constraints were not included in the scenario planning tool as they did not help determine optimality in the final solution. However, it is important to note that these constraints may become binding when trying to reach optimality.

3.3.3 Scenario Planning Tool (SPT) - Development and Testing
The regression analysis between cost and serviceability metrics was used to calculate correlation parameters for the scenario planning tool (SPT). The regression models were used to predict supply chain costs (issue, collection, relocation and inventory) and service levels (OTP for issue and collection). The SPT was designed to allow business users adjust inputs (days of coverage, number of business days, holding costs) in order evaluate changes in the output.
The SPT was tested for multiple scenarios to create a robust model, which would optimize the combined cost and propose scenarios to maximize serviceability while adhering to relevant system constraints and variability.

Historical S&OP data was also loaded into the SPT to allow users to compare future scenarios to a baseline scenario. The functionality of comparing future scenarios to the baseline also acts as a way to quickly check the feasibility of the future scenario itself.
4. Analysis and Results

Loading the historical data from 2010 to 2017 into Tableau allowed for the analysis of the correlation between cost, performance and the days of coverage. Tableau was used to segment and filter the input variables to observe patterns and trends. The trendline tool function in Tableau was used to understand the statistical significance of the information by measuring the R-square of the trendline and p-value for the coefficients of the trendline.

4.1 Anomaly Reduction

Excluding anomalies would help the proposed model reduce bias and generate statistically significant output. The higher R-square and lower p-value achieved by excluding outliers enhanced the accuracy of the final prediction model. The following steps were followed to ensure that the used data was robust:

1. Data cleansing
2. Outlining understanding and assumptions
3. Identifying outliers and their distorting effect
4. Elimination of irrelevant parameters
5. Matching data trends to subjective insights

In some cases, 2012 data was excluded due to a major shift in customer portfolio, which affected business decisions specific to only that year. In addition, null data points which the sponsor company could not provide were excluded. For example, inventory information before 2016 was unavailable and hence excluded for data analysis.

4.2 Selection of Explanatory Variable

The C-Stock Days of Coverage (DoC) variable was selected as the independent, explanatory variable as it represents the desired serviceability level, which can be used as a basis of comparison with the component costs.

Furthermore, C-Stock DoC accounts for fluctuations in both demand and inventory levels simultaneously and would be the most feasible input for the scenario planning tool.

4.2.1 Selection of Dependent Variables

The dependent variables were selected to include both cost and service parameters. The correlation of these dependent variables was analyzed with the explanatory variable, C-Stock Days of Coverage (DoC).
While we used weekly data across the years 2010-2017 for the analysis, the most relevant correlations were observed with aggregated monthly distributions. Annual distributions were used for cases where there was a paucity of data points or when there was no observed correlation with the monthly distribution.

BDays are defined as the number of business (working) days in every week or month. As the number of BDays per week was not constant, it was imperative to eliminate the effect of BDays to adjust for costs which were being aggregated on a weekly or monthly level. Hence, most costs were correlated on per BDay basis instead of using the aggregation over all days in a month.

4.2.2 Selection of Regression Type

Two regression types were used (linear and exponential) as the general trend of data followed a similar pattern. Logarithmic, power and polynomial regression types were not considered as initial analysis indicated very low R-squares and statistical insignificance due to poor fit of data.

The two methods were used to analyze the correlation and response of the explanatory variable with respect to the dependent variables. Both regression types were used to analyze the correlation of each dependent variable to the explanatory variable. Subsequently, the predictive model was built by selecting the regression type with the best fit for each variable. The main parameters for selection of the regression type for each variable was based on R-squared type goodness-of-fit summary statistics and the statistical significance (p-value) of the coefficients of regression.

The following table of dependent variables indicate the regression type and time period selected for each correlation.

<table>
<thead>
<tr>
<th>Dependent Variable vs. DoC</th>
<th>Type of Regression</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Stock Relocation Cost (per BDay)</td>
<td>Linear Regression</td>
<td>Annual</td>
</tr>
<tr>
<td>B-Stock Relocation Cost (per BDay)</td>
<td>Exponential Regression</td>
<td>Month wise</td>
</tr>
<tr>
<td>C-Stock Relocation Cost (per BDay)</td>
<td>Exponential Regression</td>
<td>Month wise</td>
</tr>
<tr>
<td>Issue OTP</td>
<td>Linear Regression</td>
<td>Month wise</td>
</tr>
<tr>
<td>Collection OTP</td>
<td>Linear Regression</td>
<td>Month wise</td>
</tr>
<tr>
<td>Inventory Cost</td>
<td>Exponential Regression</td>
<td>Annual</td>
</tr>
<tr>
<td>Issue Cost (per BDay)</td>
<td>Exponential Regression</td>
<td>Month wise</td>
</tr>
<tr>
<td>Collection Cost (per Bday)</td>
<td>Exponential Regression</td>
<td>Month wise</td>
</tr>
</tbody>
</table>
4.3 Correlations with the Explanatory Variable

Linear and exponential regression was tested for all datasets and the regression type which returned the higher R-square was selected for the prediction model in the SPT.

4.3.1 Relocation Costs

Relocation costs are incurred when RTIs are transported between in-house facilities (warehouses or service centers). The objective of running regression against C-stock days of coverage was to understand the cost impact of different scenarios of inventory. Hence, relocation cost and load were both considered and tested for correlation with days of coverage.

Firstly, we assessed the A, B and C relocation cost categories to analyze the proportion of contribution of each category to the total supply chain cost. Secondly, we assessed the variance of each category over time. This would put into perspective the relative importance of each cost category and whether a simple time series analysis could be performed on a cost category with low variance.

The findings are as follows (as illustrated in Figure 9 and Figure 10):

1. B relocation costs make up 80% of the total relocation costs. This indicates that B relocation costs would have the largest impact on the overall supply chain cost and additional emphasis should be given to ensure accuracy of the prediction model. Variance of B relocation cost is also very high over time, hence, using a regression with days of coverage would be more feasible over a time series analysis.

2. C relocation costs make up 14% of the total relocation costs. This indicates that C relocation costs should be give the next highest priority after B relocation costs. Variance of C relocation cost is also relatively high over time, hence, using a regression with days of coverage would be more feasible over a time series analysis.

3. A-stock relocation costs is the smallest category of relocation cost. The low variance and stable trend of A-stock relocation cost over the past 7 years indicate that a time series analysis would be feasible. Given the small contribution of A-stock relocation costs to the overall supply chain cost, it would be more efficient to perform a simple time series regression.
Figure 9. Relocation Cost Proportion
4.3.1.1 Relocation Costs vs. Time

As A-stock relocation costs did not show any correlation with days of coverage, the next step was to plot the A-stock relocation costs over time and run a linear regression.

The findings are as follows:

1. A-stock Relocation Cost vs. time, as seen in Figure 11:
   - Linear trend vs. time (years) provides high R-square of 0.4438
   - Regression with P-value of 0.0714

The high R-square between A-stock relocation and time shows a strong goodness-of-fit with the trendline. With every year, the A-stock relocation stock increases. This is explained mainly by the nature of growing demand. As the volume of transactions grow over the years, the A-stock relocation costs would naturally increase as well.
4.3.1.2 Relocation Load vs. Days of Coverage

The correlation between relocation load quantities and days of coverage (DoC) were tested to understand if cost variation was due to transportation cost fluctuations or due relocation volumes.

The findings are as follows:
1. B-stock Relocation Load vs. DoC, as seen in Figure 12:
   - R-square increases significantly when 2012 data is excluded. This may be largely due to a major shift in the customer portfolio in 2012 which resulted in an anomaly year.
   - Linear trend provides a higher R-square value as the data of B relocation load follows a more linear trend vs. DoC
   - R-square: 0.189235
   - P-value: <0.0001

This result means that there is a statistically significant correlation between B-stock relocation quantity and days of coverage.

It is observed that there is an inverse relation between B-stock RTI inventory and the days of coverage. This implies that as the C-stock days of coverage across distribution centers increases, the quantity of B-stock RTIs between distribution centers reduces, and vice versa. This is because of the increased likelihood that each distribution center has enough ready-
to-use RTIs to meet its forecasted demand, and does not need to relocate RTIs from other
distribution centers which could be further away from the demand. Hence, by maintaining
a healthy level of ready-to-use RTI inventory at each distribution center, the need for internal relocation and transportation can be minimized, thus reducing the associated relocation costs.

2. C-stock Relocation vs. DoC – Load, as seen in Figure 13:
   - Including only past 5 years of data (calendar year 2013-2017) provides strongest correlation
   - R-square = 0.26122
   - P-value: <0.0001

This result means that there is a statistically significant correlation between C-stock relocation quantity and days of coverage.
It is observed that there is an inverse relation between the ready-to-use C-stock RTI inventory and the days of coverage. This implies that as the C-stock days of coverage across distribution centers increases, the quantity of C-stock RTIs between distribution centers reduces, and vice versa. This is because of the increased likelihood that each distribution center has enough ready-to-use RTIs to meet its forecasted demand, and does not need to relocate RTIs from other distribution centers which could be further away from the demand. Hence, by maintaining a healthy level of ready-to-use RTI inventory at each distribution center, the need for internal relocation and transportation can be minimized, thus reducing the associated relocation costs.

4.3.1.3 Relocation Costs per Business Day vs. Days of Coverage

BDays are defined as the number of business (working) days in every week or month. The number of BDays could vary from 14 to 27 days every month. Aggregately, higher number of working days would contribute to higher monthly costs and vice versa. However, we wanted to analyze the underlying pattern of correlation of per unit relocation costs and DoC. Hence, after assessing the monthly distribution patterns with respect to loads and quantities, it was imperative to eliminate the effect of BDays and analyze the relationship between relocation cost per working day (BDay) and serviceability (DoC).

The findings are as follows:
1. B-stock Relocation vs. DoC – Cost per BDay, as seen in Figure 14:
- R-square increases slightly when 2012 data is excluded, explained by a major change in customer portfolio
- Exponential regression provides slightly higher R-square than a linear trend

This result is like the relationship with B-stock relocation cost vs. days of coverage on an aggregated weekly level, except in this case, the stock has been normalized for each business day. This accounts for the different number of business days within different weeks throughout the year.

Figure 14. B Relocation vs DoC – Cost per BDay

2. B Relocation vs. DoC – Cost per BDay: (Month wise Analysis), as seen in Figure 15
• Monthly wise analysis also excludes 2012 data to ensure consistency between monthly wise and general regression models
• 3 out of 12 months will have to rely on the general trend as they return insignificant or invalid regression results.

This result shows the relationship with B-stock relocation cost vs. days of coverage on an aggregated weekly level, except in this case, the stock has been normalized to each business day for each monthly separately. This accounts for the different number of business days within different weeks throughout the year.

<table>
<thead>
<tr>
<th>Monthly Correlation vs. DoC</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>B Relo Cost (per Bday)</td>
<td>R-Square</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-Value</td>
<td>0.4934</td>
<td>0.0012142</td>
<td>0.228223</td>
<td>0.64135</td>
<td>0.443332</td>
<td>0.124069</td>
</tr>
</tbody>
</table>

Figure 15. B Relocation vs. DoC – Cost per BDay: Month wise Analysis
<table>
<thead>
<tr>
<th>R-Square</th>
<th>0.0021343</th>
<th>0.506267</th>
<th>0.628161</th>
<th>0.396671</th>
<th>0.241265</th>
<th>0.282015</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-Value</td>
<td>0.792143</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.000431</td>
<td>0.0147928</td>
<td>0.0025325</td>
</tr>
</tbody>
</table>

- Darkened cells denote months which fall outside the statistically threshold set for prediction model.
- NA means correlation found is opposite of expected relationship (e.g. upward trend found when a downward trend is the usually observed and expected).
- R-Square denotes goodness of fit. Greater value denotes better results. R-Square > 0.2 is deemed an acceptable threshold for this model.
- P-Value analyses statistical significance of regression coefficients. P-Value < 0.05 is an acceptable threshold.

3. C Relocation vs. DoC – Cost per BDay, as seen in Figure 16:
- Including only past 5 years of data (calendar year 2013-2017) provides higher R-square than including full data (2010-2012), possibly due to changes in the collection process from 2010-2011 and major shift in customer portfolio in 2012.
- Exponential regression provides slightly higher R-square than a linear trend.
- R-square = 0.214969
- P-value: <0.0001

This result shows the relationship with C-stock relocation cost vs. days of coverage on an aggregated weekly level, except in this case, the stock has been normalized for each business day. This accounts for the different number of business days within different weeks throughout the year.
4. C Relocation vs. DoC – Cost per BDay: (Month wise Analysis), as seen in Figure 17

- All years of data included (2010-2017)
- Exponential regression provides slightly higher R-square than a linear trend
- Six out of 12 months will have to rely on the general trend as they return insignificant or invalid regression results.

This result shows the relationship with C-stock relocation cost vs. days of coverage on an aggregated weekly level, except in this case, the stock has been normalized for each business day for each monthly separately. This accounts for the different number of business days within different weeks throughout the year.
### Monthly Correlation vs. DoC

<table>
<thead>
<tr>
<th>C Relo Cost (per Bday)</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-Square</td>
<td>0.0010051</td>
<td>0.310347</td>
<td>0.329175</td>
<td>0.227816</td>
<td>0.0149788</td>
<td>0.188545</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.894444</td>
<td>0.0107221</td>
<td>0.0027118</td>
<td>0.0333262</td>
<td>0.607229</td>
<td>0.0557496</td>
</tr>
<tr>
<td>R-Square</td>
<td>NA</td>
<td>NA</td>
<td>0.471784</td>
<td>0.6587</td>
<td>5.70E-05</td>
<td>0.0237263</td>
</tr>
<tr>
<td>P-Value</td>
<td>NA</td>
<td>NA</td>
<td>0.0002332</td>
<td>&lt;0.0001</td>
<td>0.977855</td>
<td>0.516733</td>
</tr>
</tbody>
</table>

- Darkened cells denote months which fall outside the statistically threshold set for prediction model
- NA means correlation found is opposite of expected relationship (e.g. upward trend found when a downward trend is the usually observed and expected)
- R-Square denotes goodness of fit. Greater value denotes better results. R-Square>0.2 is deemed an acceptable threshold for this model
- P-Value analyses statistical significance of regression coefficients. P-Value <0.05 is an acceptable threshold.

### 4.3.2 Issue and Collection Costs

In addition to relocation costs, the issue and collection costs also contribute to total supply chain costs. As seen in Figure 18, issue cost accounts for 53% of total supply chain cost and collection costs account for 19% of total supply chain cost. With issue and collection
costs forming such a significant portion of total supply chain cost, there is heavy emphasis to analyze these two cost factors closely in order to enhance accuracy of the prediction model.

Figure 18. Breakdown of supply chain costs including issue and collection costs

4.3.2.1 Issue Cost per Business Day vs. Days of Coverage

Issue costs are defined as the costs involved in transporting ready-to-use RTI to customers. As issue costs account for 53% of total transportation costs (largest cost component), predictions on issue cost would affect the final prediction model result most significantly. Hence, it is imperative to investigate its correlation with the explanatory variable much more closely than other cost components.

The findings are as follows:
1. Issue Cost vs. DoC – Cost per BDay, as seen in Figure 19
   - All years of data included (2010-2017)
Exponential regression provides a slightly higher R-square value than a linear trend
- R-square: 0.307492
- P-Value: <0.0001

Figure 19. Issue vs DoC – Cost per BDay

2. Issue Cost vs DoC – Cost per BDay (Month wise Analysis), as seen in Figure 20
- All years of data included (2010-2017)
- Exponential regression provides slightly higher R-square than a linear trend

This result shows that there is a statistically acceptable correlation between the C-stock days of coverage and the Issue costs per BDay.

It is observed that there is an inverse relation between the ready-to-use C-stock RTI inventory and the costs associated with issuing ready-to-use RTIs to customers. This implies that as the ready-to-use RTI inventory across distribution centers increases, the cost of issues of RTIs to customers decreases, and vice versa.

This correlation is true for months before the peak season. During the off-peak season, inventory in other areas of the supply chain network is used to satisfy demand from a further distance if there is a shortage of inventory at the nearest distribution facility. This possibility gives rise to higher issue cost when C-stock days of coverage is low, as demand being satisfied from a sub-optimal location.
However, this correlation changes during the peak season, from April to July, where there is no statistical observation of a valid correlation. This is because new RTIs are constantly injected into the system during the peak season to meet increasing demand. The usual business processes are not followed and additional action taken to meet demand reduces the statistical significance and consistency of correlations for historical data.

![Figure 20. Issue vs. DoC – Cost per BDay: Month wise Analysis](image)

### Monthly Correlation vs. DoC

<table>
<thead>
<tr>
<th>Month</th>
<th>Issue Cost (per BDay)</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R-Square</td>
<td>0.325605</td>
<td>0.252431</td>
<td>0.148276</td>
<td>0.0142233</td>
<td>0.0337089</td>
<td>0.113657</td>
</tr>
<tr>
<td></td>
<td>P-Value</td>
<td>0.0015203</td>
<td>0.0064373</td>
<td>0.0223581</td>
<td>0.545535</td>
<td>0.34968</td>
<td>0.0796674</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Month</th>
<th>Issue Cost (per BDay)</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R-Square</td>
<td>0.0544886</td>
<td>0.55514</td>
<td>0.519796</td>
<td>0.556648</td>
<td>0.505474</td>
<td>0.3625</td>
</tr>
<tr>
<td></td>
<td>P-Value</td>
<td>0.177159</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.0002098</td>
</tr>
</tbody>
</table>

- Darkened cells denote months which fall outside the statistically threshold set for prediction model
- NA means correlation found is opposite of expected relationship (e.g. upward trend found when a downward trend is the usually observed and expected)
- R-Square denotes goodness of fit. Greater value denotes better results. R-Square > 0.2 is deemed an acceptable threshold for this model
- P-Value analyses statistical significance of regression coefficients. P-Value < 0.05 is an acceptable threshold.
4.3.2.2 Collection Cost Cost per Business Day vs. Days of Coverage

Collection costs are defined as the costs involved in collecting A stock RTI from customers to distribution centers. This cost is only incurred when customers do not return the RTIs themselves.

The findings are as follows:
1. Collection Cost vs. DoC – Cost per BDay, as seen in Figure 21
   - Including only past 5 years of data (calendar year 2013-2017) provides higher R-square than including full data (2010-2012), possibly due to changes in the collection process from 2010-2011 and major shift in customer portfolio in 2012
   - Exponential regression provides slightly higher R-square than a linear trend
   - R-square: 0.31979
   - P-Value: <0.0001

This result shows that there is a statistically acceptable correlation between the C-stock days of coverage and the Collection costs per BDay.

It is observed that there is an inverse relation between the ready-to-use C-stock RTI inventory and the costs associated with collecting used RTIs from customers. This implies that as the ready-to-use RTI inventory across distribution centers increases, the cost of RTIs from customers decreases, and vice versa. This could be explained by the reduced need to collect RTIs in a closed-loop supply chain to satisfy demand if there is sufficient inventory. Hence, existing inventory in storage facilities is used to satisfying any unexpected demand. In cases when inventory is low, additional investments are made to ensure RTIs came back into the distribution centers fast, causing collection costs to increase as days of coverage increase.
2. Collection Cost vs. DoC – Cost per BDay (Month wise Analysis), as seen in Figure 22
   • Month wise analysis of general trend provided much higher accuracy as 10 out of 12 months had R-square values above acceptable threshold of 0.2
36

Figure 22. Collection vs. DoC – Cost per BDay: Month-wise Analysis

<table>
<thead>
<tr>
<th>Monthly Correlation vs. DoC</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection Cost (per BDay)</td>
<td>R-Square</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.445121</td>
<td>0.378192</td>
<td>0.250449</td>
<td>0.171627</td>
<td>0.202604</td>
<td>0.254418</td>
</tr>
<tr>
<td></td>
<td>P-Value</td>
<td>0.0001054</td>
<td>0.0004969</td>
<td>0.0022012</td>
<td>0.0283964</td>
<td>0.0162414</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.202604</td>
<td>0.0162414</td>
<td>0.0061989</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Darkened cells denote months which fall outside the statistically threshold set for prediction model
- NA means correlation found is opposite of expected relationship (e.g. upward trend found when a downward trend is the usually observed and expected)
- R-Square denotes goodness of fit. Greater value denotes better results. R-Square>0.2 is deemed an acceptable threshold for this model
- P-Value analyses statistical significance of regression coefficients. P-Value <0.05 is an acceptable threshold.

4.3.3 On-Time Performance (OTP)

On Time Performance (OTP) is defined as the ratio of acceptable RTI stock to total RTI stock. Acceptable RTI stock refers to the stock which were excepted by clients on time. It is the measure of on-time service levels for the sponsor company. Issue OTP is defined as the ratio of RTIs delivered to customers on time, to the total number of RTIs shipped to
customers. Collection OTP is defined as the ratio of RTIs collected from customers on time, to the total number of RTIs collected from customers.

The correlation of OTP and DoC of Issue and Collection stocks would assist investigation of the predictive power of OTP over the explanatory variable DoC.

Regression was done for the following two types of OTP: Issue and Collection.

### 4.3.3.1 On-Time Performance vs. Days of Coverage

The findings are as follows:

1. **Issue OTP vs. DoC**, as seen in Figure 23
   - R-square increases slightly when 2012 data is excluded, explained by a major change in customer portfolio
   - Linear trendline proved to be a better fit than exponential trendline as it returned a higher R-square
   - R-square: 0.1342449
   - P-value: <0.0001

   ![Figure 23. OTP vs. DoC – Issue](image)

2. **Issue OTP vs. DoC (Month wise distribution)**, as seen in Figure 24
   - Month wise analysis of general trend provided much higher accuracy as 8 out of 12 months had R-square values much higher than acceptable threshold of 0.2, ranging from 0.25 to 0.68.
Figure 24. OTP vs. DoC – Issue: Month wise Analysis

This means that there is a statistically acceptable correlation between the C Stock Days of Coverage and the Issue OTP.

It is observed that there is a direct relation between the ready-to-use RTI inventory and the on-time service levels associated with issuing ready-to-use RTIs to customers. This implies that when the inventory levels of ready-to-use RTIs is high, the sponsor company is able to service more customer orders on time, and vice versa. This correlation is especially
true for the peak season months. This correlation is intuitive because a higher ready-to-use inventory position typically allows for timelier servicing of customer demand from a nearer location.

This correlation does not hold significance when the demand is low, especially during the months of November to February. This is because the demand for RTIs is low during these months, and can be met on time by a low amount of inventory. Hence, building further inventory during these months will have no significant effect on service levels.
3. Collection OTP vs. DoC, as seen in Figure 25

- Including only past 5 years of data (calendar year 2013-2017) provides strongest correlation, possibly due to changes in the collection process from 2010-2011 and major shift in customer portfolio in 2012
- Linear trendline proved to be a better fit than exponential trendline as it returned a higher R-square (Linear R-square: 0.0705034, Exponential R-square: 0.0604527)
- R-square for general trend is low, hence, predictability of collection OTP will be low. However, low P-value indicates a statistically significant correlation even the trendline can represent a small portion of the data
- A low R-square for collection OTP may be more acceptable as the collection OTP reflects only the reverse logistics segment of the supply chain. Issue OTP has a relatively higher importance as it directly reflects the service level in terms of fulfilling customer orders.
- R-square: 0.0705034
- P-value: <0.0001

There is no statistically acceptable correlation between the C-stock days of coverage and the Collection OTP. This means that there is low correlation between the ready-to-use RTI inventory and the on-time service levels associated with collecting ready-to-use RTIs from customers. This implies that inventory levels of ready-to-use RTIs have a negligible effect on the sponsor company’s ability to collect RTIs from its customers on time.

Figure 25. OTP vs. DoC – Collection
4. Collection OTP vs. DoC (Month wise distribution), as seen in Figure 26
   • Month wise analysis of general trend did not improve accuracy as 9 out of 12 months had R-square values which did not meet the acceptable threshold of 0.2
   • Hence, the prediction model will largely have to use the general trend regression results as the general trend regression is statistically significant.

This result shows the relationship with collection cost vs. days of coverage on an aggregated annual level. Except in this case, the stock has been analyzed month wise to account for consistent seasonality in demand across the year.

![Figure 26. OTP vs. DoC – Collection: Month wise Analysis](image)

<table>
<thead>
<tr>
<th>Monthly Correlation vs. DoC</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-Square</td>
<td>0.0910281</td>
<td>0.109217</td>
<td>0.320696</td>
<td>0.398444</td>
<td>0.178892</td>
<td>0.325685</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.196087</td>
<td>0.154694</td>
<td>0.0031668</td>
<td>0.0028385</td>
<td>0.0631648</td>
<td>0.0085942</td>
</tr>
</tbody>
</table>

- Darkened cells denote months which fall outside the statistically threshold set for prediction model
- NA means correlation found is opposite of expected relationship (e.g. upward trend found when a downward trend is the usually observed and expected)
– R-Square denotes goodness of fit. Greater value denotes better results. R-Square > 0.2 is deemed an acceptable threshold for this model
– P-Value analyses statistical significance of regression coefficients. P-Value < 0.05 is an acceptable threshold.

This means that there is a statistically acceptable correlation between the C Stock Days of Coverage and the Collection OTP.

It is observed that there is a direct relation between the ready-to-use RTI inventory and the on-time service levels associated with issuing ready-to-use RTIs to customers. This implies that as the inventory levels of ready-to-use RTIs increases, the sponsor company is able to service more customer collections on time, and vice versa. This correlation is especially true for the peak season months. This correlation is intuitive because a higher ready-to-use inventory position typically allows for servicing customer demand on time from a nearer location.

4.3.4 Inventory Costs
The correlation between the total inventory stock and the explanatory variable days of coverage (DoC) was studied to understand the underlying trend and effect of both inventory costs and related quantities on DoC. This would account for inventory costs when determining the optimal holding inventory across all months of the year.

4.3.4.1 Inventory Costs vs. Days of Coverage
The findings are as follows:
1. Inventory vs. DoC - Cost, as seen in Figure 27
   • Only 2016-2017 data was provided, hence, prediction model will not be as robust if more years of data was provided.
   • R-square: 0.200214
   • P-value: 0.0009943

This means that there is a statistically acceptable correlation between the C-stock days of coverage and the total inventory costs.

It is observed that there is an inverse relation between the ready-to-use RTI availability and the inventory holding and storage costs. This implies that as the availability of ready-to-use RTI inventory across distribution centers increases, the total inventory holding costs reduces, and vice versa. This is true on an annual aggregated basis, and when the inventory position is within the acceptable target range. Hence, by maintaining a healthy level of
ready-to-use RTI inventory at each distribution center, the aggregated inventory storage and holding costs can be minimized.

2. Inventory Quantity vs. DoC, as seen in Figure 28
   - Exponential regression provides slightly higher R-square than a linear trend
   - Regression on inventory quantity returns a higher R-square than regression on inventory cost as different holding costs increased the scatter of data points, and hence, increasing the variance on inventory cost distribution
   - The prediction model will rely on first predicting the inventory quantity based on the days of coverage before applying the future or forecasted holding costs to predict future inventory cost
   - R-square: 0.386459
   - P-value: <0.0001
4.4 Scenario Planning Tool (SPT)

The Scenario Planning Tool (SPT) is an interactive tool created in MS Excel. It was developed to incorporate the regression results based on historical data, and predict cost and service parameters based on optimal inventory position.

A snapshot of the SPT can be seen below in Figure 27:
4.4.1 Input and Output Parameters

The SPT is an interactive tool that can help the sponsor company monitor and predict the optimal monthly inventory position across the fiscal year, based on the monthly cost and service metrics.

4.4.1.1 Characteristics

The tool is based on the empirical weekly S&OP data from 2010 to 2017. It creates a user-friendly interface which accepts monthly data on cost and service parameters, calculates the inventory position, and presents the supply chain plan, based on key assumptions and regression coefficients.

4.4.1.2 Input Parameters

The tool accepts the following input parameters:

1. Baseline year- The user can select the relevant fiscal year from a drop-down list.
2. Inventory holding cost rate- The rate of holding or storing Plant stock (P-stock) as inventory. The units are USD/unit RTI.
3. Monthly S&OP data for the relevant fiscal year, for the following:
   - C-stock DoC
4.4.1.3 Output Parameters

The tool calculates the monthly distribution of the cost, service and inventory position, based on the regression coefficients and inputted data. It also calculates the annual supply chain cost across the fiscal year selected.

Users can view month wise breakdown as well as the total annual values of the output parameters as listed below:

1. Cost Factors
   - B-stock Relocation Cost
   - C-stock Relocation Cost
   - Issue Cost
   - Collection Cost
   - Per-unit Issue Cost
   - Per-unit Collection Cost
   - Monthly Total (Predicted Cost)
   - Monthly Baseline (Historical)

2. Serviceability Factors
   - Issue OTP
   - Collection OTP

3. Inventory Factors
   - Inventory Load (Quantity)
   - Inventory Cost

4.4.2 Modeling

In addition to the outputs generated based on the inputs, the tool also compares the baseline versus optimal inventory position and corresponding costs, based on input parameters. It can be used to benchmark the existing data to the optimal position, and well as perform a sensitivity analysis on the cost and service parameters to analyze the changes in inventory position and days of coverage (DoC).

4.4.2.1 Baseline Modeling

The SPT can be used to monitor the monthly supply chain metrics across different years and calculate the related costs, service parameters based on inventory position. The baseline
functionality will allow the user to compare any scenario to any year found in historical data.

4.4.2.2 Optimal Modeling
The SPT can be used to create an optimal supply chain plan for a fiscal year. This supply chain plan shall estimate the monthly costs, serviceability metrics based days of coverage (DoC). The optimization is based on key service factor targets, while minimizing the total annual supply chain cost for the fiscal year. The decision variable would be the days of coverage.

This plan can be used for planning purposes and guide functional and organizational decision-making. For example, based on the forecasted S&OP data and desired Days of Coverage, the tool shall calculate the optimal monthly inventory position, costs and OTP. This plan shall reflect the optimal supply chain plan, that would lead to minimizing the total annual supply chain cost given the forecast and serviceability target ranges, based on the prediction model.

4.4.2.3 Custom Modeling
The SPT can also be custom modeled. Users will be able to adjust or edit manually the optimal plan based on business constraints faced and quantify how such constraints would impact service levels and cost.

4.5 Limitations

4.5.1 Systemic Limitations
The inherent limitations in the scenario planning tool affect the predictive power for integrating costs and serviceability. These limitations mainly arise due to the following reasons:

1. **System Complexity:** The closed-loop supply chain is a complex system of inflows and outflows governed by a plethora of strategic and operational decision-making factors, which results in stochasticity of the data. The stochasticity of the data naturally increases the variance of forecasts and reduces the predictive power.

2. **Interrelated variables:** The system complexity is further intensified by the abundance of interrelated variables across the supply chain. Days of coverage is directly related to demand and C-stock inventory. C-stock inventory is dependent on new RTIs, orders fulfilled and repaired B-stock RTIs. Any change in these variables would inevitably
affect the other variables. It was necessary to assume *ceteris paribus* for days of coverage when optimizing inventory position.

3. **Aim for simplicity:** The aim of the Scenario Planning Tool (SPT) is to assist the functional teams in their operational and tactical decision-making process. The tool is aimed to be simple with a user-friendly interface that can be used across multiple teams by multiples users. Consequently, the number of inputs required and outputs display was kept at the minimum possible.

4. **Statistical significance in real-world scenarios:** While academic models are governed by a high predictive power, statistically significant R-square values $>0.7$; real-world scenarios generally have a relatively low statistical significance with R-square values. The R-square values above 0.2 were deemed to be acceptable, especially for smaller cost factors such as A-stock relocation and C-stock relocation costs.

4.5.2 Statistically Insignificant Correlations

As a result of the changes in business processes and customer portfolio over the years of data analyzed, a few statistically insignificant correlations were found:

**4.5.2.1 No Correlation between A-stock relocation and Days of Coverage**

No correlation found. Given that A-stock relocations are largely dependent on customers return or asking for a collection, the days of coverage of ready-to-use inventory will generally not affect fluctuate. Furthermore, there is a very small business need to relocate A-stock RTIs as inspections can be conducted in any facility. With the low variance of A-stock relocation costs, a simple linear regression against time was used for the prediction model in the SPT.

**4.5.2.2 Low Predictability for Specific Months for B-stock and C-stock Relocation Cost per Business Days**

For some months of the year, predictability is low due to low R-square between Days of Coverage and other respective variables. For months where predictability was low, regression trendlines from all historical data points from 2010-2017 were used, after adjusting for anomalies and excluding outliers. Refer to Appendix for R-Square Correlation Table (Month wise).

4.5.3 Inherent Forecasting Error

The Scenario Planning Tool (SPT) calculates the regression coefficients and predicts the baseline and optimal supply chain plan. The tool is based on empirical data from 2010 to
2017. Prediction is based on models generated through regression of on historical correlations. Empirical historical data was aggregated and averaged to create a predictive model. Using this model to predict the correlations for specific years or future years may give results with marginal error. Every year is unique in terms of its business profile and underlying environment, and there may be key real-time unexpected macroeconomic or price changes (like change in transportation cost due to paucity of trucks or diesel prices) that may affect underlying assumptions of past data. Hence, it is recommended that the tool be used as directional guidance to support decision-making by functional and organizational teams, and not as an exact prediction based on given inputs.
5. Discussion and Conclusion

This section reviews and summarizes the findings and insights from the regression and analysis conducted. The in-depth analysis has revealed strong correlations between inventory policies and supply chain cost as well as service levels. These findings would allow the sponsor company to make more informed inventory policy decisions. Improvements in costs and service levels have been quantified based on historical data and can be applied for future scenario planning.

5.1 Summary of Findings

1. Relocation Costs

- A-stock relocation costs are relatively stable and form the smallest cost segment. A-stock relocation shows a strong goodness-of-fit with the trendline, however the relevant regression coefficient is not statistically acceptable. Hence plotting the correlation may not give accurate predictions for alternate values. This implies that the ready-to-use RTI inventory across distribution centers increases, the relocation of total number of RTIs between distribution centers also increases, and vice versa. However, it is not possible to predict a statistically accurate number of relocations as the relocations typically depend on the specific type of inventory available (repairable or ready-to-use). Aggregately, while the relocations may show a correlated trend, the underlying reasons of relocations may not be as evident.

- B-stock relocation costs comprise 80% of the total relocation costs, and is critical to the correlation analysis.

- There is an inverse relation between the ready-to-use RTI inventory and both the costs associated with moving repairable RTIs (B-stock) and ready-to-use RTIs (C-stock) between distribution centers. This implies that as the ready-to-use RTI inventory across distribution centers increases, the relocation of RTIs between distribution centers reduces, and vice versa. This is because each distribution center has enough ready-to-use RTIs to meet its forecasted demand, and does not need to satisfy demand from other distribution centers located further away. Hence, by maintaining a healthy level of ready-to-use RTI inventory at each distribution center, the internal relocation and transportation can be minimized, thus reducing the associated relocation costs.

2. Issue, Collection and Return Costs

- Issue costs contribute to more than 50% of the total transportation cost. Hence, correlation between issue costs and days of coverage is critical in predicting future scenarios. It is observed that there is an inverse relation between the costs associated
with issuing ready-to-use RTIs to customers and the ready-to-use RTI inventory. This implies that as the ready-to-use RTI inventory increase, the issues of RTIs to customers increases, the ready-to-use RTI inventory across distribution centers reduces, and vice versa. This correlation is true for months before the peak season, as the total number of RTIs in the network is constant. The RTIs are either issued for circulation to customers or are stored as inventory in the distribution centers. However, this correlation changes during the peak season, from July to September, where there is no statistical observation of a valid correlation. This is because new RTIs are constantly injected into the system during the peak season to suffice increasing demand.

- With respect to collection costs, it is observed that return costs are negligible as customer bear the costs of returning RTIs to the sponsor company.
- Issue and Collection costs fit exponential regression and have a higher correlation with days of coverage for a month wise analysis for specific months.

3. On-Time Performance (OTP)

- Issue OTP: There is a direct relation between the ready-to-use RTI inventory and the on-time service levels associated with issuing ready-to-use RTIs to customers. This implies that as the inventory levels of ready-to-use RTIs increases, the sponsor company is able to service more customer orders on time, and vice versa. This correlation is especially true for the peak season months, from June to September. This correlation is intuitive because a higher ready-to-use inventory position typically allows for timelier servicing of customer demand as there is a lower risk of stock-out or extended lead times. This correlation is not statistically significant when the demand is low, especially during the months of November to February. This is because the demand for RTIs is low during these months, and can be satisfied on time by a low amount of inventory. Hence, building further inventory during these months will have not see a significant effect on service levels.

- Collection OTP: There is no statistically acceptable correlation between the C-stock days of coverage and the Collection OTP. This means that there is low correlation between the ready-to-use RTI inventory and the on-time service levels associated with collecting ready-to-use RTIs from customers. This implies that inventory levels of ready-to-use RTIs have a negligible effect on the sponsor company’s ability to collect RTIs from its customers on time.

- R-square for all years of data relatively low, but high for some month wise regressions. This implies that the goodness-of-fit is higher for specific monthly OTP. A possible contributing factor for a low R-square on OTP is that there are probably other
exogenous factors which affect service levels, for example, varying lead times due to shipping distance.

- 4. Inventory Cost

  - Inventory holding costs account for less than 5% of the total supply chain costs.
  - Inventory quantity (load) is a better parameter for the scenario planning tool than the inventory holding costs to account for correlation with C-stock days of coverage, due to different holding costs which depend on total volume of RTIs in closed-loop supply chain.
  - There is an inverse relation between the ready-to-use RTI availability and the inventory holding and storage costs. This implies that as the availability of ready-to-use RTI inventory across distribution centers increases, the total inventory holding costs reduces, and vice versa. This is true at an annual aggregated basis, and when the inventory position is within the acceptable target range. Hence, by maintaining a healthy level of ready-to-use RTI inventory at each distribution center, the aggregate inventory storage and holding costs can be minimized.

5.2 Key Takeaways

Correlation between inventory policies and supply chain costs have been identified in this project. Understanding the quantifiable impact of changing the days of coverage gives an opportunity to optimally plan inventory coverage to minimize supply chain costs while meeting service level targets.

The exponential trends observed in historical data indicate that 100% service levels can be achieved before minimal supply chain costs are attained. This would mean that increasing days of coverage beyond a specific point would not generate marginal value. Hence, building up inventory to increase days of coverage after the threshold is reach would only add to costs without improving service levels.

Findings show that transportation and logistics cost is the largest cost component in a closed-loop supply chain for returnable transport items (RTIs). This is mainly explained by the fact that every RTI circulates in the closed-loop network a few times before being discarded. Hence, it would be critical to compare the transportation and relocation cost savings against the cost of adding new RTIs into the closed-loop supply chain network when determining the optimal inventory policy.
5.3 Benefits

The Scenario Planning Tool (SPT) is an interactive tool that can help the sponsor company monitor and predict the optimal monthly inventory position across entire calendar year, based on the monthly cost and service metrics. The model helps in understanding the underlying statistical correlation between days of coverage and supply chain cost and serviceability factors.

The SPT can be used in different ways to monitor, predict, optimize and improvise the supply chain metrics, based on the functional and organizational requirements. It can be used to develop an optimal supply chain plan that maximizes service levels, while minimizing the total annual supply chain costs.

The tool also compares the baseline versus optimal inventory position and corresponding costs, based on input parameters. It can be used to benchmark the existing data to the optimal position, and well as perform a sensitivity analysis to analyze the impact of any change in inputs on supply chain cost and service levels.

The SPT is an effective tool that can be utilized for guiding functional and organization decisions for planning the inventory position across entire year to minimize the annual supply chain costs, while ensuring optimal service levels during the entire year, especially during peak demand period.

Based on the regressive correlations, predictive power and optimization using the SPT, we created an optimal inventory plan for the years 2010 to 2017. Historical data was included in the model to allow users to compare predicted scenarios with historical data. This would allow users to understand the magnitude of improvement and have a quick sense check for the predicted results.

The results showed that the optimal supply chain plan can lead to an improvement of 5.3%-24% cost and 0.3%-5.6% service level. The comparison of baseline data with the SPT optimal plan is shown below for the years 2010 to 2017.

<table>
<thead>
<tr>
<th>Year</th>
<th>% Improvement over Baseline</th>
<th>Annual Total Supply Chain Cost</th>
<th>Annual Issue OTP</th>
<th>Annual Collection OTP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011*</td>
<td>5.3%</td>
<td>0.4%</td>
<td>3.0%</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>8.6%</td>
<td>1.0%</td>
<td>4.6%</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>9.0%</td>
<td>0.3%</td>
<td>1.7%</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Illustration of annual supply chain costs and service levels comparing the baseline historical data with the optimal plan calculated using SPT.
<table>
<thead>
<tr>
<th>Year</th>
<th>Cost</th>
<th>Service</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>14.4%</td>
<td>2.2%</td>
<td>2.8%</td>
</tr>
<tr>
<td>2015</td>
<td>21.5%</td>
<td>5.6%</td>
<td>4.3%</td>
</tr>
<tr>
<td>2016</td>
<td>24%</td>
<td>2.6%</td>
<td>2.8%</td>
</tr>
<tr>
<td>2017*</td>
<td>9.5%</td>
<td>2.4%</td>
<td>4.2%</td>
</tr>
</tbody>
</table>

The table shows how the cost and service levels can be improved by leveraging the predictive power of SPT in guiding decision making.

* Full year of baseline data unavailable, comparison may not be fully accurate

## 5.4 Future Extensions and Recommended Next Steps

The analysis is based on empirical data from 2010 to 2017, excluding anomalies and outliers. As always, with any forecasting tool, the prediction model is not 100% precise for future predictions. However, regression coefficients can be regularly updated on an annual basis to ensure prediction model is continuously relevant. The following extensions can be incorporated to suit changing business environments:

- The Scenario Planning Tool (SPT) can be annually updated by running regression with newer to keep parameters updated as business grows and changes.
- Additional constraints like ramp-up limitations, new RTI introduction rates and their respective costs can be built into the model.
- Sensitivity analysis can be done to study changes in supply chain plan costs due to price fluctuations in transport, labor and land.

The concepts and correlations explored in this study visualizes and quantifies the different supply chain costs and service levels, based on different inventory plans. The insights from this capstone allows for better decision making, which is applicable to any closed-loop supply chain company. With stronger supply chain policies, based on a holistic view on costs and service levels, the entire ecosystem of business stakeholders and end-consumers will stand to benefit from improved levels and reliability of service in the future.
6. References


### 7. Appendix

#### A1. Table of R-square and P-value of Regression Trendlines

<table>
<thead>
<tr>
<th>Correlation vs. DoC</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>B Relo Cost (per Bday)</td>
<td>R-Square: 0.46934</td>
<td>0.0012142</td>
<td>0.228223</td>
<td>0.64135</td>
<td>0.443332</td>
<td>0.124069</td>
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<td></td>
<td>P-Value: 0.000221</td>
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<td>0.0075884</td>
<td>&lt;0.0001</td>
<td>0.0003833</td>
<td>0.0913994</td>
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<td>C Relo Cost (per Bday)</td>
<td>R-Square: 0.0010051</td>
<td>0.310347</td>
<td>0.329175</td>
<td>0.227816</td>
<td>0.0149788</td>
<td>0.188545</td>
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<tr>
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<td>P-Value: 0.894444</td>
<td>0.007221</td>
<td>0.0027118</td>
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<td>0.0003833</td>
<td>0.0913994</td>
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<tr>
<td>Issue OTP</td>
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<tr>
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<td>P-Value: 0.172978</td>
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<td>0.002396</td>
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<td>0.0913994</td>
</tr>
<tr>
<td>Collection OTP</td>
<td>R-Square: 0.0910281</td>
<td>0.109217</td>
<td>0.320696</td>
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<td>P-Value: 0.196087</td>
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<td>0.0913994</td>
</tr>
<tr>
<td>Issue Cost (per Bday)</td>
<td>R-Square: 0.325065</td>
<td>0.252431</td>
<td>0.148276</td>
<td>0.0142233</td>
<td>0.0337089</td>
<td>0.113657</td>
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<tr>
<td></td>
<td>P-Value: 0.0015203</td>
<td>0.0064373</td>
<td>0.0223581</td>
<td>&lt;0.0001</td>
<td>0.0003833</td>
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<tr>
<td>Collection Cost (per Bday)</td>
<td>R-Square: 0.415121</td>
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<td>0.0913994</td>
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</table>

<table>
<thead>
<tr>
<th>Correlation vs DoC</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>B Relo Cost (per Bday)</td>
<td>R-Square: 0.002134</td>
<td>0.500267</td>
<td>0.628161</td>
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<td>0.282015</td>
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<td></td>
<td>P-Value: 0.792143</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
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<td>0.014793</td>
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<tr>
<td>C Relo Cost (per Bday)</td>
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<td>0.245446</td>
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<td>0.394747</td>
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<td></td>
<td>NA</td>
<td>NA</td>
<td>0.471784</td>
<td>0.6587</td>
<td>5.70E-05</td>
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<tr>
<td>Issue OTP</td>
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<td>0.013828</td>
<td>0.000343</td>
<td>0.001326</td>
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</tr>
<tr>
<td></td>
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<td>0.098972</td>
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<td>NA</td>
<td>NA</td>
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<tr>
<td>Collection OTP</td>
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<td>0.555184</td>
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<td>&lt;0.0001</td>
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<td>&lt;0.0001</td>
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