Inventory Planning in Engineer-to-Order (ETO) Steel Industry

by

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Submitted to the Program in Supply Chain Management
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Requirements for the Degree of Master of Applied Science in Supply Chain Management

ABSTRACT

Inventory planning is one of the most important processes in supply chain management that plays an important role in the success of an Engineer-to-Order (ETO) business. Supply chain and inventory managers in ETO businesses always face challenges in determining an appropriate inventory level because of the uncertainty nature of the ETO industry. In particular, for the steel ETO industry, better inventory planning will help the company reduces the inventory cost significantly. This capstone studies the raw materials inventory planning of an ETO utility infrastructure manufacturer. The current inventory planning of the sponsor company is outdated and does not meet the required service level. Thus, the company aims to improve its inventory management system by replacing the traditional methods with scientific-based ones. In the initial stage of this capstone, several challenges such as uncertain demand, uncertain lead time, uncertain project bid win/loss possibility have been identified that affect the inventory decisions of the company. This capstone focuses on the normal business process, which does not consider unexpected demand surge, and which assumes winning the returning project. This study first identifies the models applicable to the company and then compares the total cost of the selected models under a centralized (aggregated) decision process. Two inventory planning models (s,Q model and R,S model) were studied. The main contribution of the model is to suggest optimal safety stock level, review period, and order quantity to the company. After comparing the total cost of the two models, the (R,S) model was chosen. This model will help the case company to optimize the inventory spending on an annual basis. Sensitivity analysis was conducted on lead time and service level (CSL) of the (R,S) model. Further studies are suggested to capture the unexpected demand surge, uncertain lead time, new project win/loss, etc.

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1. Introduction

Inventory planning plays an important role in the success of a business. In 2008, firms operating in the United States spent $420 billion to maintain inventories valued at almost $2 trillion (Wilson 2009). Businesses always pursuit the right amount of inventory at the right time within the right time frame. The effective use of inventory, both strategically and tactically, is crucial for success in this global and volatile world. Although just-in-time inventory is the ultimate goal of every inventory planning process, it is not realistic, especially in the ETO business, where decoupling point starts from the design stage (Gosling and Naim 2009). The ETO supply chain involves design, engineering, and manufacturing based on each new customer order, and normally includes modifications and customizations (Gosling and Naim 2009). In addition, demand uncertainty and long lead time make the inventory planning for ETO complex.

This capstone identified several challenges that affect the inventory planning process of the case company: safety stock, lead time, and ETO project-based order pattern. This study focuses on the regular business process, which does not consider unexpected demand surge, and which assumes winning the returning project. The data used in this capstone is provided by a leading agriculture and infrastructure manufacturing company. The goal of this study is to suggest optimal safety stock level, review period, and order quantity. The new findings and solutions will provide guidelines to the company for potential inventory planning.

In all, this project answers the following questions:

1. What is the optimal inventory policy of the company under regular business process?
2. For each manufacturing sites, under the selected policy, what is the optimal review period, safety stock level, and order quantity?

The Senior VP of Supply Chain serves as the sponsor and the key contact for this capstone project. By interviewing the department managers of the company, simple and easy models would be applicable for the operators to understand and to apply to their daily work. This paper suggests two inventory models

--- (s,Q) model and (R,S) model -- that can be applied to improve the inventory management of the company under study. The methodology section compares the models and recommends which model is better to be implemented by the company.

The (s,Q) model and the (R,S) model were constructed. Both the (s,Q) model and (R,S) model were calculated on the aggregated dataset. By comparing the two models, (R,S) was better than the (s,Q) model. Then the finding (R,S) model was applied to each individual manufacturing site (the company's five important manufacturing sites). The above research questions are answered for each of the five sites in this disaggregating process.

The subsequent sections of this paper are as follows: Sections 2 introduces the literature review on the ETO industry. Section 3 provides an overview of the company and its supply chain. Section 4 addresses the methodology for this capstone. Section 5 describes data, data collection, and data analysis. Section 6 explains the modeling and Section 7 shows the result and validates the model. Section 8 provides a sensitivity analysis of the optimal findings. Section 9 applies the optimal findings to disaggregated manufacturing sites. Section 9 provides scenarios analysis on each site. Section 10 concludes the paper and provides further research suggestions.

2. Literature Review

This section discusses the literature regarding the ETO industry and its features.

2.1 Literature Review of the ETO Business Type

A number of different types of manufacturing processes have been studied by different scholars (Porter et al. 1999). However, different scholars have used different terms to distinguish the variations of the ETO business type. Especially, there is some confusion between Engineer-to-Order (ETO) and Design-to-Order (DTO). Gosling and Naim (2009) define ETO as a standard product range offered with the added availability of modifications and customizations. DTO, on the other hand, is defined as new product introductions with design, engineering, and manufacturing based on each new customer order. These definitions, however, do not draw a clear boundary between ETO and DTO. Gosling and Naim (2009) in the same study classify the ETO manufacturing supply chain as a supply chain where the "decoupling point" is located at the design stage. Furthermore, Amaro, Hendry, and Kingsman (1999) define a "versatile manufacturing sector" which are involved in a competitive bidding situation for every order and the "repeat business customizers", which may receive a series of similar orders from particular customers.

The business type of the company fits well in the ETO structure that Amaro (1999) distinguished, in which the supply chain starts from the design stage, follows a competitive bidding process, and the repeated customization process for some orders. This capstone will focus on the repeated order and customization process of the inventory management of the ETO business that starting the supply chain from the design stage and winning the bid.

2.2 Inventory Strategy, Safety Stock, and Lead Time

Stocking the right amount of inventory is always a big challenge for any organization. For the project-based ETO industry, due to the uncertain demand, and long procurement and production lead time, choosing the right inventory policy becomes more complicated. The operations managers in the ETO environment, using the company as an example, are focusing on how much inventory is enough, when the inventory is available for the production of the winning project, and how to buffer and balance the inventory and lead time when order (actual demand) becomes available. However, it costs extra for the company whether the inventory is overstocked or understocked. In understock situations, the companies may suffer from idle production, low service level and low fill rate (Wilson 2009). Humair (2013) stated that the companies that can best manage the trade-off between customer service and inventory are the ones best placed to compete and win. In addition, a study showed that a typical manufacturing company spends 55% of earned revenue on raw materials (Johnson et al. 1998). All of these reasons put more pressure on inventory managers to make the optimal decisions to balance all the inventory decision factors, such decisions as what the optimal inventory level is, how much should order, and when should order, etc.

Lead time and safety stock play an imperative role in the business (Boute et al. 2014). This is confirmed by Boute, Disney, Lambrecht and Van Houdt (2014), who proved that "Coordinating lead times and safety stocks is imperative in a supply chain where the supplier produces the retailer's orders on a make-to-order basis. In such an environment the supplier may opt to not hold inventory, but the retailer does hold safety stocks to satisfy immediate consumer demand" (p. 52). Ruiz and Mahmoodi (2010) also suggested that safety stock plays an important role to retain the balance between overstock and understock. Safety stock has to be maintained in order to satisfy inventory requirements, even when parameters such as the demand, replenishment times, and replenishment quantities are volatile. In the project-based ETO environment, supplier normally does not receive the order as long as the producer wins the project and triggers the order to the supplier with the specifications and customizations.

How to correlate demand, safety stock, and lead time is also really crucial to the supply chain and inventory management. Boute (2014) proved that the correlation in demand has an important impact on the performance of the supply chain in terms of safety stocks and lead time. Boute, Lambrecht, and Van

Houdt (2007) studied the operational impact of demand variability on lead times and safety stocks. This study has shown that increased demand variability has a double impact on supply chain and inventory performance. It not only increases inventory variability (thereby inflating safety stocks) but also prolong the lead times, due to the increased order variability, which reinforces the increase in safety stocks.

Many scholars have proposed models and methodologies to optimize inventory. A work by Lisan (2018) stated that inventory control models in the research literature and in textbooks typically assume that the demand distribution and all its parameters are known. On the other hand, Prak, Teunter, and Syntetos (2017) proved that in practice such information is not available, and future demands have to be forecasted based on historical observations. However, in the project-based ETO business, such forecasts and historical observations may not always be available.

Lisan (2018) in a recent study suggested a modified EOQ model to calculate the optimal inventory level. The model accounts ordering cost, holding cost, pricing, time, demand variation lead time and even forecasting errors. However, Lisan (2018) also stated that although EOQ may be one of the acceptable solutions for safety stock calculations, the EOQ has some drawbacks and limitations under the uncertain scenario. In addition, Humair (Humair et al. 2013) stated that most inventory models incorporate demand variability, but far fewer rigorously account for lead-time variability, particularly in multi-echelon supply chain networks. Lisan (2018) stated that "Even though in inventory literature, there are many complex theories used, but in most of the cases, the users of the theories have a hard time to understand and use the models" (p. 5). The purpose of the capstone is to recommend a solution for the inventory managers of the company to guide them make better inventory decisions.

3. Case Company

This section will discuss the case company and its supply chain.

3.1 The Company 's Background

The sponsor company for this capstone project is the leading agriculture equipment and infrastructure steel manufacturing company in the world. It is also the largest utility pole manufacturer in North America. This capstone targets the utility segment of the business, which is the ETO project-based business. The utility division produces large size utility power substations and power transmission poles. Due to the nature of the business and industry, the products (power distribution, power substations, power transmissions, and/or utility lighting poles) are design-to-bid for every first-time customer. Even though they may be for the same customer, different projects have different specifications and requirements. The business of the utility pole division fits well the ETO business model.

This capstone focuses on utility products that consume steel as raw material. This capstone project provides the optimal inventory policy for the centralized inventory planning team. The team is responsible for ordering raw material for all manufacturing sites. Processes involved in ordering the steel (coil and plate) will be examined. The data including sales and raw material inventory planning will be gathered and analyzed.

3.2 The Supply Chain of the Company

The company has seven manufacturing sites in North American where every site works under the central inventory planning unit. The company started its realignment of the centralized supply chain operation about a year ago. Previously, the company had a decentralized supply chain with seven manufacturing sites acting as a stand-alone cost center. Each site had unique production lines, machining, tooling, lead times, and capacities. Sites produced on their own schedule and served their own customers with little transparency among them. Outside of routine issues, unexpected stochastic events would disrupt the existing supply chain operations. For example, events such as natural disasters, vendor bankruptcy, and new steel sanctions had a meaningful impact on supply chain operations. In the summer of 2017, when Hurricanes Irma and Maria made landfall, there was a significant surge in demand for replacement utility structures, which resulted in a heavily interrupted supply chain. Those disruptions bottlenecked the whole company's supply chain for more than a half year.

Currently, the central purchasing team is led by the Senior Supply Chain Manager, who is responsible for all seven manufacturing sites' raw material inventory planning for the utility division. The Senior Supply Chain Manager reports to the Director of Purchasing, who is responsible for the purchasing decision for all divisions. The Director of Purchasing reports to the Senior VP of Supply Chain, who oversees all supply chain issues from all divisions. There are two sub-teams under the Senior Supply Chain Manager, the coil and plate inventory management teams, and each team has a Senior Supply Chain Analyst. Each manufacturing site has its own inventory planner, to monitor the inventory level and purchase order status. Figure 1 shows the organization chart of the purchasing team.

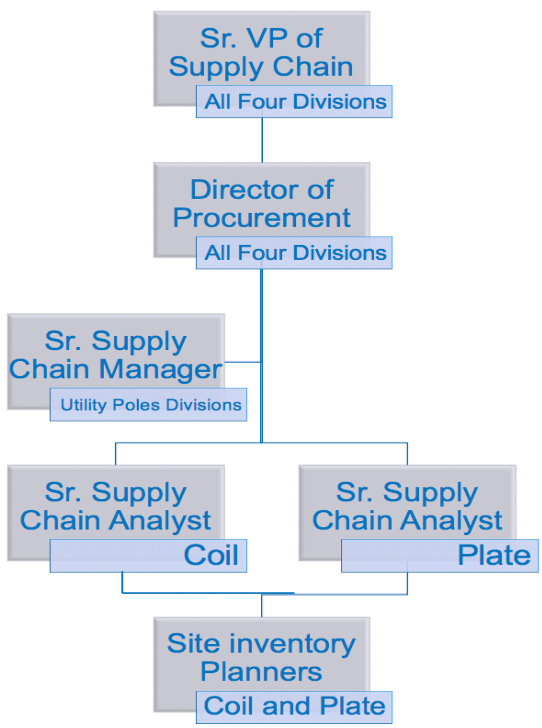


Figure 1 Purchasing Org Chart

Every week, the steel coil and plate inventory requirements are gathered by the inventory planners from each manufacturing site and reported to the Senior Supply Chain Analyst respectively. Along with the inventory reports and purchase order reports, the Senior Supply Chain Manager makes the centralized purchase decision for all manufacturing sites. Currently, there is not a formal process to determine and calculate the safety stock, order quantity, and order time. The current inventory policy is based on the intuition and past experience, but not a mathematical and scientific way. Under current policy, the supply chain manager, inventory planners and supply chain analysts review the inventory level every week.

The supply chain of the company starts from the bidding process. Every time the company bids on a new project, the company gathers the information for bidding, such resources as customer requirements, land/location character, steel raw material requirements (grade, thickness, carbon mix), production facility capacity, lead time, etc. All of those requirements cascade down from the upstream to the downstream supply chain. The information is gathered in reverse, from downstream to upstream, then to engineer team for the proposed design, and finally to the salesperson for bidding. At the time of the information gathering, a phantom demand is created in the system as a rough forecast because the design is created already and stored in the ERP system. If the company wins the bid and the project, the phantom demand becomes the gross requirements. The production lead time is normally more than 6 to 9 months. Furthermore, the engineering team has to re-evaluate the winning design and then pass the revision on to the customer for necessary changes.

At the time the project final design is approved by both parties, it becomes an actual demand and the Bill of Material (BOM) from the engineering design transfers to the ERP system. However, there are several disconnects in the current process of the supply chain. First, the S&OP process is not well established. The current S&OP process is more focused on the dollar amount (sales revenue) than the SKU level of the raw material, serving for the strategic planning purposes but not the entire supply chain. The current forecasting process is not well established for raw materials. The forecasts serve more a high-level capacity planning and profit & loss purpose than the actual demand in the ERP. Second, the BOL is not rolling up all the way to the raw material steel coil level. The current system does not have the correct way to record the SKU of the coil. Instead, the company records the raw material coil and plate as weight (tonnage) and inventory planning for raw material is based on weight. Third, there are several platforms that store the supply chain data, but all the systems do not communicate with each other seamlessly. The data is lost in the transition from one platform to another. Fourth, historical “bad data” is somehow still in the system, and it will take a long time and much effort to clean out those bad data. Fifth, due to the lagged technology, it is hard to forecast the appropriate level of the safety stock. The unrealistic safety stock, coupled with the long purchasing and production lead time, makes the supply chain decision more difficult.

4. Methodology

This section states the methodology developed to answer the research questions. The first step was data collection, followed by data analysis. Then two of the inventory models were chosen and formulated. The two models were compared in the model validation section. The better model was chosen in the model validation process. Last part of the methodology section is the sensitivity analysis of the selected model. Figure 2 shows the methodology of this capstone project.

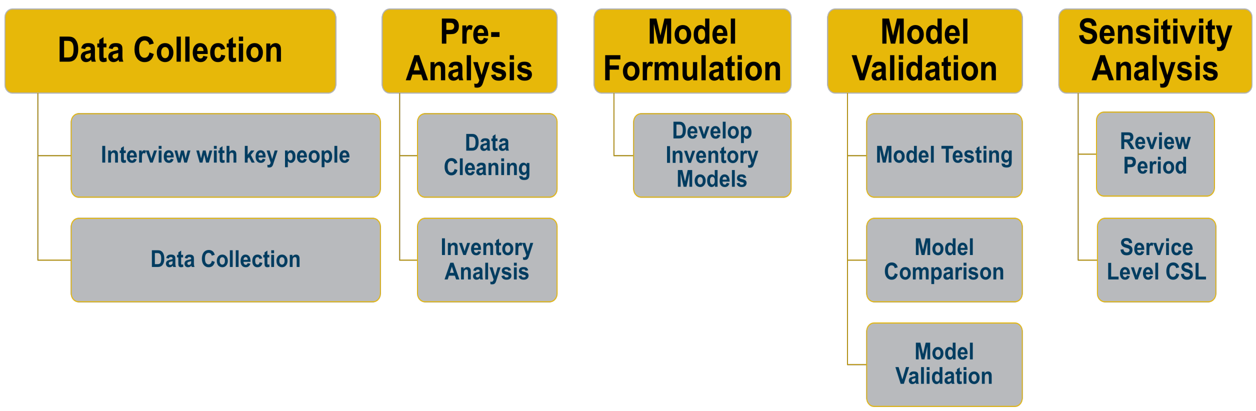


Figure 2 Methodology Mapping

4.1 Data Collection

Interviewing the Senior VP of Supply Chain yielded thorough knowledge of the products, the situation, and the disconnections in the supply chain, operations, planning, and the production. A tour was conducted to the production line, inventory warehouse, and inbound/outbound logistics. The sales team explained the process of gathering the demand data. The engineering team explained the design and engineering process. The detailed data collection process is in Section 5.

4.2 Pre-analysis

The company started upgrading the software systems a couple of years ago. The upgrading process including adopting new systems and designing applications in house. Due to the connection issue, all the data systems did not connect to each other. The sales data is collected based on a Tableau report that pulled and queried from various platforms. Even though the sales data is collected from the past 10 years, some empty cells on important features from 2009 to 2015 making the record not useful. During the data cleaning process, only the latest three years of data is useable (from 2016 to 2018). The inventory data is much cleaner since the inventory planning team keep a hard-copy record on the spreadsheets. In the data cleaning process, the inventory data got cleaned and useful.

Initial demand and inventory data analysis was done in the pre-analysis stage, to define the pattern of the past demand. Missing information was gathered from the company as well.

4.3 Model Formulation

Because of the lagged technology, sophisticated scientific models will not be feasible to explain to the company. The models need to be simple to understand and adopt by decision-makers to guide the optimal inventory policy. Two of the inventory models were chosen: the continuous review inventory model (s,Q) and the periodic review inventory model (R,S). The model answered the research questions: the optimal inventory policy, the order quantity, the safety stock level, and the order interval time.

4.4 Model Validation

After the two models were formulated, the validation process is testing on a 52 weeks period, and calculated on the total relevant cost base. Comparing the total relevant cost of the two models, the lowest total relevant cost model is selected, which is (R,S) model.

4.5 Sensitivity Analysis

In the sensitivity analysis, two of the parameters were tested: the review period interval and the service level. The purpose of the sensitivity analysis is to show the impact on the total relevant cost if one of the parameters moves one unit from the optimal point. The sensitivity analysis was tested on both the aggregated central purchasing level and disaggregated level for five of the major manufacturing sites.

5. Data Collection and Data Analysis

This section will discuss the detailed data and the initial analysis of the data.

5.1 Data

This section describes the data collection process and the data needed for this capstone to address the inventory issue with the company.

First, in order to collect the data from the company, the discussion has been started with the Senior VP of Supply Chain to gain detailed knowledge of the process regarding how the supply chain works, what functional area should be targeted on, and who should reach out to obtain additional information. The Senior VP of supply chain introduced me to Director of Sales, Director of Finance, Director of Logistics, Senior Logistics Manager, Director of Procurement, and Senior Supply Chain Manager. During the interviews with the key stakeholders identified above, main challenges were identified in the inventory planning process. The inventory cost has a huge impact on the gross margin. It has little or no transparency from the upstream supply chain for the inbound logistics team since the order quantity and delivery schedules are not known. According to the discussion with the Senior VP of Supply Chain, Director of Procurement and Senior Supply Chain Manager of the company, there is no formal inventory policy, the inventory decision is made every week and the safety stock level is determined based on the intuition of the sites' inventory planner. The VP of supply chain and the procurement team are searching for a solution to guide them make better inventory decisions.

Historical sales (demand) data set was gathered from the Director of Sales. The data includes all the sales records from 2009 to 2018, including sales amounts, weights, and orders on each shipment. The sales data is gathered on each manufacture sties.

Inventory data was collected from the Senior Supply Chain Manager, the inventory data includes inventory history from 2012 to 2018. The inventory data is split by each manufacturing site and include the inventory values and weights of steel coil and plate.

5.1.1 Demand Analysis

The first data set obtained is the sales data from 2009 to 2018. The data include sales history by customer orders from each manufacturing sites. The data also gathered from each production locations. The data provides detailed shipment information and invoice records associated with each shipment. Even though the data set includes the weight and dollar amount of each shipment, the weight is not accurate after analyzing. I discussed the findings with the company and found out that because of the newly implemented applications and a high degree of manual entry of the customer orders, there is some data loss during the transition between applications. The weight associated with inventory consumption is not useful. However, the demand pattern can be drawn from analyzing the sales data set.

In order to come up with a sound solution for analyzing the demand data, the company recommends using the shipment weight limit per truck. As mentioned, because of the large structure of the utility pole, one utility pole per shipment ratio is common in the industry. On average, the structure is about 40,000 lbs per shipment. I use this shipment weight limit multiplies by the total number of shipments to get the total demand of tons for raw materials in a certain period.

5.1.2 Raw Material Inventory

The raw material inventory data was requested and obtained after analyzing the sales data. The inventory data gathered from 2013 to 2018. The data set includes the total dollar cost and weight of the raw material inventory (Steel Coil and Steel Plate). Furthermore, inventory records by each manufacturing sites were gathered. In addition, raw material inventory type (coil, plate, cut-to-length, mill direct) was split and analyzed.

5.1.3 Price

Since the sales data is not connected to the inventory data I gathered from the company, it is a little hard to determine the proper level of the sale price of the product. The purchasing team suggests use a 60% margin on top of the cost to calculate the sales price for the models.

5.1.4 Raw Material Cost

Raw material cost ($ per lbs) has been collected and calculated. The data collected is from 2007 to 2018. On average of 2018, the dollar per lbs of the raw material is $0.51 ($1,010 per ton). Figure 3 shows the average per lbs cost variance, we can see that the cost follows a pattern. The cost shows a rising pattern from 2016 to 2018. The average increasing rate from 2016 to 2018 is 10.5%. After talking to the purchasing team, 2019 will also be a strong year for the raw material inventory since the raw material cost and the tax burden are a little high. This capstone assumes the increase for 2019 is the average of the past years (from 2007 to 2018), which is 8% increase, $0.55 per lbs ($1,100 per ton).

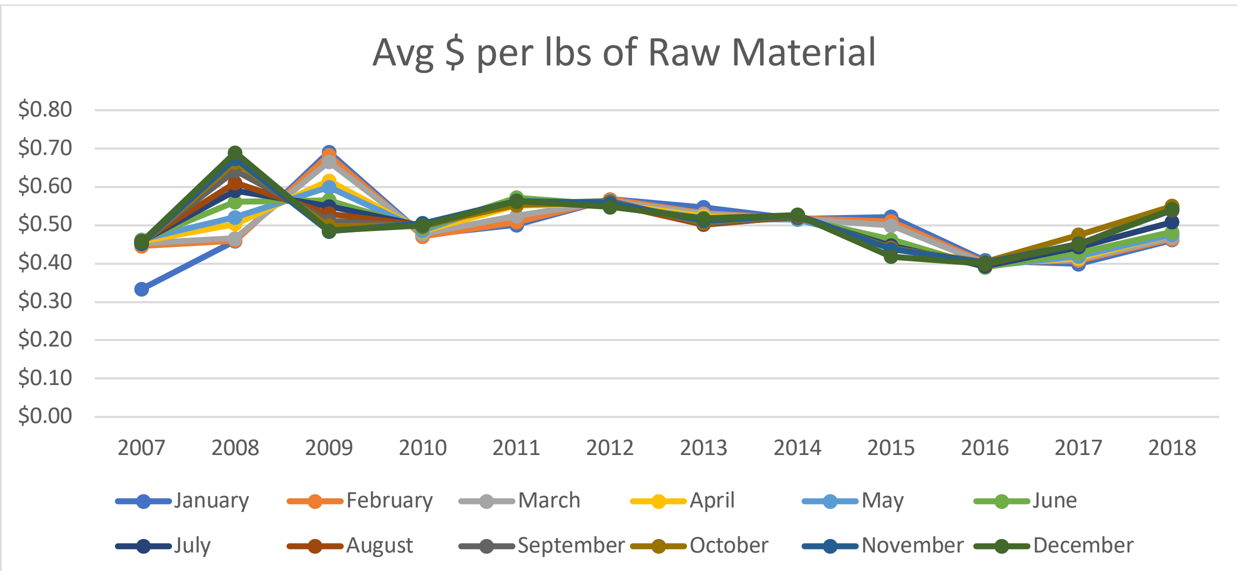


Figure 3 Average Dollar Per Pound of Raw Material – Steel Coil and Steel Plate

5.1.5 Inventory Holding Cost

The inventory holding rate is provided by the corporate finance team. The management determines the annual inventory holding rate of 12.5%.

5.1.6 Ordering Cost

According to the purchasing team, there is not a clear ordering cost to suppliers. The ordering cost is reflected in the purchasing cost (per lbs) to the supplier. However, there are some costs associated with the purchase order, such as labor hour to place the order, inspection, and quality assurance costs. An estimation of $1,500 purchasing cost would be appropriate.

5.1.7 Service Level

According to the management team, the average service level is set to be 90%.

5.1.8 Lead Time

According to the purchasing manager, the lead time varies depending on the type of raw material. The company can either order steel coil or steel plate from the vendors. If the company orders steel plate, it takes a longer time. The discrete plate from the mill is 8 weeks, cut-to-length is 2 weeks or less, mill direct coil is 5-6 weeks. In general, 4-week lead time would appropriate for most of the cases, despite any uncertainty.

5.1.9 Backorder Cost

The backorder cost, according to the supply chain team, is 10% more than the regular raw material cost.

5.1.10 Shortage Cost

The shortage cost from the supply chain and procurement team is 20% additional of the original raw material cost.

5.2 Data Analysis

This section discusses the data analysis of this capstone. The past three years of sales data (along with forecasting, invoices weights and dollar amounts) was collected from the company. The data was processed, cleaned and filtered for analysis. As mentioned earlier in this capstone, due to the nature of the business, there is no formal procedure to determine the inventory level (raw steel coil and plate) and safety stock, and lead times are around 6 to 9 months. This capstone will suggest an inventory policy for the company for certain inventory level, safety stock and lead time.

5.2.1 Demand

Analysis of the data from the company shows a huge bias between forecasted demand and actual shipments invoiced. Basic statistical analysis shows that the sales in each of the past three years followed similar patterns. We can find from figure 4 that the high demand points in a year are Feburary, June, August, and September, and historical low demand points are April and July. This finding interestingly suggests that even for the ETO business, for instance, the company, the demand does show a certain pattern year after year.

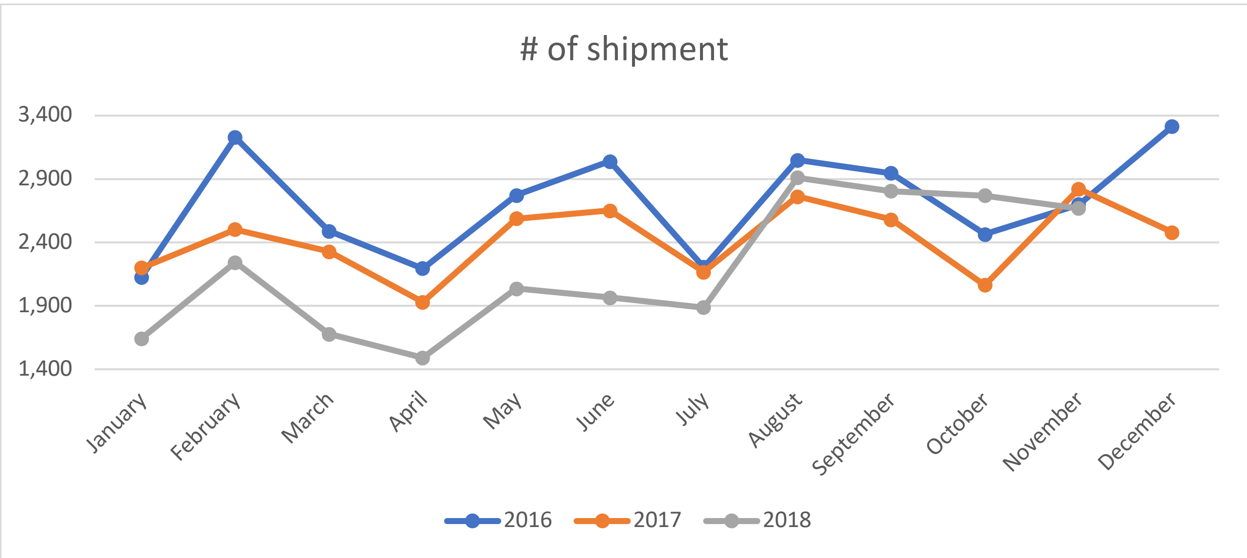


Figure 4 Count of Shipment

Another conclusion can be drawn from the analysis is that the late summer months tend to have higher demands. That may be true because of the hurricane season in summer months: the company responded with emergency production to replace poles damaged by the severe weather. For instance, in 2017 August and September, Hurricane Harvey, Irma, and Maria made landfall in the United States, causing 3,671 people dead and costing more than $270 billion (data from NOAA). The actual shipments of the company in the same period tended to be higher and the trends reflected in later months as well.

5.2.2 Inventory

As discussed with the Senior VP of Supply Chain and Senior Supply Chain Manager from the company, there is not a good inventory policy across the supply chain. Because of the unstable demand, and long lead time, the buyers normally make the purchase order for the raw material (steel coil and plate) depending on their intuition and reference to last year's same period demand. The buyers normally order for next period (month) by reviewing every 3 to 4 weeks of the on-hand inventory. However, by analyzing the inventory data from the company for the past 7 years, there is some kind of seasonality historical pattern for the company raw material. Figure 5 shows that normally, in April, July, September, and December, inventory level tends to be higher than other months.

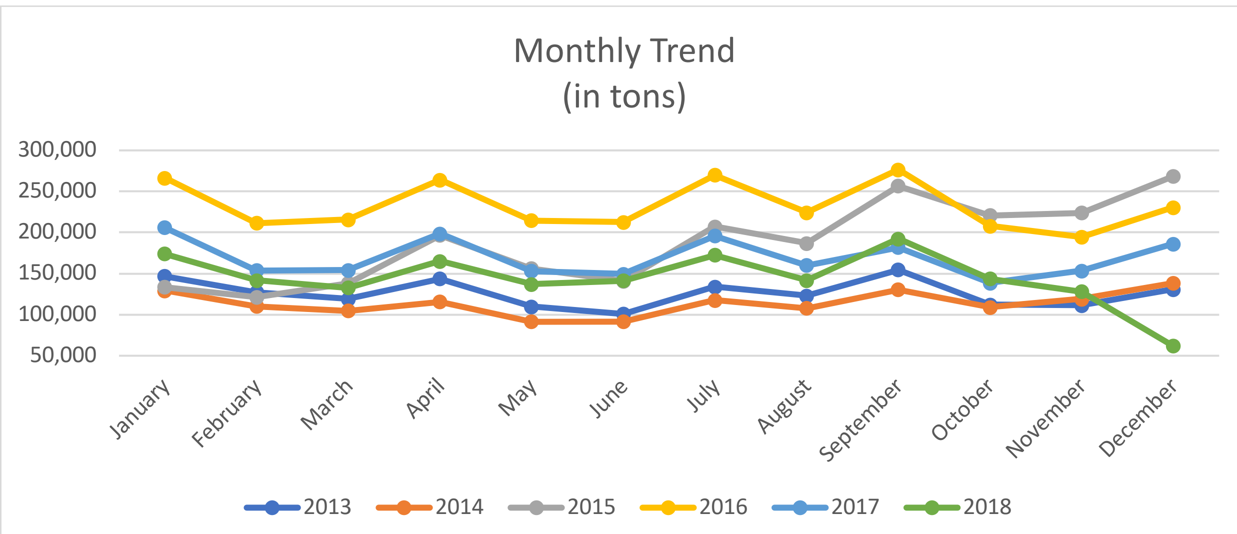


Figure 5 Monthly Trend

6. Models Formulation

In this section, the detailed model formulation described in the methodology session will be discussed.

6.1 Model Assumptions

The models of this capstone were built on below assumption:

1) The demand is variable and continuous. The model considers that the company will win the bid and the demand is continuous coming.
2) The lead time for the raw material is constant and deterministic. This capstone assumes the lead time for the purchase order is 4 weeks.
3) Review time can vary, either continuous or periodic review.
4) All of the raw materials (steel coil and plate) are independent items.
5) The model assumes the capacity is unlimited.
6) The model assumes the excess demand as lost sales, which will occur a shortage cost.
7) Planning horizon for the model is infinite.
8) Number of planning items is aggregated as the total tonnage of (steel coil and plate), so the number of planning items is one.

Two inventory models are appropriate for the inventory policy according to the assumptions above. For continuous replenishment cycles, event-based base stock policy (s,Q) model is a good choice, and for periodic replenishment cycles, time-based periodic review (R,S) models is a better choice. In the end, this capstone uses the total cost formula to provide the optimal solutions for the company to determine a proper inventory policy.

6.2 Notation

First, let’s look at the notation of inventory position (IP).

The calculation for the inventory position equals the inventory on hand plus inventory on order minus backorders. The equation is shown as follow:

Inventory Position (IP) = Inventory on Hand (IOH) + Inventory on Order (IOO) – Backorders

Table 1: Notation

c	Cost of raw material (dollar per ton)
i	Index for review period (review period per week)
h	Inventory holding rate – annual (% of inventory cost)
C_s	Shortage Cost (dollar per ton)
C_t	Ordering cost (dollar per order)
C_e	Inventory holding cost (dollar per ton) $C_e = c * h$
s	Reorder point (weight - tonnage)
μ_{DL}	Mean demand over lead time (weight - tonnage)
σ_{DL}	Standard deviation of demand over lead time (weight - tonnage)
CSL	Service level: 90% -- management decided
	$CSL = 1 - \text{Prob [Stockout]} = 1 - \text{Prob [X} > \text{s]} = \text{Prob[X} <= \text{s]}$
k	Safety stock factor
	$k = norm.s.inv\ (1 - \text{P X} > \text{s})$ or $k = norm.s.inv(CSL)$
$g(k)$	Unit short factor
	$g(k) = norm.dist(k, 0,1,0) - k \times (1 - norm.s.dist\ (k, 1))$
S	Order up-to point (weight - tonnage)
R	Review time period - 1 week in this case
μ_{DL+R}	Mean demand over lead time and review period (weight - tonnage)
σ_{DL+R}	Standard deviation of demand over lead time and review period (weight - tonnage)
Q	Order quantity (weight - tonnage)
TRC	Total relevant cost (dollar of total tonnage)

6.3 Continuous Review Inventory Model (s,Q) – Event Based

Under the regular production period, one of the models used is the continuous review inventory model, which called (s, Q) policy, or order-point, order-quantity policy. The (s,Q) policy assumes to order Q (quantity) when inventory position reaches to reorder point s. The reorder points s equals to the mean demand over lead time plus the safety stock, which equals to the safety stock factor multiply by the standard deviation of demand over lead time.

The model for the (s,Q) policy is

$$\boldsymbol{s = \mu_{DL} + k \times \sigma_{DL}} \tag{1}$$

The total relevant costs include the ordering costs, the holding costs, and the shortage costs. The below details the information for each cost. The ordering cost derives from the total annual demand divide by the order quantity, then multiply by the ordering cost ($C_t * \left(\frac{D}{Q}\right)$). There are two costs content in the holding cost, the average inventory (average quantity purchased) ($\frac{Q}{2}$), and the safety stock level (safety stock factor multiply by the standard deviation over lead time and review period) ($k * \sigma_{DL}$), the two inventory levels add together then multiply by the holding cost rates set by the management ($C_e * \left(\frac{Q}{2} + k * \sigma_{DL}\right)$). The shortage cost derives from the probability of the stock out and multiply by the shortage cost rate ($C_s * Prob[Stock\ Out]$) or ($C_s * \sigma_{DL} * g(k) * \left(\frac{D}{Q}\right)$).

The notation for the total relevant costs under (s,Q) policy equals to purchasing cost plus ordering cost plus the holding cost and plus the shortage cost.

$$TRC(Q) = \sum_{i=1}^{52}(C_t * \left(\frac{D}{Q}\right) + C_e * \left(\frac{Q}{2} + k * \sigma_{DL}\right) + C_s * Prob[Stock\ Out]) \tag{2}$$

or $$TRC(Q) = \sum_{i=1}^{52}(C_t * \left(\frac{D}{Q}\right) + C_e * \left(\frac{Q}{2} + k * \sigma_{DL}\right) + C_s * \sigma_{DL} * g(k) * \left(\frac{D}{Q}\right)) \tag{3}$$

6.4 Periodic Review Inventory Model (R,S) - Time Based

Another model I used is the periodic review inventory model, which called (R,S) policy, or review period, order up to policy. The (R,S) policy assumes to order Q (quantity) in every review period, but up to a S inventory level. The order quantity Q is not consistent every time. The order up to level S equals to the mean demand over lead time and review period plus the safety stock, which equals to the safety stock factor multiply by the standard deviation of demand over lead time and review period.

Order up to S units every R time period.

The model for the (R,S) policy is

$$\boldsymbol{S = \mu_{DL+R} + k \times \sigma_{DL+R}} \tag{4}$$

The total relevant costs under (R,S) policy include the ordering costs, the holding costs, and the shortage costs. Below details the information for each cost. The ordering cost derives from the total annual demand divide by the order quantity, then multiply by the ordering cost ($C_t * \left(\frac{D}{Q}\right)$). There are two costs content in the holding cost, the average inventory (average quantity purchased) ($\frac{Q}{2}$), and the safety stock level (safety stock factor multiply by the standard deviation over lead time and review period) ($k * \sigma_{DL+R}$), the two inventory levels add together then multiply by the holding cost rates set by the management ($C_e * \left(\frac{Q}{2} + k * \sigma_{DL+R}\right)$). The shortage cost derives from the probability of the stock out and multiply by the shortage cost rate ($C_s * Prob[Stock\ Out]$) or ($C_s * \sigma_{DL+R} * g(k) * \left(\frac{D}{Q}\right)$).

The notation for the total relevant costs under (R,S) policy is as below:

$$TRC(Q) = \sum_{i=1}^{52}(C_t \left(\frac{D}{Q}\right) + C_e\left(\frac{Q}{2} + k * \sigma_{DL+R}\right) + C_s * Prob[Stock\ Out]) \tag{5}$$

or $$TRC(Q) = \sum_{i=1}^{52}(C_t \left(\frac{D}{Q}\right) + C_e\left(\frac{Q}{2} + k * \sigma_{DL+R}\right) + C_s * \sigma_{DL+R} * g(k) * \left(\frac{D}{Q}\right)) \tag{6}$$

7. Model Validation

This section discusses the results and model validation.

7.1 Continuous Review Inventory Model (s,Q)

After formulating the (s,Q) model, a 52-week simulation was run to find the total annual relevant cost. The data used in the simulation are the past 3 years weighted demand data with the seasonality factor and the inventory data of 2018. The simulation was built in Microsoft Excel analysis and solver toolpak. The result under this policy model shows the optimal order point "s" level is 45,685 tons. The order quantity Q shows 104,346 ton. The safety stock under this policy is 10,795 tons. Under this policy, there is only one-time stock out, the stock out probability is very low.

Figure 6 shows the inventory level under (s,Q) -Order point, Order Quantity policy. the dotted red lines show the inventory position. In each order period, the inventory position increases 104,346 tons. The quantity will receive in 4 weeks (lead time). The yellow line shows the inventory on hand (IOH). The result shows there is only 5 times need to place an order in 52-weeks, in weeks 1, 13, 27, 37 and 46. Based on equation (2) or (3) total annual relevant cost equation, the Total Relevant Costs (TRC) for this policy is $14.8 million annually.

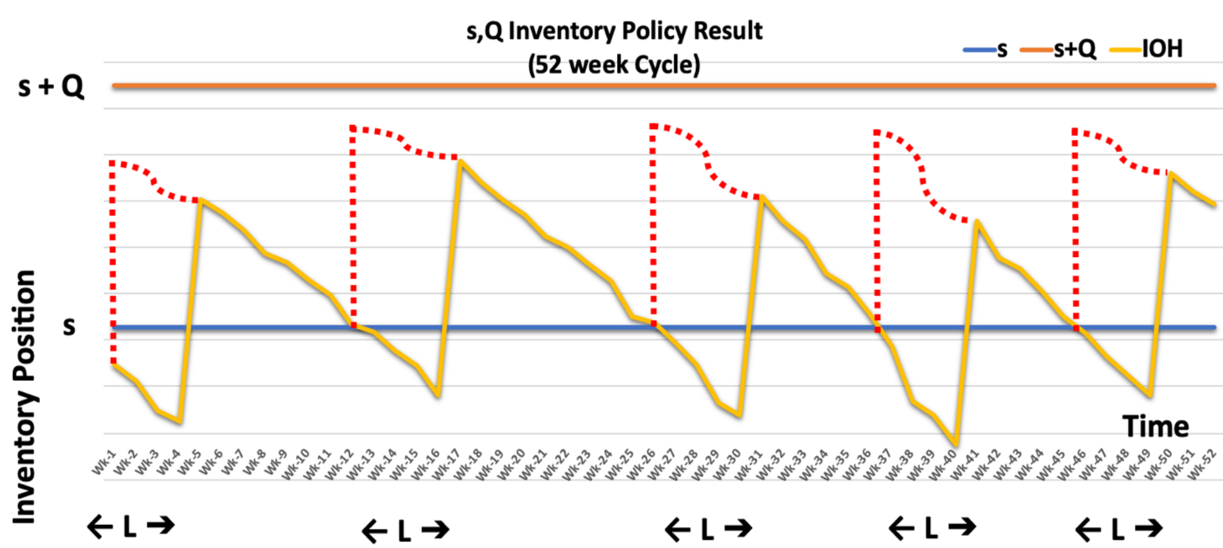


Figure 6 s,Q Inventory Policy Model Result

7.2 Periodic Review Inventory Model (R,S)

The result under this policy model shows the review period is 2 weeks, and the order up to level is 65,556 tons of raw materials. Based on equation (5) or (6) The total relevant cost under this policy is a little over $10 million. Figure 7 shows the inventory position, the review period and up to S level under this policy in the 52-week period.

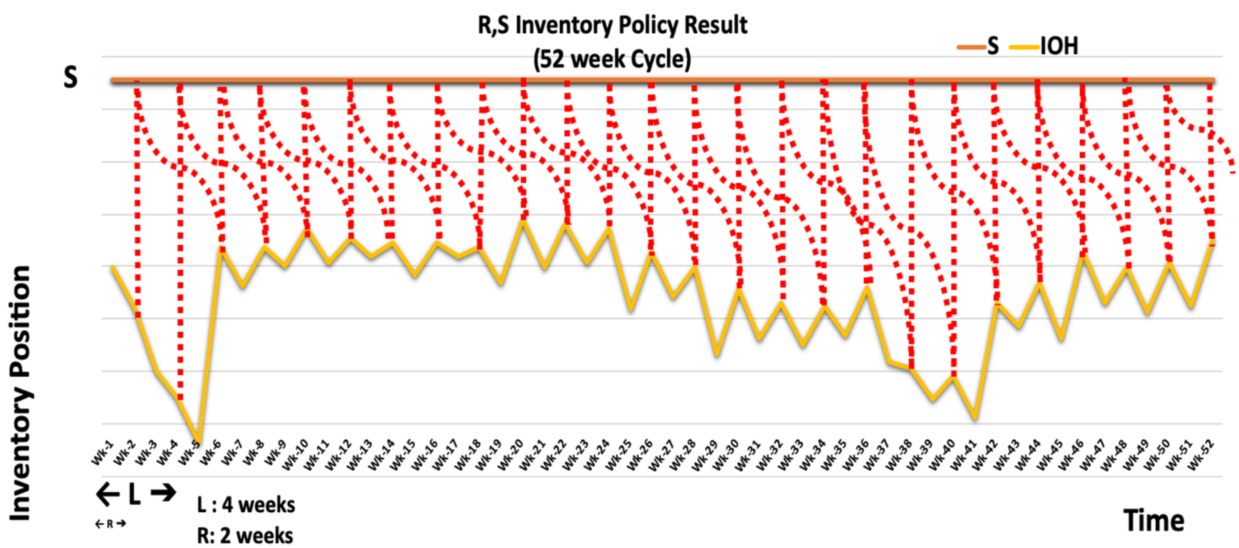


Figure 7 R,S Inventory Policy Model Result

Since in each period, the order quantity Q* is different, the order quantity is determined by the amount reaching to the up to level. The ordered amount is set to be the difference between the up to level S and the inventory position. Different quantities are ordered in each review period and received in 4 weeks (lead time) later in inventory. Figure 8 shows the position of the order and receive quantity for the 52 weeks period.

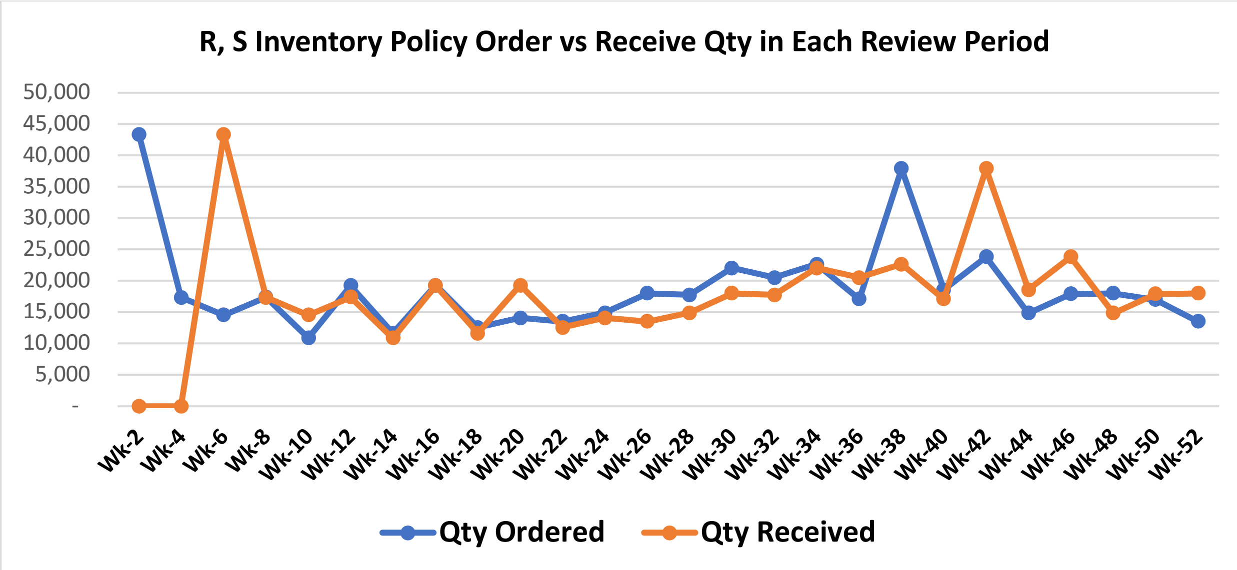


Figure 8 Inventory Policy Order vs Receive Qty in Each Review Period

Table 1 shows the detailed quantity of the order and receive quantity for each of the 52-weeks period.

Table 1 R,S Inventory Policy Order Quantity with Review Period

Week Ordered	Qty Ordered	Week Received
Wk-2	43,362	Wk-6
Wk-4	17,334	Wk-8
Wk-6	14,562	Wk-10
Wk-8	17,406	Wk-12
Wk-10	10,890	Wk-14
Wk-12	19,242	Wk-16
Wk-14	11,664	Wk-18
Wk-16	19,278	Wk-20
Wk-18	12,582	Wk-22
Wk-20	14,076	Wk-24
Wk-22	13,536	Wk-26
Wk-24	14,922	Wk-28
Wk-26	18,000	Wk-30
Wk-28	17,748	Wk-32
Wk-30	22,032	Wk-34
Wk-32	20,538	Wk-36
Wk-34	22,644	Wk-38
Wk-36	17,100	Wk-40
Wk-38	37,926	Wk-42
Wk-40	18,594	Wk-44
Wk-42	23,850	Wk-46
Wk-44	14,832	Wk-48
Wk-46	17,910	Wk-50
Wk-48	18,000	Wk-52
Wk-50	16,974	Wk-2 Following Year
Wk-52	13,536	Wk-4 Following Year

7.3 Total Relevant Cost Comparison

The comparison of the total relevant cost under these two inventory policies is shown in Table 2. The model shows that under the (R,S) policy total annual relevant cost is much lower than under the s,Q policy with the same service level. The saving is about $4.6 million dollars. The ordering cost under (R,S) policy is much higher than under the (s,Q) policy mainly because of the smaller order quantity but higher order frequency. The holding cost of the (s,Q) policy is higher, due to huge on-hand inventory costs (cycle stock), longer order intervals and larger order size in each order interval.

Table 2 s,Q and R,S Inventory Policy Total Relevant Cost Comparison

s,Q Inventory Policy

Quantity				
s - Reorder Point	**Q in ton**	**Safety Stock**	**Shortage**	**Ttl Order Count**
45,685	104,346	10,794	399	5

TRC			
Order Cost	**Holding Cost**	**Shortage Cost**	**Total Cost**
$7,500	$14,687,189	$43,864	$14,738,553

R,S Inventory Policy

Quantity				
S - Order upto	**Q in ton**	**Safety Stock**	**Shortage**	**Ttl Order Count**
65,556	* Table 1	13,220	488	24

TRC			
Order Cost	**Holding Cost**	**Shortage Cost**	**Total Cost**
$39,000	$10,038,357	$53,723	$10,131,081

8. Sensitivity Analysis

This section addresses two sensitive analysis: the review period (R) and the service level (CSL).

8.1 Review Period Sensitivity Analysis

As in the previous section, the review period is identified as 2 weeks. Further analysis was done to find the impact if the review period changes to every week, every 3 weeks, every 4 weeks, and every 5 weeks. The impact is measured on the total annual relevant cost as defined in the methodology section – equation (5) or (6). The service level (CSL) set as management decided, which is 90%.

The number of the review period was changed in the model and then the total relevant cost result of each model run has been recorded. Figure 9 shows the trend of an increasing number of the review period. It can easily be seen that the lowest TRC of the review period is 2 weeks.

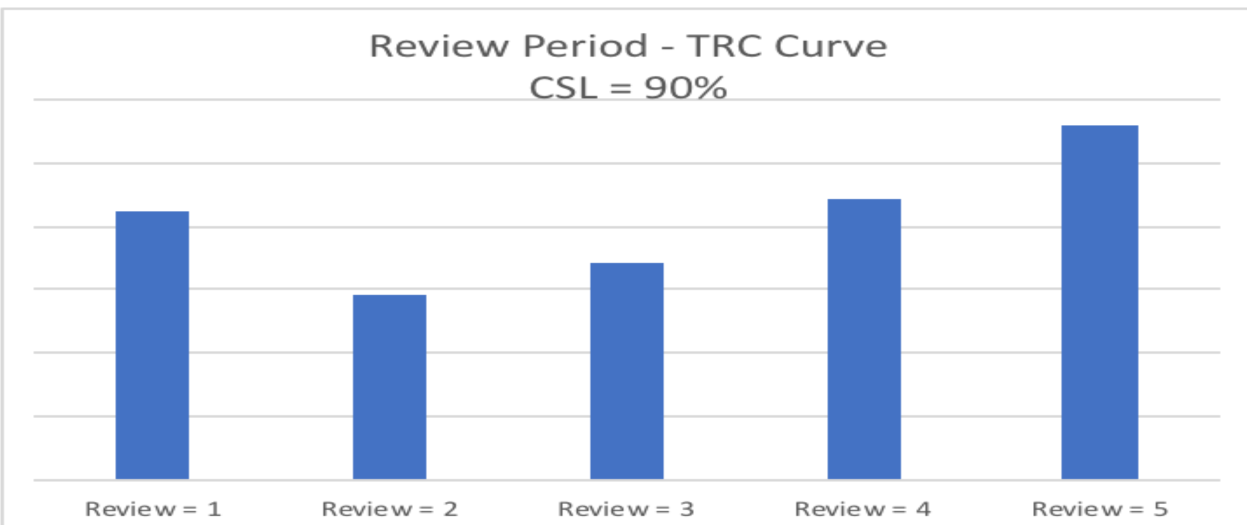


Figure 9 Sensitivity Analysis on Review Period – R

Table 3 shows the dispersion of the total relevant cost has a huge impact on different review periods.

Table 3 Review Period Sensitivity Analysis TRC of Review Period = 2 and Service Level CSL = 90%

Review Sensitivity - Dispersion from the management advised csl (R=2, CSL 90%)

CSL 90%	Review = 1	Review = 2	Review = 3	Review = 4	Review = 5
TRC	($675,984)	$0	($4,719,743)	($5,216,229)	($5,799,050)

8.2 CSL Sensitivity Analysis

The next step was setting the defined review period to 2 weeks to find if the management decided 90% service level is a proper service level for the company. The review period was set to 2 weeks and changed the CSL setting for every model run. The model suggests the optimal CSL is 95%. Figure 9 shows the TRC curve of the different CSL levels. It can easily seen in figure 10 that 95% CSL posts the lowest total relevant costs.

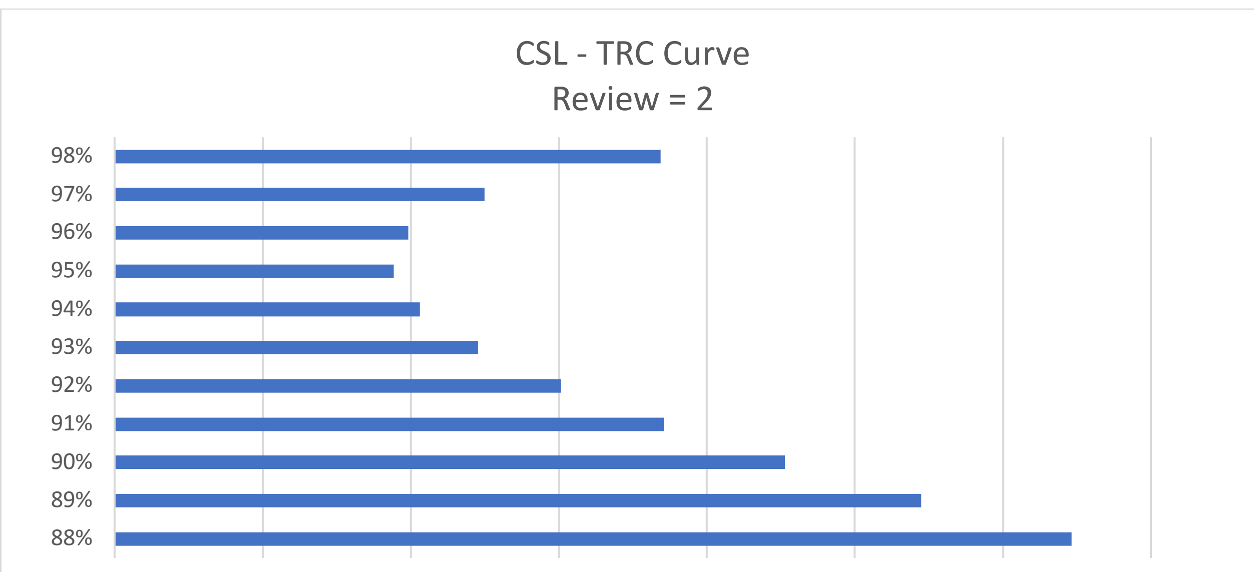


Figure 10 Service Level CSL Sensitivity Analysis Total Relevant Cost Curve

The result is obviously different from the management decided, which is 90% level, by comparing to the impact of the different (CSL) levels. Table 4 shows the dispersion of the total relevant cost from the optimal solution that the model found, which is the review period as 2 weeks and CSL as 95%.

Table 4 Sensitivity Analysis TRC Difference

TRC Sensitivity - Dispersion from the optimal (R=2, CSL 95%)

CSL 90%	Review = 1	Review = 2	Review = 3	Review = 4	Review = 5
TRC	($940,379)	($264,395)	($531,359)	($1,027,845)	($1,610,666)

Review Period = 2 Weeks	93%	94%	95%	96%	97%	98%
TRC	($57,032)	($17,957)	$0	($10,193)	($61,259)	($180,566)

Table 4 shows that if the company uses 95% CSL and review every 2 weeks, the company is going to lose almost $264,400 for a year period than the currently defined result, which is 90% CSL and 2 weeks review period. For the review period as 2 weeks, the company is going to lose $17,957 for service level at 94% and lose $10,193 for service level at 96%. However, even though the model suggested that we use 95% CSL, it is not recommended that a high service level. The reasons are so many uncertainties and constraints in the industry, such as the production capacity, long production lead time, the labor burden rate, the design change, the warehouse capacity, etc. The high 95% CSL will hurt the business if the company cannot meet the customer demand within the committed lead time and it will also create a huge inventory holding costs. I would suggest the company to rethink the strategy and find a proper service level anyway between 91% - 93%.

9. Scenarios for Each Site

In the section above, a better inventory policy was identified for the company, which is the (R,S) policy. This policy is calculated under the aggregated level from centralized inventory planning. In order to do a better inventory planning for the centralized team, individual manufacturing sites' inventory policy need to be consolidated. In this chapter, the (R,S) policy is applied to 5 major manufacturing sites. The data gathered is specifically from those 5 manufacturing sites. The methodology and parameters align with the (R,S) inventory model defined in the previous chapter. The purpose is to find the optimal safety stock, review period and order quantity for each site under the selected inventory policy.

9.1 Site 1 Inventory Policy

Site 1 is one of the manufacturing facilities located in Nebraska. Under the selected (R,S) policy, this site should order every 3 weeks. The safety stock level for this site is 2,948 tons of material. Figure 11 shows the inventory chart for site 1.

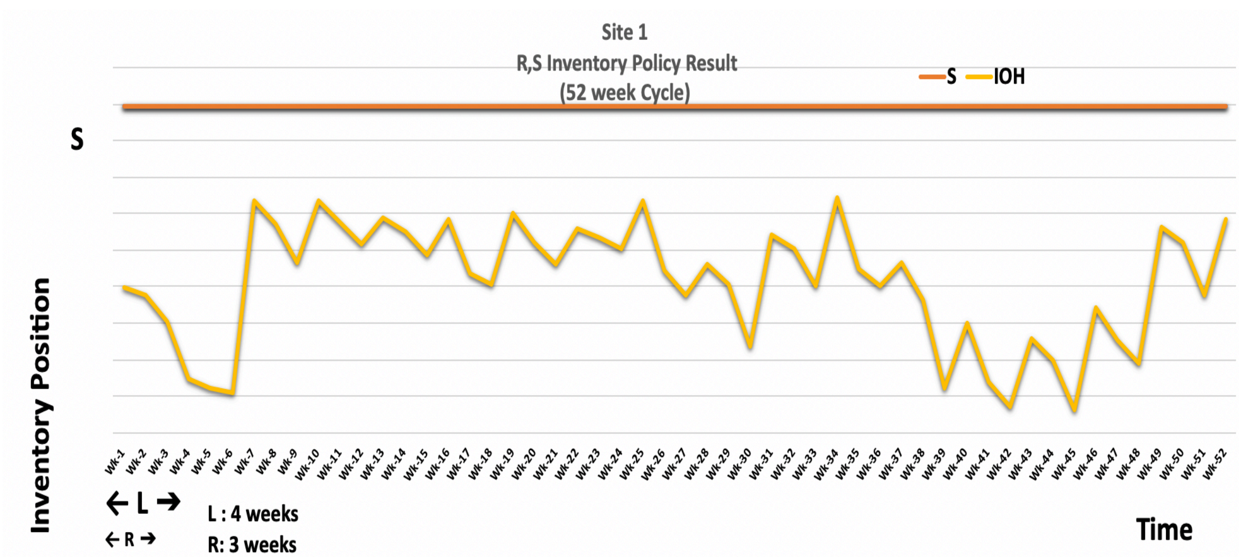


Figure 11 Site 1 R,S Inventory Policy Result

The order vs receive quantity position is shown in figure 12.

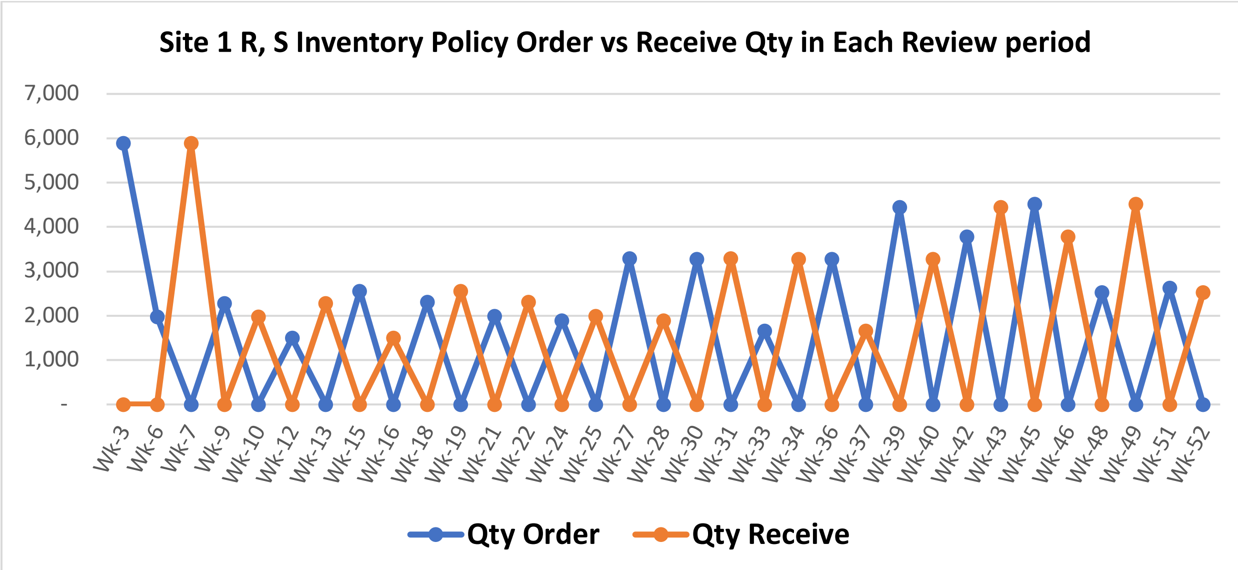


Figure 12 Site 1 R,S Inventory Policy Order vs Receive in Each Review Period

The detailed order quantity for site 1 is shown in Table 5.

Table 5 Site 1 R,S Inventory Policy Review Period with Order Quantity

Week Ordered	Qty Order	Week Received
Wk-3	5,886	Wk-7
Wk-6	1,980	Wk-10
Wk-9	2,286	Wk-13
Wk-12	1,494	Wk-16
Wk-15	2,556	Wk-19
Wk-18	2,304	Wk-22
Wk-21	1,998	Wk-25
Wk-24	1,890	Wk-28
Wk-27	3,294	Wk-31
Wk-30	3,276	Wk-34
Wk-33	1,656	Wk-37
Wk-36	3,276	Wk-40
Wk-39	4,446	Wk-43
Wk-42	3,780	Wk-46
Wk-45	4,518	Wk-49
Wk-48	2,520	Wk-52
Wk-51	2,628	Wk-3 Following Year

9.1.1 Site 1 Optimal Solution

After running several scenarios, the optimal review period for Site 1 if order individually is every 3 weeks. Figure 10 shows that if review period is every 3 weeks, the total relevant cost will be slightly lower than review in every 2 weeks. If review period is every week, the company will pay a lot of ordering cost and inventory holding cost.

Other scenarios were run to find the optimal CSL, which is 93%. Figure 13 shows the changes of the total relevant cost curve. The TRC is lowest at the CSL 93% with review period in every 3 weeks.

The total savings of the CSL at 93% and review period in every 3 weeks is $14,905 lower than the selected CSL 90% and review in every 2 weeks if site 1 make the inventory decision individually.

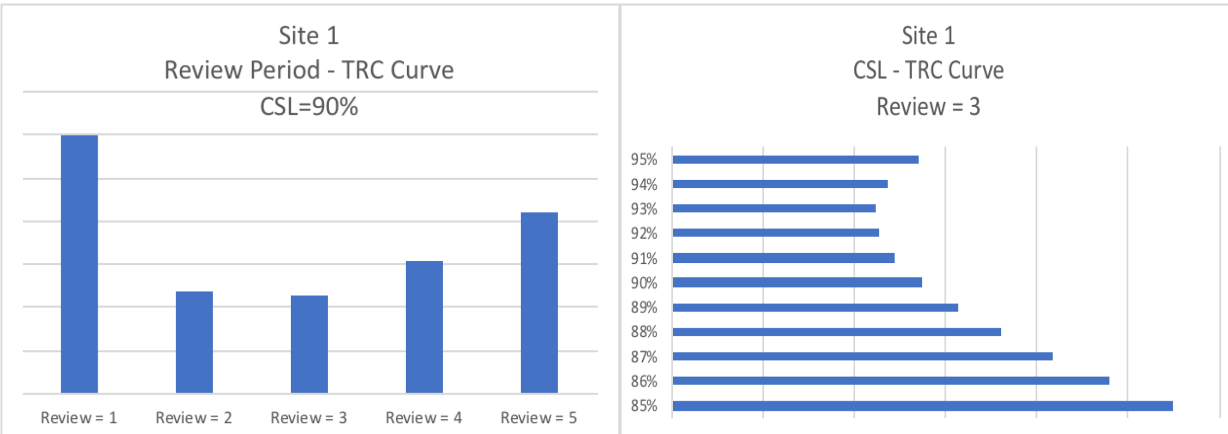


Figure 13 Site 1 Review Period and Service Level Sensitivity Chart

If the Site 1 makes the decision individually, the model suggests the recommended solution to manage and plan the inventory is review every 3 weeks and a 93% service level.

9.2 Site 2 Inventory Policy

Site 2 is another manufacturing facility located in Kansas. Under the selected (R,S) policy, this site orders every 2 weeks. The safety stock level for this site is 1,757 tons of material. Under this policy, this site experienced two stock shortages, in week 4 and week 5. Figure 14 shows the inventory policy chart for site 2.

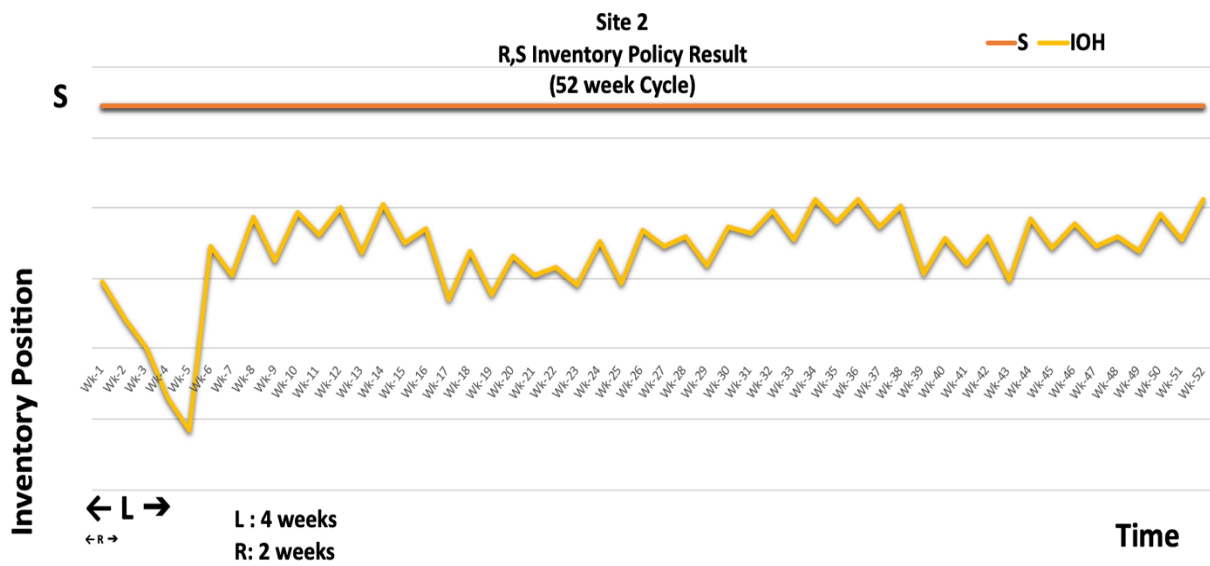


Figure 14 Site 2 R,S Inventory Policy Result

The order vs receive quantity position for site 2 is shown in figure 15.

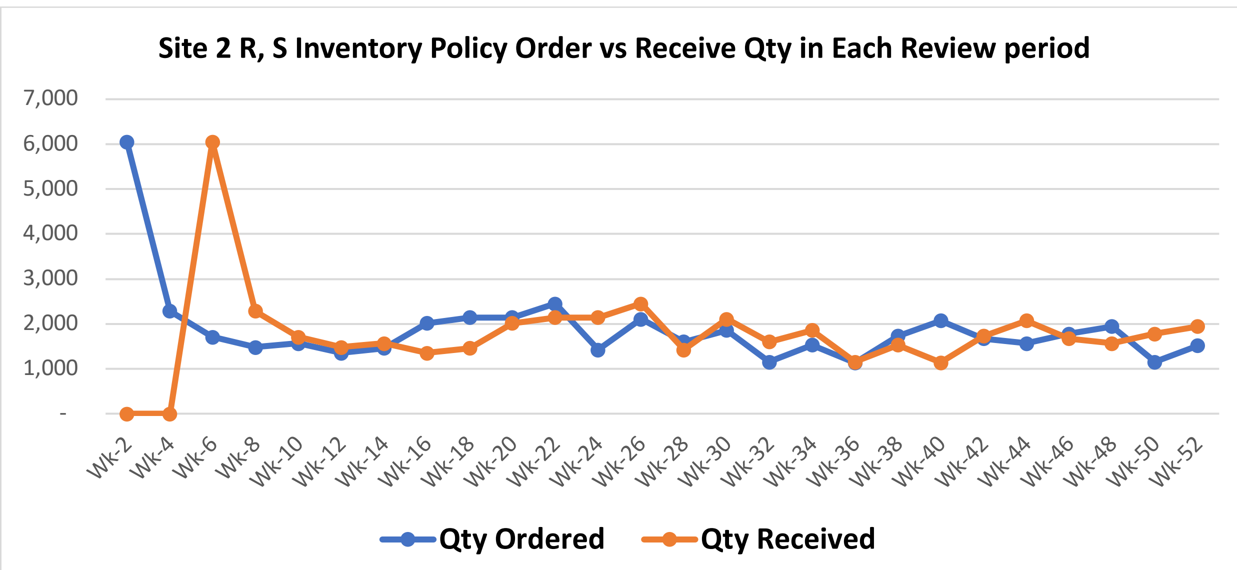


Figure 15 Site 2 R,S Inventory Policy Order vs Receive in Each Review Period

The detailed order quantity for site 2 is shown in Table 6.

Table 6 Site 2 R,S Inventory Policy Review Period with Order Quantity

Week Ordered	Qty Ordered	Week Received
Wk-2	6,048	Wk-6
Wk-4	2,286	Wk-8
Wk-6	1,710	Wk-10
Wk-8	1,476	Wk-12
Wk-10	1,566	Wk-14
Wk-12	1,350	Wk-16
Wk-14	1,458	Wk-18
Wk-16	2,016	Wk-20
Wk-18	2,142	Wk-22
Wk-20	2,142	Wk-24
Wk-22	2,448	Wk-26
Wk-24	1,422	Wk-28
Wk-26	2,106	Wk-30
Wk-28	1,602	Wk-32
Wk-30	1,854	Wk-34
Wk-32	1,152	Wk-36
Wk-34	1,530	Wk-38
Wk-36	1,134	Wk-40
Wk-38	1,728	Wk-42
Wk-40	2,070	Wk-44
Wk-42	1,674	Wk-46
Wk-44	1,566	Wk-48
Wk-46	1,782	Wk-50
Wk-48	1,944	Wk-52
Wk-50	1,152	Wk-2 Following Year
Wk-52	1,512	Wk-4 Following Year

9.2.1 Site 2 Optimal Solution

Figure 16 shows the TRC curve for the review period and service level for Site 2 by using the same methodology as described in Site 1 analysis. The result suggests the optimal review period is every 2 weeks and the optimal service level is 95%.

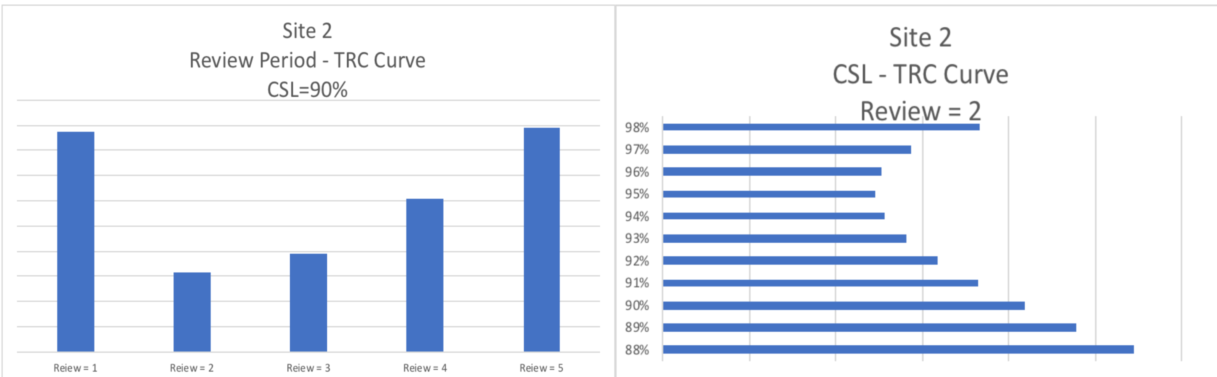


Figure 16 Site 2 Review Period and Service Level Sensitivity Chart

9.3 Site 3 Inventory Policy

Site 3 is the manufacturing facility located in the far east coast in Pennsylvania. Under the selected (R,S) policy, this site orders every 2 weeks. The safety stock level for this site is 2,020 tons of material. Under this policy, this site did not experience a stock shortage. Figure 17 shows the inventory policy chart for site 3.

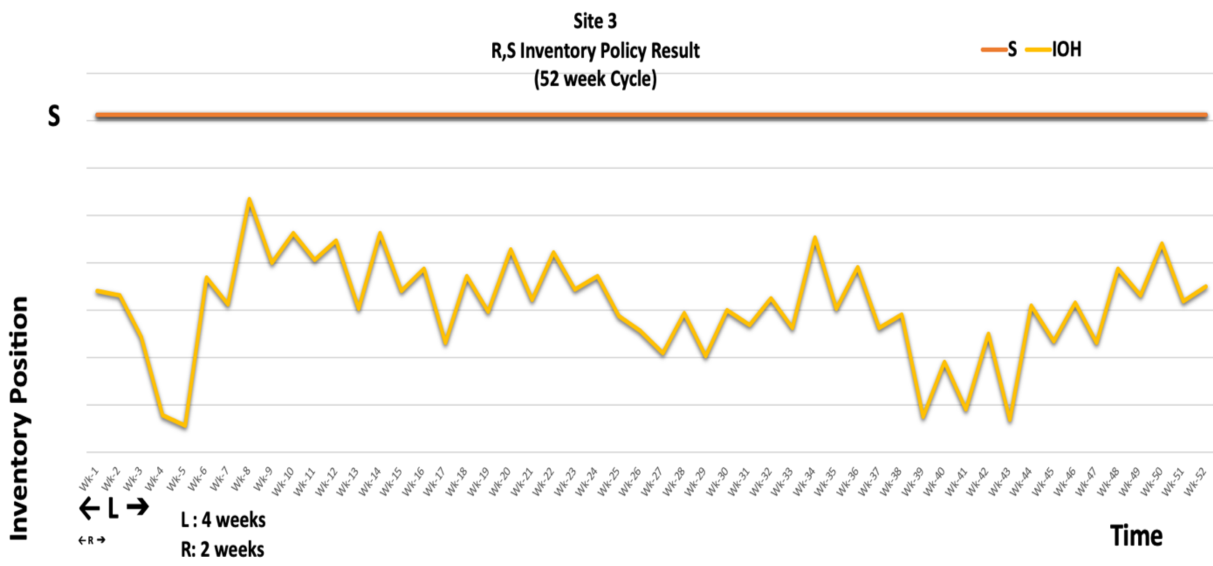


Figure 17 Site 3 R,S Inventory Policy Result

The order vs receive quantity position for site 3 is shown in figure 18.

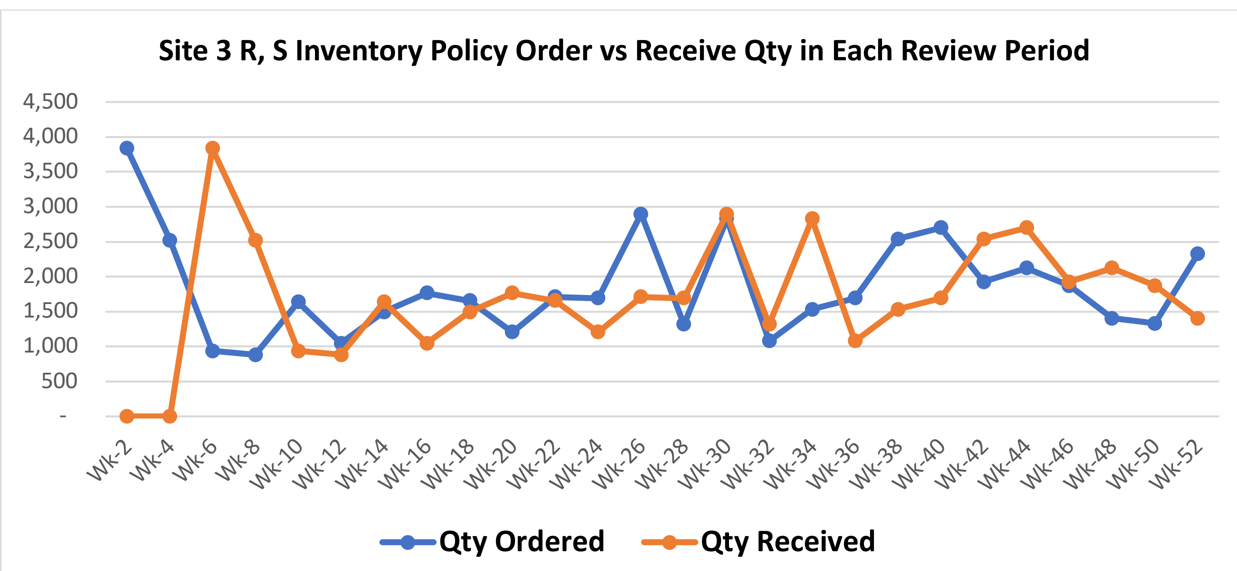


Figure 18 Site 3 R,S Inventory Policy Order vs Receive in Each Review Period

The detailed order quantity is shown in Table 7.

Table 7 Site 3 R,S Inventory Policy Review Period with Order Quantity

Week Ordered	Qty Ordered	Week Received
Wk-2	3,834	Wk-6
Wk-4	2,520	Wk-8
Wk-6	936	Wk-10
Wk-8	882	Wk-12
Wk-10	1,638	Wk-14
Wk-12	1,044	Wk-16
Wk-14	1,494	Wk-18
Wk-16	1,764	Wk-20
Wk-18	1,656	Wk-22
Wk-20	1,206	Wk-24
Wk-22	1,710	Wk-26
Wk-24	1,692	Wk-28
Wk-26	2,898	Wk-30
Wk-28	1,314	Wk-32
Wk-30	2,826	Wk-34
Wk-32	1,080	Wk-36
Wk-34	1,530	Wk-38
Wk-36	1,692	Wk-40
Wk-38	2,538	Wk-42
Wk-40	2,700	Wk-44
Wk-42	1,926	Wk-46
Wk-44	2,124	Wk-48
Wk-46	1,872	Wk-50
Wk-48	1,404	Wk-52
Wk-50	1,332	Wk-2 Following Year
Wk-52	2,322	Wk-4 Following Year

9.3.1 Site 3 Optimal Solution

Figure 19 shows the TRC curve for the review period and service level for Site 3 by using the same methodology as in Site 1 analysis. The result suggests the optimal review periods is every 2 weeks and the optimal service level is 95%.

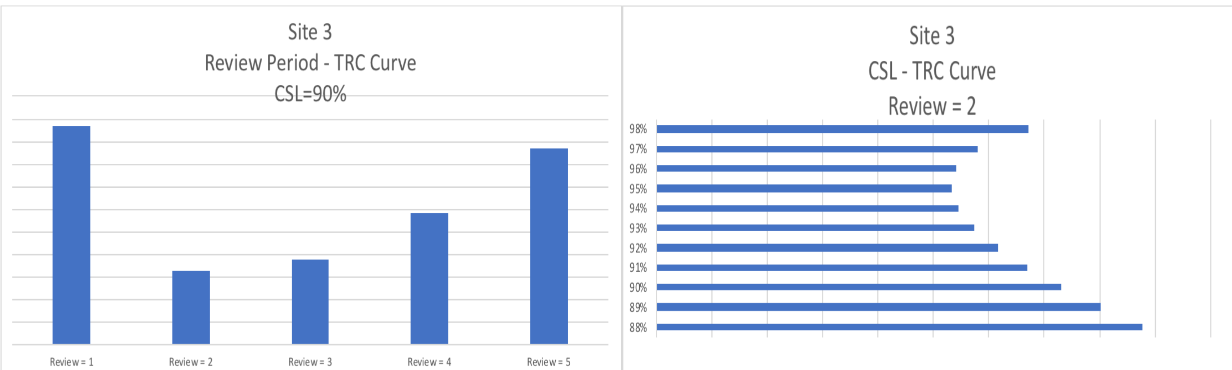


Figure 19 Site 3 Review Period and Service Level Sensitivity Chart

9.4 Site 4 Inventory Policy

Site 4 is one of the largest manufacturing facilities located in Tenseness. Demand is very unstable in this facility. Under the selected (R,S) policy, this site orders in every 2 weeks. The safety stock level for this site is 6,198 tons of material. Under this policy, this site experienced five stock shortages, in weeks 4, week 5, week 39, week 41 and week 43. Figure 20 shows the inventory policy chart for site 4.

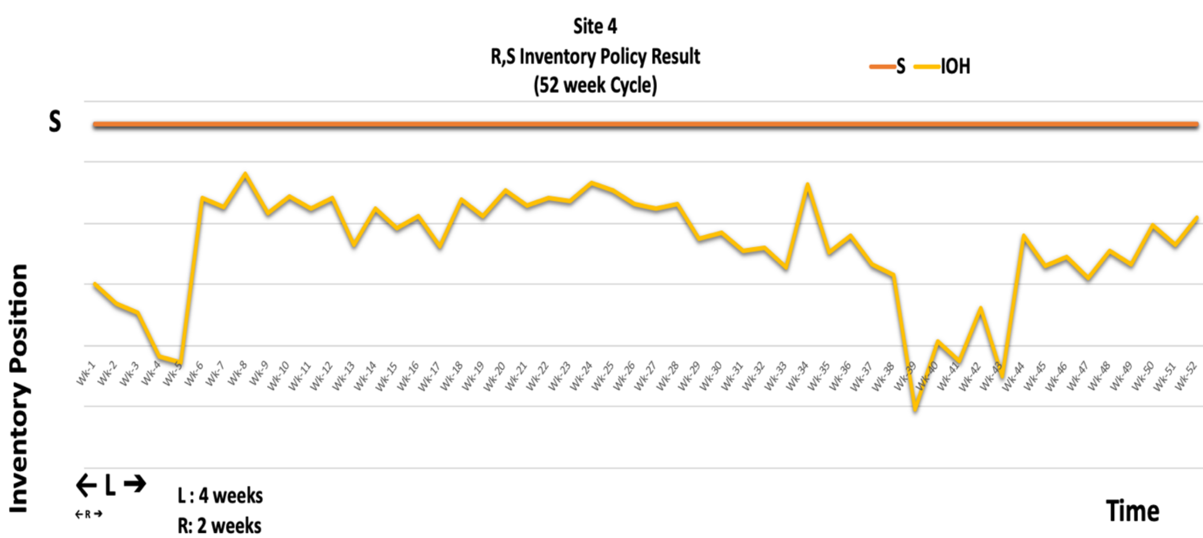


Figure 20 Site 4 R,S Inventory Policy Result

The order vs receive quantity position for site 4 is shown in figure 21.

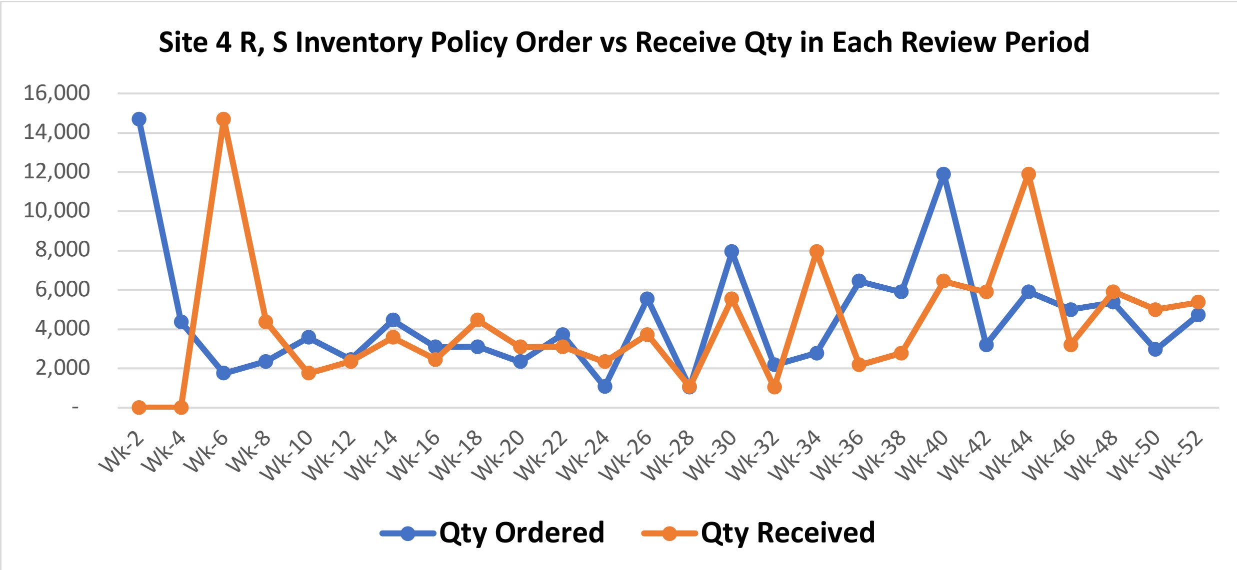


Figure 21 Site 4 R,S Inventory Policy Order vs Receive in Each Review Period

The detailed order quantity in each review period is shown in Table 8.

Table 8 Site 4 R,S Inventory Policy Review Period with Order Quantity

Week Ordered	Qty Ordered	Week Received
Wk-2	14,688	Wk-6
Wk-4	4,374	Wk-8
Wk-6	1,746	Wk-10
Wk-8	2,358	Wk-12
Wk-10	3,564	Wk-14
Wk-12	2,448	Wk-16
Wk-14	4,446	Wk-18
Wk-16	3,078	Wk-20
Wk-18	3,096	Wk-22
Wk-20	2,340	Wk-24
Wk-22	3,726	Wk-26
Wk-24	1,062	Wk-28
Wk-26	5,544	Wk-30
Wk-28	1,026	Wk-32
Wk-30	7,938	Wk-34
Wk-32	2,178	Wk-36
Wk-34	2,772	Wk-38
Wk-36	6,444	Wk-40
Wk-38	5,886	Wk-42
Wk-40	11,898	Wk-44
Wk-42	3,204	Wk-46
Wk-44	5,904	Wk-48
Wk-46	4,986	Wk-50
Wk-48	5,364	Wk-52
Wk-50	2,952	Wk-2 Following Year
Wk-52	4,716	Wk-4 Following Year

9.4.1 Site 4 Optimal Solution

Figure 22 shows the TRC curve for the review period and service level for Site 4 by using the same methodology as in previous analysis. The result suggests the optimal review periods is every 2 weeks and the optimal service level is 95%.

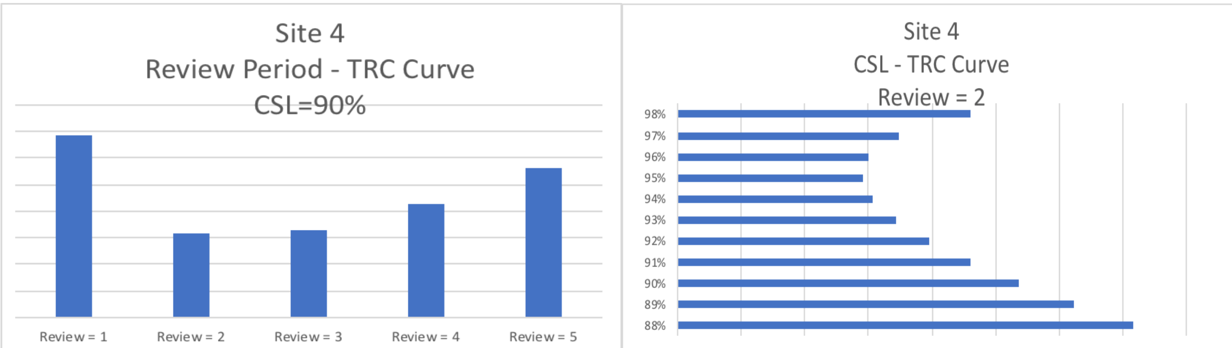


Figure 22 Site 4 Review Period and Service Level Sensitivity Chart

9.5 Site 5 Inventory Policy

Site 5 is the largest manufacturing facility located in Oklahoma. Demand tends to be stable for this site. Under the selected (R,S) policy, this site orders in every 2 weeks. The safety stock level for this site is 5,190 tons of material. Under this policy, this site experienced three stock shortages, in week 3, week 4 and week 5. Figure 23 shows the inventory policy chart for site 5.

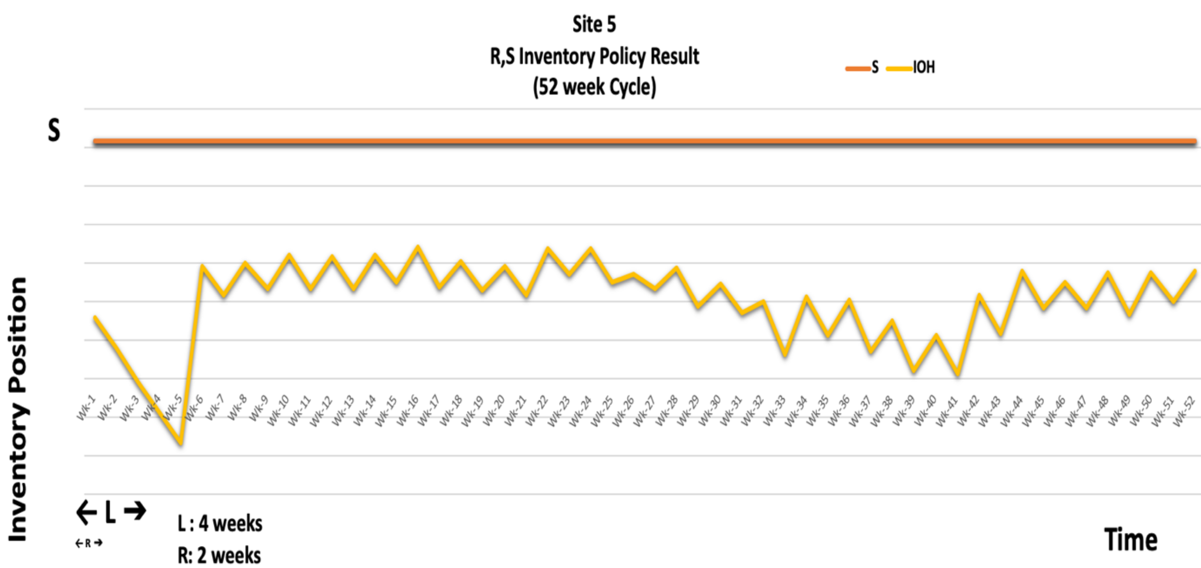


Figure 23 Site 5 R,S Inventory Policy Result

The order vs receive quantity position for site 5 is shown in figure 24.

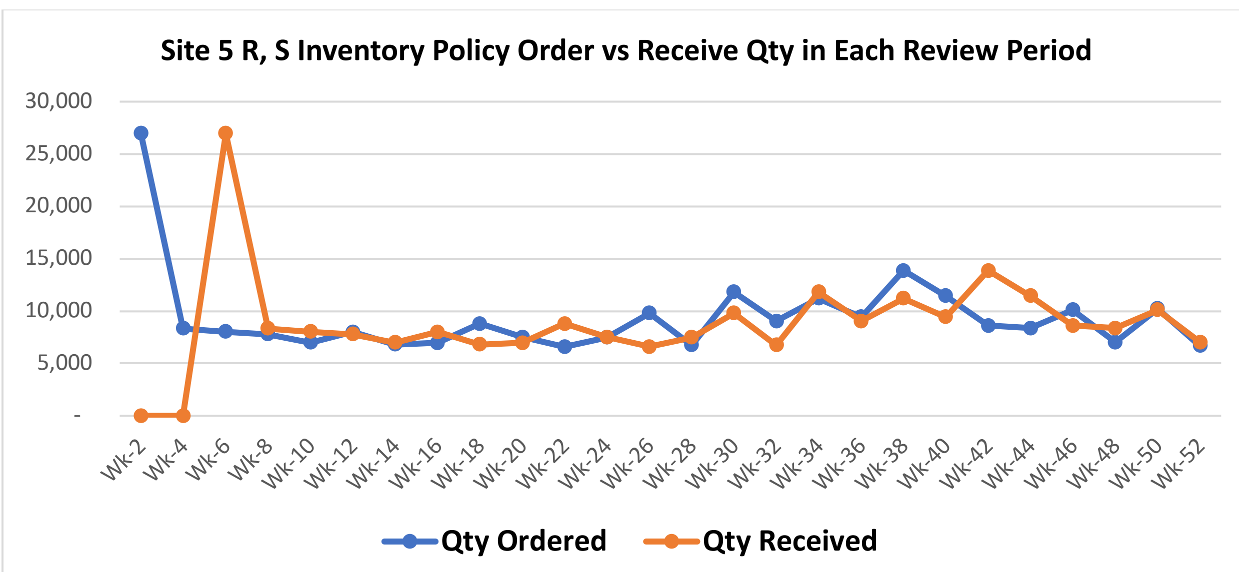


Figure 24 Site 5 R,S Inventory Policy Order vs Receive in Each Review Period

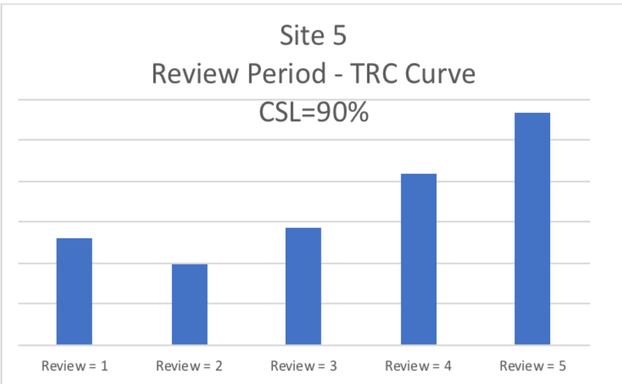
The detailed order quantity in each review period is in Table 9.

Table 9 Site 5 R,S Inventory Policy Review Period with Order Quantity

Week Ordered	Qty Ordered	Week Received
Wk-2	26,946	Wk-6
Wk-4	8,352	Wk-8
Wk-6	8,046	Wk-10
Wk-8	7,794	Wk-12
Wk-10	6,984	Wk-14
Wk-12	7,992	Wk-16
Wk-14	6,822	Wk-18
Wk-16	6,966	Wk-20
Wk-18	8,802	Wk-22
Wk-20	7,524	Wk-24
Wk-22	6,588	Wk-26
Wk-24	7,470	Wk-28
Wk-26	9,792	Wk-30
Wk-28	6,750	Wk-32
Wk-30	11,826	Wk-34
Wk-32	9,054	Wk-36
Wk-34	11,214	Wk-38
Wk-36	9,432	Wk-40
Wk-38	13,878	Wk-42
Wk-40	11,448	Wk-44
Wk-42	8,622	Wk-46
Wk-44	8,370	Wk-48
Wk-46	10,098	Wk-50
Wk-48	7,020	Wk-52
Wk-50	10,224	Wk-2 Following Year
Wk-52	6,678	Wk-4 Following Year

9.5.1 Site 5 Optimal Solution

Figure 25 shows the TRC curve for the review period and service level for Site 5 by using the same methodology as in previous analysis. The result suggests the optimal review periods is every 2 weeks and the optimal service level is 95%.



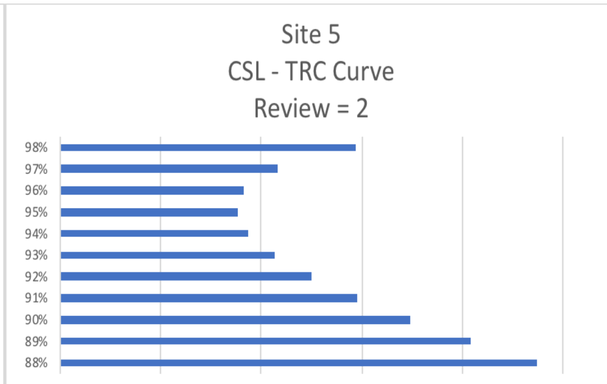


Figure 25 Site 5 Review Period and Service Level Sensitivity Chart

9.6 Observations and Suggestions

As we can see from the above sensitivity analyses, the models suggest that 4 out of 5 sites use the 95% service level. According to the model, the company will have savings if it adopts the 95% CSL rather than the current management defined 90%. However, even though the model suggested to go with 95% CSL, that high service level is not recommended for the company, because of the constraints and uncertainties reasons in the company and the industry. The company should rethink the strategy and find a proper service level between 91%-93%, which did not have huge cost than 90% CSL but leverage the risks of 95% CSL.

10. Conclusion and Future Research

This capstone project studied the raw materials inventory planning of an ETO utility infrastructures manufactures. The study compared two inventory models, the continuous (s,Q) inventory model and periodic (R,S) inventory model, for the ETO company.

To limit the scope, this capstone builds on long-term and returned customers, who order from the company on a regular basis. Even if there are new products from those customers or the current products require some design changes, the order is guaranteed to be placed with the company. This elliminated the limitation on the uncertain bid win/loss situations.

The (s,Q) model calculates different order quantities for every order cycle when inventory reaches a certain point. The model suggests a safety stock level by using the managerial decided service level 90%. The (R,S) model suggests the optimal review period is 2 week. The model provides safety stock level and more detailed order quantity in each review period.

The better model, (R,S) inventory model, was suggested based on running a 52-week total annual relevant cost simulation. The model suggests proper safety stock level, review period and order quantity for the company, and for each manufacturing site as well.

Sensitivity analysis was built to test how different values of the input variables affect the total annual relevant cost. According to the sensitivity analysis, a 2-week review period is confirmed the optimal solution. However, the managerial decided service level 90% will not be the optimal solution for the company. The model suggests the service level at 95% is optimal. The management team should re-evaluate their decisions on the service level.

During the model building process, there were some limitations and constraints that need to be further considered, such as project bid win or loss uncertainty, bid project-based ETO business model, inefficient S&OP process, etc. Furthermore, during severe weather conditions, such as hurricane season, many power utility poles and power substations destroyed and the demand to the company to replace those destroyed structures skyrocketed. Since the company is one of the largest utility power substation and utility power transmission poles in North America, the sporadic extreme weather events magnified the already problematic supply chain. In all, how to correlate those uncertainties with the models will improve the performance of the model. Future researches need to consider the weather conditions in the demand forecast for the company and this particular industry.

References

Amaro, G., Hendry, L., Kingsman, B., 1999. Competitive advantage, customization and a new taxonomy for non-make-to-stock companies. International Journal of Operations & Production Management 19 (4), 349–371.

Boute, Robert N., Stephen M. Disney, Marc R. Lambrecht, and Benny Van Houdt. 2014. "Coordinating Lead Times and Safety Stocks under Autocorrelated Demand." European Journal of Operational Research 232 (1): 52–63.

Boute, R. N., Lambrecht, M. R., & Van Houdt, B. 2007. Performance evaluation of a production/inventory system with periodic review and endogenous lead times. Naval Research Logistics, 54(4), 462–473.

Caceres, Hernan, Dongchen Yu, and Alexander Nikolaev. 2018. "Evaluating Shortfall Distributions in Periodic Inventory Systems with Stochastic Endogenous Demands and Lead-Times." Annals of Operations Research, January.

Gosling, Jonathan, and Mohamed M. Naim. 2009. "Engineer-to-Order Supply Chain Management: A Literature Review and Research Agenda." International Journal of Production Economics 122 (2): 741–54.

Graves, C, Stephen 1987 "Safety Stocks in Manufacturing Systems".

Humair, Salal, John D. Ruark, Brian Tomlin, and Sean P. Willems. 2013. "Incorporating Stochastic Lead Times Into the Guaranteed Service Model of Safety Stock Optimization." Interfaces 43 (5): 421–34.

Johnson, P. F., Leenders, M. R., & Fearon, H. E. 1998) Evolving roles and responsibilities of purchasing organizations. International Journal of Purchasing and Materials Management, 34(4), 2–11.

Kozjek, Dominik, Rok Vrabič, Borut Rihtaršič, and Peter Butala. 2018. "Big Data Analytics for Operations Management in Engineer-to-Order Manufacturing." *Procedia CIRP* 72: 209–14.

Lisan, Sharfuddin. 2018. "Safety Stock Determination of Uncertain Demand and Mutually Dependent Variables." International Journal of Business and Social Research, 11. Volume 08, Issue 03, 2018. 01-11

Mukherjee, Sayanti, Roshanak Nateghi, and Makarand Hastak. 2018. "A Multi-Hazard Approach to Assess Severe Weather-Induced Major Power Outage Risks in the U.S." Reliability Engineering & System Safety 175 (July): 283–305.

Porter, M. E., & Millar, V. E. 1985. How information gives you competitive advantage. Harvard Business Review, pp. 149–160.

Porter, K., Little, D., Peck, M., Rollins, R., 1999. Manufacturing classifica- tions: relationships with production control systems. Integrated Manufacturing Systems 10 (4), 189–199.

Prak, D., Teunter, R., & Syntetos, A. 2017. On the calculation of safety stocks when demand is forecasted. European Journal of Operational Research, 256(2), 454-461. doi:10.1016/j.ejor.2016.06.035

Ruiz-Torres AJ, Mahmoodi F 2010. Safety stock determination based on parametric lead time and demand information. International Journal of Production Research 48(10):2841–2857.

Wilson, R. 2009. 20th Annual State of Logistics Report. Council of Supply Chain Management Professionals.

Appendix A – Sensitivity analysis on each site (Review Period R and Service Level CSL)

Site 1 TRC Sensitivity - Dispersion from the optimal (R=3, CSL 93%)

CSL 90%	Review = 1	Review = 2	Review = 3	Review = 4	Review = 5
TRC	($194,709)	($14,904)	($10,074)	($49,485)	($105,719)

Review Period = 3 Weeks	90%	91%	92%	93%	94%	95%
TRC	($10,074)	($4,263)	($761)	$0	($2,603)	($9,512)

Site 2 TRC Sensitivity - Dispersion from the optimal (R=2, CSL 95%)

CSL 90%	Review = 1	Review = 2	Review = 3	Review = 4	Review = 5
TRC	($145,329)	($34,547)	($48,807)	($92,802)	($148,899)

Review Period = 2 Weeks	93%	94%	95%	96%	97%	98%
TRC	($7,355)	($2,276)	$0	($1,461)	($8,349)	($24,300)

Site 3 TRC Sensitivity - Dispersion from the optimal (R=2, CSL 95%)

CSL 90%	Review = 1	Review = 2	Review = 3	Review = 4	Review = 5
TRC	($166,799)	($39,838)	($48,741)	($90,835)	($146,889)

Review Period = 2 Weeks	93%	94%	95%	96%	97%	98%
TRC	($8,502)	($2,640)	$0	($1,657)	($9,553)	($27,869)

Site 4 TRC Sensitivity - Dispersion from the optimal (R=2, CSL 95%)

CSL 90%	Review = 1	Review = 2	Review = 3	Review = 4	Review = 5
TRC	($488,839)	($123,010)	($133,157)	($233,946)	($369,816)

Review Period = 2 Weeks	93%	94%	95%	96%	97%	98%
TRC	($26,380)	($8,243)	$0	($4,946)	($29,045)	($85,125)

Site 5 TRC Sensitivity - Dispersion from the optimal (R=2, CSL 95%)

CSL 90%	Review = 1	Review = 2	Review = 3	Review = 4	Review = 5
TRC	($237,827)	($103,565)	($288,258)	($551,138)	($843,845)

Review Period = 2 Weeks	93%	94%	95%	96%	97%	98%
TRC	($22,301)	($7,006)	$0	($4,044)	($24,132)	($71,009)