Raw Material Inventory Strategy for Make-to-Order Manufacturing

by

Vikash Chandra
Bachelor of Technology, Production Engineering, National Institute of Technology, Tiruchirappalli, 2008

and

Michael Tully
Bachelor of Science, Management, United States Military Academy, 2005

SUBMITTED TO THE PROGRAM IN SUPPLY CHAIN MANAGEMENT
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ENGINEERING IN LOGISTICS

AT THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2016

Signature of Author.. Signature redacted
Master of Engineering in Logistics Program
May 12, 2016

Signature of Author.. Signature redacted
Master of Engineering in Logistics Program
May 12, 2016

Certified by.. Signature redacted
Dr. Fredrik Eng Larsson
Postdoctoral Associate, Center for Transportation & Logistics
Thesis Supervisor

Accepted by.. Signature redacted
Dr. Yossi Sheffi
Director, Center for Transportation and Logistics
Elisha Gray II Professor of Engineering Systems
Professor, Civil and Environmental Engineering

Raw Material Inventory Strategy for Make-to-Order Manufacturing

by

Vikash Chandra

and

Michael Tully

Submitted to the Program in Supply Chain Management
on May 12, 2016 in Partial Fulfillment of the
Requirements for the Degree of Master of Engineering in Logistics

ABSTRACT

What is the appropriate raw material inventory strategy for a make-to-order manufacturing company? As companies grow in size and the business environment changes over time, many companies adapt their operating policies to remain competitive. However, some policies, such as raw material inventory policies, are left untouched as "legacies" of the company's past due to lower priorities or lack of adequate data. These raw material inventory policies are of particular importance to manufacturing firms, especially those that often operate at maximum capacity or have seasonality in demand. This research proposes a raw material inventory policy evaluation tool that allows a company to understand how certain key performance indicators are affected by various changes in its inventory policy and helps the company devise a strategy. This evaluation tool can then guide the company towards a better inventory policy in the absence of cost information and shows the results in terms of number of events. The company can then adjust various replenishment policies depending on the product's demand characteristics. In addition, the research demonstrates that inventory policy changes can be used to partially overcome supplier service level declines and demand variability.

Thesis Supervisor: Dr. Fredrik Eng Larsson

Title: Postdoctoral Associate, Center for Transportation & Logistics

Acknowledgements

We would like to thank everyone who has assisted us in conducting this research. Our sincerest appreciation goes to our advisor, Dr. Fredrik Eng Larsson. The importance of Fredrik's guidance and constant push to find new ways of exploring and presenting information cannot be overstated. We would also like to thank the Kishore, Thomas and the rest of the team at our sponsor company, without whose support this research would not be possible.

Vikash Chandra would like to thank his family for their unwavering support and guidance that they have provided throughout his life. His mother Veena and father Dinesh are really special people who have gone through a lot of difficulty in their own lives in order to provide the best education for their children. He would like to thank his sister Madhu for always being there for support and showing the right way. He would also like to thank all the members of the SCM family for their friendship, constant support and encouraging smiles. Without each and every one of them, the whole SCM journey wouldn't have been the same.

Michael Tully would like to thank his family for their unending support in all of his endeavors. His mother Susan and father Michael deserve paramount credit for instilling the value of education and for standing by him in his journey for higher learning. He would like to thank his sister Kimberly for her everlasting and exceptionally valuable counsel and encouragement. Finally, he would like to express gratitude to his fellow members of the SCM program for their friendship and contributions to his education.

Table of Contents

List of Figures

List of Tables

1. Introduction

Safety stock policies for raw materials (RM) are of prime concern for companies with large amounts of capital invested in manufacturing facilities. A disruption in the flow of RM can lead to costly stoppages, setup costs and service level breaches. At the same time, overstocking can tie up capital and lead to wastage as materials become obsolete. In this thesis, we devise and test strategies for inventory policies that can offer operational and financial improvements on how to order and stock raw materials so as to maximize the plant utilization and maintain high service levels to customers. In our context, the current process used by our sponsor, a consumer products manufacturer, is a combination of traditional vendor to plant purchasing, vendor consignment fulfillment and intra-company transfers (transshipments) in which raw materials are moved from a plant with excess material to a plant in need of raw material. Additionally, the current policy is reactive in nature and often involves a combination of expedited orders and increased freight fees in order to meet production deadlines. Production schedules are created with the assumption that raw materials are in stock at the appropriate plant. In the event that raw materials are not available for use at a given plant, the planning and transportation teams must then coordinate the movement of raw materials to the appropriate location. This thesis proposes a more proactive inventory policy grounded in analytics to ensure efficiency and reduce costs.

The objective for this thesis is to evaluate the current inventory policy of the sponsor and compare different inventory policies under varying circumstances to create strategies for raw materials replenishment. These strategies will then be used as guidelines by the sponsor to optimally set the replenishment policies in the Enterprise Resource Planning (ERP) system to more efficiently procure and allocate safety stock.

A number of researchers have tackled the scenario of one centralized raw material inventory serving multiple locations while allowing for transshipments between locations. Generally, the research has considered only one or two replenishment routes. Many also use zero or negligible lead-time for replenishment in models along with assumptions that demand is lost if it cannot be immediately met. Some of these studies have shown transshipment to be an effective part of inventory management policy as it allows a company to better match supply with demand across several locations. However, such programs should be tailored to an individual situation. Additionally, none of the research tackling these problems allows for raw material quality checks. The situation researched in this thesis is unique in that we attempt to explore a safety stock policy that combines three different urgency dependent replenishment routes for a plant with non-zero lead times and quality checks. In addition, the centralized inventory is also subject to a non-zero lead time replenishment.

1.1. Background

Motivation for this research stems from changes in the business environment over the last decade. The manufacturer has grown significantly since its founding and its business model is evolving. Inventory practices that were acceptable during the firm's growth phase and when the company was a fraction of its current size might now be placing the company at a disadvantage in a very price sensitive and crowded market.

As a make-to-order manufacturer, the sponsor has the benefit of carrying minimal finished goods inventory. While make-to-order manufacturing is traditionally better for a producer in terms of managing inventory, the tradeoff is that customers must be willing to accept a longer lead time (Sean Willems, Lecture 2 MAR 2016). Market realities, however, simply do not permit for extended lead times – in fact, the sponsor sees short lead times as a differentiator and something that must be maintained.

Not all SKUs are produced or sold at the same rate, thus items are often classified by order of importance in an "ABC." At the top of the importance scale are Class A items. These items are generally those with high volumes and dollar values and those items for which the carrying or shortage costs are high enough to warrant specialized attention. For this research, the focus is on the high volume SKUs which have high customer service level adherence requirements.

In manufacturing, inventory has historically been seen as a means to an end. As Churchill and Lewis (1983) described in their analysis of company lifecycles, businesses generally focus on core competencies and product quality during the growth phase of the firm without much attention paid to additional costs incurred by expanding operations. As companies grow and mature management must turn its focus to controlling inefficiencies brought about by the growth process. Management at the sponsor recognizes the potential for more refined processes and cost savings and thus initiated this research project. With large annual production volumes and a national footprint of plants, inventory has become increasingly costly. Reexamination of the raw material inventory strategy provides an opportunity for both operational and financial improvement for the company. One of the key purposes of inventory – to serve as a buffer against uncertainty in demand – requires that any modifications to inventory policy be empirically sound and implementable in a fashion that doesn't severely disrupt operations. There are numerous forces in play when it comes to inventory policy for a large company, only some of which are internal to the firm and under the direct control of company management. Market forces, government regulations and supplier capacity, for example, are dictated to the manufacturer by outside entities. Conversely, there are policies and actions which a company is able to manipulate freely. In the following section, we explore various loci of control within the operations of the manufacturer. Beginning at the highest level, we establish the company's overall supply chain environment and move into more specific areas of focus known as the supply chain system and eventually onto supply chain processes. Referred to as *the manufacturer*, this research focuses on a FMCG manufacturer with several manufacturing facilities or plants in the U.S.

In the supply chain *environment*, the manufacturer interacts with various stakeholders, all of which provide constraints and or inputs to the manufacturer's production system. Vendors for the manufacturer provide raw materials, but do so with varying lead times and levels of quality. On the down-stream side of the supply chain, product is delivered to retailers in accordance with short lead times. These short lead times are seen as a core competency for the manufacturer. Connecting the entities in the supply chain are freight service providers, which have logistical and regulatory limits on how quickly items can be moved throughout the manufacturer's network. In addition to federal guidelines on freight companies, the operating environment is shaped by federal as well as local regulation. The most impactful parameters for this research are market dynamics (manifested by consumer demand and customer priority) and vendor constraints (lead times, services levels).

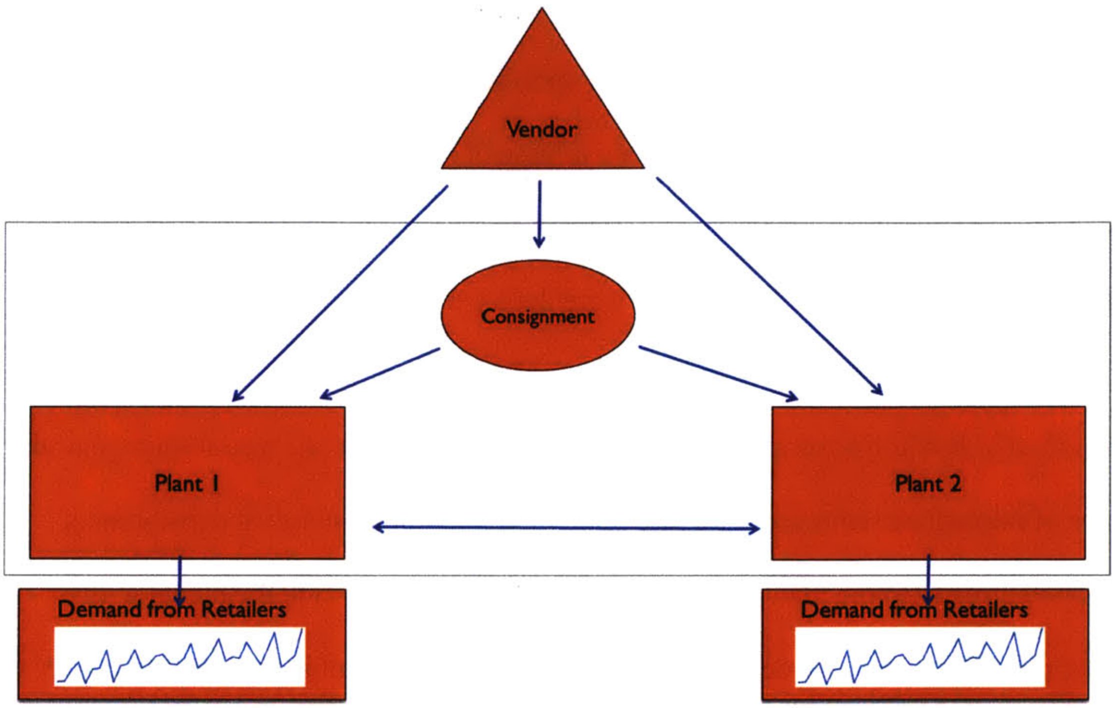

Figure 1-1 Raw material movement (system)

In the manufacturer's supply chain *system*, vendors supply raw material for the manufacturer (and in some cases hold it free of charge in a consignment arrangement). When called for by the planning department at the manufacturer, raw materials are released from the vendor/consignment facility to the manufacturing plants using different shipment modes depending on the urgency. Plants are manufacturing facilities that consume raw materials for manufacture and package the finished goods in various configurations as per customer preference. Finished goods are then either stored in warehouses to be shipped later or are shipped to stores or distribution centers of various retailers. In this thesis, we focus on the upstream side of this system and refer to the retailers as customers.

In the supply chain *process*, there are specifics that dictate how the actual flow of raw materials occurs. After vendors produce the raw materials for a given purchase order, the items are stored in consignment facilities. Raw materials are held free of charge in consignment for a given period of time (often up to several weeks) until the plant (through the planning department) requests a release of raw material. The consignment facilities are not necessarily stand-alone buildings and may simply be an area of the vendor's production facility. However, they are depicted as separate buildings in Figure 1-1 in order to facilitate understanding of material flow. The advantage of consignment is the reduction of holding costs associated with raw material due to the free storage period. At times of immediate requirement, a raw material might not be stored at consignment and shipped directly to the plants. While consignment should provide the plants with a ready supply of raw material, demand spikes from customers combined with fulfillment times (discussed below) can lead to stock outs. Raw material shortages are also exacerbated by supplier service failures in which raw material is either not received on time or the quality of the product does not meet the standards required by the manufacturer. Blanket increases in order size are not feasible as obsolescence costs prevent storage of raw materials in consignment status for any longer than the currently negotiated free consignment period of 90 days. Should finished goods demand fall below forecasted levels and the free storage period is exhausted, the company would incur high inventory and obsolescence costs. The manufacturer maintains a network in which each plant has different vendors for different raw materials and vendors may be shared among plants. While the manufacturer in this research has a nationwide network of plants, we focus on a "plant region" which uses the same supply chain processes that are followed network wide. This “plant region” contains vendors, consignment facilities and plants (Figure 1-1) that work together to support customer demand in the region. While the manufacturer aims to avoid material shortages altogether, transshipments of raw materials between plants in this region can occur in emergency situations.

The purchase orders are placed with the supplier for raw materials after the demand is forecasted for the upcoming year. The contracts with suppliers are for minimum guaranteed orders. The orders are placed with 20-30% flexibility on the supplier side. For example, if the order is for 100 units, the supplier should have the capacity to produce 120 or 130 if requested by the manufacturer. This is a protection against demand surges. The orders are then called off (released) from the supplier on an as needed basis. It is important to note that order fulfillment is not instantaneous. If materials are available at consignment facilities, the manufacturer will receive them within 7 days, otherwise production of raw materials requires a 30-day lead time. For items that require faster fulfillment, the sponsor company can use interplant transfers of raw materials with a 2 day lead time. Furthermore, raw material planners have triggers at 15 days for regular replenishment and 8 days for expedited replenishment. These trigger points are legacy figures that have been used at the manufacturer for years. Expedited replenishment incurs additional costs and is a resource which the manufactures aims to use sparingly. Figure 1-2 visualizes the decision timeline associated with the manufacturer’s procurement process.

Raw material planning and acquisition is based on 18-week rolling forecasts that take into account the contracted amounts with the customers and expected deviations. Production schedules for this make-to-order manufacturer are prepared two days prior to production. The steps involved then ultimately boil down to: place order, call off raw materials, and schedule the runs.

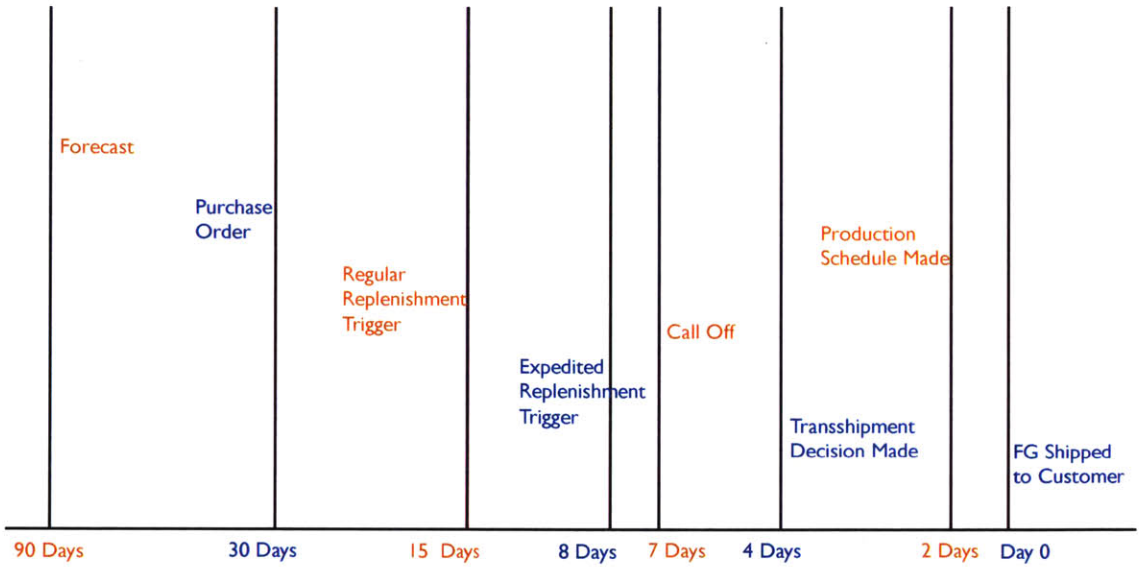

Figure 1-2 Procurement and replenishment timelines (process)

(Note: Alternating colors are used for readability – A blue action on a line is associated with a blue time period)

1.2. Definitions

In this section we define several fundamental terms associated with the inventory modeling process in this thesis.

<u>Safety stock</u> – The expected net stock of an item just before replenishment arrives (Silver, Pike, Peterson, 1998). Safety stock is used to cover variability over lead-time for item replenishment based on an established service level.

<u>Lead time</u> – the period between when an order is placed and when the items actually arrive. The difference in lead times between regular purchase order, replenishment order,

item release from an existing PO and transshipment is a central factor in inventory decision making in this particular business.

Supplier service level – The average raw material amount sent by the supplier that passes the quality check on the production floor. This average value is taken over the period of one year. The raw material check is not performed when the raw material arrives because of the nature of raw material's packaging but rather during the production itself where automated machines as well as manual checks are in place to ensure quality sufficiency.

2. Literature Review

Raw material inventory policy serves many functions and requires numerous quality data points in order to be accurate. Planners must account for lead times and safety stock as well as how demand for items fluctuates over time. While raw materials must be on hand in order to feed manufacturing lines and produce finished goods, the exact amount of material to have on hand or on order can vary based on a number of factors unique to that industry or the company's priorities. Tiered pricing from vendors, transportation costs and customer service requirements are all tied to raw material inventory policy. In the end, companies must juggle how much to spend on inventory against any effects of high or low inventory levels on their overall business.

With the interconnected nature of a company's operating environment, system and processes, it is important to ensure that one is not viewing a single manufacturing plant as an isolated site. Given the sponsor's nationwide network of facilities, it important to understand the effects of moving material between sites – known as transshipment. The research on inventory policy that can incorporate transshipments in a multi-location system is continuously evolving. Most of the research is generic and provides a basic framework that needs to be tailored to the particular industry and situations that are being faced. Since most of the research builds upon the formulations and frameworks provided by the previous researchers, we will discuss research primarily in a chronological manner. Correlated research will be discussed in context with its foundational work. The literature review aids in understanding the changing parameters or inventory policy and how they can be adapted for further research by us. There are key differences between the needs of the research partner and what past academics have studied. We build on the prior research, but also note differences and the need for new exploration.

Most prior research assumes a retail setting where a customer arrives at a store and either purchases the product or (in the case of a stock out) leaves without it and demand is lost. For the purposes of our research, demand arrives at the plant and the plant has the ability to source the product in multiple ways: the facility has the raw materials on hand and fulfills the order, or the plant replenishes/transships the raw material to the facility with the shortage before fulfilling demand. Demand is never lost and if it cannot be met immediately, the shortage must be carried over to the new production run for that product. This is a key difference from much of the earlier research involving inventory policies and transshipment.

Gross (1963) is the first work to tackle the multi-location problem with transshipments. He focuses on a policy where a single item can be stored at multiple locations and is supplied by a common source. Much like our sponsor, Gross concentrates on having centralized inventory control for all locations in the system. A key system feature in this paper is the idea of transshipments between the inventory locations – these decisions to utilized transshipment are determined by centralized inventory control (corporate headquarters). The paper emphasizes the advantages of using transshipments where one location may be overloaded and the other may be under stocked. In many cases, it can be cheaper and faster to transport the inventory using this method rather than sourcing from a vendor and dealing with the associated fulfillment times. Transshipment is of particular interest in our research because of the faster response time than traditional replenishment methods. Our research differs from Gross because he assumes that orders and transshipments are made before demand is realized. Olsson (2009) has an approach similar to that of Gross in wanting to use transshipment to balance demand. Our research seeks to avoid stock-outs first and foremost, but then to utilize transshipment as a backup plan given the company's robust national network of plants.

A study of stock outs and transshipments similar to ours, albeit with some key differences, is one by Fredrik Olsson (2009). Olsson describes that when a demand occurs and no stock is on hand, transshipment is made from a sister facility with the appropriate stock. However, Olsson assumes zero lead-time for transshipments - which is far too optimistic for our research. Additionally, Olsson assumes that if demand cannot be met with transshipment, it is lost – this differs from our simulation in that customer demand must always be met. If demand cannot be sourced from one plant, it is supported from another facility or that demand is rolled over until a time when raw materials arrive and the customer requirement can be met. In our model, demand cannot simply disappear.

Notably, Olsson allows for asymmetry, where one location can be replenished directly from a vendor while another location is only resupplied through lateral transshipment from that first location, and states this is sometimes the optimal method. This is a novel concept, but one that may elicit business model complications for a company.

In exploring multi-location inventory management while allowing for transshipments, Das' (1975) research is of note. In a similar vein to our question, Das' research focuses on a two-location inventory problem with uncertain demand that proposes a periodic review policy minimize total system costs for a finite planning horizon. It differs from Gross (1963) mainly in the assumption that between every two re-ordering points, the stocks can be redistributed. The idea of continuously re-balancing inventory is not germane to our research as the sponsor aims to use transshipment only in emergency situations.

In the sponsor's current model, raw materials can be in one of three states: on order, at consignment or delivered to the plant. Hoadley and Heyman (1977) examine a similar two-echelon system with one inventory location in first echelon and multiple inventory locations in the second echelon. At the beginning of each period, three functions are performed as necessary. At the first echelon, the items are adjusted via the purchase order process. At the second echelon, transshipments are performed. Between the two echelons, items are brought to desirable levels by re-balancing as necessary. While the period under review is still ongoing, the shortages are tackled by expediting shipments either within the second echelon or among the echelons. The solution then becomes the initial stock level at the initial (or first) echelon and the allocation of stock in the lower echelon. This method can significantly reduce the shortage and carrying costs. In the Hoadley and Heyman model, one redistribution per period can reduce the overall inventory cost.

The redistribution in a single period setting is further explored in Jonsson & Silver (1985). In their work, they make corrections for the imbalances left by using PUSH control systems (Brown, 1982). Inventory levels at the locations are monitored and demand functions are formulated. Only one redistribution is allowed under this model. Since most stock outs tend to happen at the end of the order cycle, the redistribution is focused near these times. Jonsson & Silver allow for transshipments between similar locations and then creates a procedure to obtain optimal stocking levels along with the expected number of lateral transshipments.

Related to this thesis is also the work of Hau Lee (1987), in which the neighboring locations in close proximity to each other are allowed to share demand with each other when stock at one of the locations is near depletion. However, the locations need to be identical in nature. A linear programming approach is then applied to determine the levels to be maintained at the locations. This approach is of interest in our research because Lee recommends it for systems where the service levels are to be kept high.

In a scenario such as ours, with a multi-location, multi-period stochastic inventory problem with an available recourse action of transshipments, Robinson (1990) studies the trade-off between holding & shortage costs and transshipping costs. Transshipments are considered for solution where a demand needs to be satisfied but only as an action for emergency situations. Robinson uses a similar simulation approach to the one we will discuss later in the paper. Instead of an exact solution that can guarantee optimal results, a heuristic is developed which can be used much more easily while giving near optimal results. However, Robinson assumes negligible transshipment and replenishment lead-times. In our scenario, the lead times for both replenishment and transshipment greatly affect production and procurement decisions.

When a company stores inventory in multiple locations (as is the case with firms that have multiple factories), the company should seek to ensure that inventory decisions are made for the good of the company and not just individual plants. Individual plant managers may deal with suppliers directly and seek to increase inventory levels at their respective sites to guard against material shortages. Such thinking often leads to high inventory holding costs and ties up working capital. Rudi, Kapur and Pyke (2001) examine situations where surplus stock is available at a neighboring location and transshipment is possible between the two locations. The analysis then extends to the optimal inventory orders at the locations. It is recommended that plant inventories be managed by a company-wide decision-making process with the possibility of plant-to-plant restock shipments and additional vendor to plant shipments.

The redistribution of raw material through transshipment among plants when a particular plant experiences shortages is generally performed by keeping some of the inventory for the releasing plant's own requirements. The question of how much to keep for the overall benefit of the system is tackled by Xu et al. (2003) where an additional parameter called hold back level is proposed that determines how much is kept by a plant to meet its own requirements before releasing the extra quantity to the plant with raw material shortage. Although this is used in conjunction with a traditional (R,Q) policy, it can be utilized with other policies as well. An approximate analytical model is developed to determine all the three parameters R, Q and H for a two-location inventory replenishment problem. This research is of particular interest to us as the policies implemented currently at the sponsor and included in this research involve the use of the hold back level.

The prior research provides us with a good starting point from which to understand the mathematical formulations involved while designing such an inventory policy. In addition, they are an excellent source of understanding the feasibility of solutions since most of the earlier research is not just theoretical, but emphasizes the practicality of results. We intend to build upon this and devise an inventory policy that will incorporate the unique parameters present in our scenario and provide a mathematical solution.

3. Methodology

This section explains the process followed to replicate the current system in order to develop the evaluation tool and sets a framework for the analysis of results under alternate safety stock policies. It provides the general approach used to create the evaluation tool utilizing a simulation model and describes how procedural enhancements gathered from the literature review will be used to improve the current system.

3.1. Experimental Design

We divide the current structure into a two echelon model with the first echelon having the vendor location and the second echelon having the plant locations. For both the echelons, we formulate the current policies mathematically to keep track of inventory changes and decision points. The input parameters at these echelons provide a starting point for the evaluation which has been designed to cover an entire operating cycle. The output of the simulation aggregated over multiple runs will then be tabulated under an analysis framework of KPIs to find an improved strategy while remaining within the constraints of the system. This will then be used in conjunction with the sponsor's Enterprise Resource Planning (ERP) systems to proactively manage inventory and eliminate extraneous costs.

3.2. General approach

We divide the methodology into the chronological steps below which will be discussed in further detail. These steps were all performed in close collaboration with the sponsor.

1. Identify a representative region for the analysis.
2. Understand the current process flow and decision making logic.
3. Collect the requisite data for the analysis.
4. Identify enhancements as per reviewed literature.
5. Develop the model.
6. Analyze the results.

3.2.1. Identify a representative region for the analysis

The analysis performed in this research should be general in order to be applicable to all such environments with the sponsor's network. Performing the analysis on the entire network can provide the most complete results, however, it will be unrealistic to obtain the complete data and perform the analysis in the timeline while also adding mathematical complications to the model. For achieving the objectives of this research, it is essential that we focus on a smaller subset region that can be representative of the overall business. This will restrict the results to a more general form but it can be sufficiently informative to be utilized across the network and can be scaled easily. We chose two plants in close proximity in the western United States for this study as all the business critical processes followed across the network are followed here. In addition, the data required for the analysis is readily available.

3.2.2. Understand the current process flow and decision making logic

Understanding of the process flow for inventory policies requires both the location as well as the time reference for the replenishment and depletion activities. Per the experimental design, we divided the locations among two echelons, the higher echelon with the vendor and the lower echelon with the two plant locations. All the locations at a particular echelon follow similar processes. For the time reference, we chose a production day as representative of the operations at a plant. For each location and for each production day, the starting and ending inventories are determined based on the production and movement of raw materials. The production itself incorporates the daily demands as well as accumulated backorders. The daily demands are forecasted ahead in time and the true demand is only known when the production plan is frozen. Before the raw materials are utilized for production, a quality check is performed to assess the usability. The ending levels of inventory at different locations are used to decide whether to place orders for replenishments or not. These levels are measured in terms of days on hand (DOH) availability. The production and replenishment decisions are made independently at each location and the replenishment orders are realized after the lead time duration. For all of these processes, rules are put in place to determine the decision points. We categorized these rules into three separate categories:

- Consignment inventory rules
- Plant inventory rules
- Plant production and backordering rules

Consignment inventory rules: The consignment location is managed by the vendor free of charge and can accommodate up to 90 DOH worth of raw materials. At the expiration of the 90 days, the stock must be transported to the sponsor's location or the manufacturer is required to pay a storage fee. Historically, the manufacturer avoids the storage fee and takes delivery of all material. The inventory position of the consignment at any time includes the inventory on hand as well as inventory on order. The replenishment lead time is 30 days from the placement of purchase order. Two purchase orders can be under process simultaneously if the demand at the plant locations is high. However, the two orders will be fulfilled independently. The timelines for the replenishment decisions are provided in Table 3-1.

Plant inventory rules: The plant locations' inventories are managed independently. The inventory position of the plant at any time includes the inventory on hand as well as inventory on order. There are three possible replenishment methods: regular, expedited and transshipment. Regular and expedited replenishments can only be ordered from the consignment location whereas transshipment can only be ordered from another plant. These three shipments are exercised at different levels of inventory shortage. The replenishment rules and lead times are provided in Table 3-1 and Table 3-2.

Plant production and backordering rules: The demands at a plant are realized in accordance with the rules provided in Table 3-3. Any demand that can't be met at a plant in a production day due to raw material shortage is then rolled over to the next production day if the same SKU is scheduled for production.

Table 3-1 Replenishment decisions

Factor	Consignment	Plant
DOH sufficiency for replenishment decision	>= 45 days	>= 15 days
DOH extra ordered	45 days (beyond available)	15 days (beyond available)
DOH calculation method	Average demand for next 45 days	Average demand for next 15 days
Review frequency	Weekly	Daily

Table 3-2 Replenishment lead times

Parameter	Consignment	Plant
Regular replenishment lead time	30	7 days
Expedited replenishment lead time	-	4 days
Transshipment lead time	-	2 days

Table 3-3 Demand and production timelines

Factor	Value
Forecasted demand known	18 weeks in advance
Revised demand known	7 days in advance
True demand known	2 days in advance
Production freeze	2 days in advance, backorders accommodated if same SKU run scheduled

3.2.3. Collect the requisite data for the analysis

For the research, reliable data is needed for quantifying implementation parameters. Where the data is not available or if it is not reliable, reasonable assumptions have been made and are discussed in the chapter "Model Development". The data sources used for this research are listed in Table 3-4.

Table 3-4 Company data

Data	Used to
Production Run Data	determine the demand pattern
Year to date sales data	validate the production run data against the sales data for correctness
Inbound RM transfer file	determine the lead time for raw materials

3.2.4. Identify enhancements per reviewed literature

The literature we reviewed on the subject of inventory policies in presence of transshipments is heavily focused on cost considerations and is geared towards providing the best inventory policy under a certain set of conditions. However, the evaluation tool being developed in this research does not attempt to find the best policy but rather provide outputs for a range of possible inputs in terms of events. This limits the amount of enhancement that can be borrowed from literature without altering the research purpose.

Xu et al. (2001) proposes the addition of a third parameter called hold back level in addition to the traditional parameters of re-order point and re-order quantity to determine the level at which transshipment is allowed. The inventory policy that is being followed currently can easily be modified to add this enhancement without changing the scope of the research and adds substantial value to the research. Transshipment is already a part of the inventory policy currently in place and addition of the hold back level to allow the facilitation of transshipments under different conditions can provide broader options that can then be evaluated to identify the preferred course of action. We incorporate this parameter into the simulation model.

3.2.5. Develop the model

The evaluation tool utilizes a simulation model for replicating the current business processes as mathematical modeling does not completely capture the real-life operations of the sponsor. A simulation model is a computerized mathematical rendition of an actual system that mimics that system as closely as possible and can be used to analyze the system to make policy decisions. It helps in gaining insights while reducing complex analytical requirements. Although simulation can't provide the exact answers, it can provide a close to optimal solution while at the same time allowing for further enhancement without building another model from scratch. In addition, the models developed are easily demonstrable (Chung, 2003).

Chapter 4 discusses the entire model development process.

3.2.6. Analyze the results

In this research, we want to analyze the model results over a varied set of input simulation parameters to understand the impact of different combinations of these inputs. This necessitates standardization of KPIs that are most relevant to the sponsor and can be used uniformly to make a like to like comparison between the results. In addition to being informative, the KPIs should capture the most relevant information for the decision making process and present it as an easily interpretable and comparable value.

The main KPIs that are relevant to the research and are used for the interpretation of results were developed in consultation with the sponsor company are listed in Table 3-5.

Table 3-5 Key performance indicators

KPI	Description
Regular shipments	The number of regular shipments triggered at the plant
Expedited shipments	The number of expedited shipments triggered at the plant
Transshipments	The number of transshipment events triggered at a plant
Average Inventory	Average ending inventory in the plant at the end of a simulation run of 365 days
Stock-out events	The number of times a plant has DOH = 0
Production Fill Rate	Percentage of order fulfilled without backordering

The results of the model must be a reflection of the real life scenario and should also be transferable to the actual processes being followed. As such, we divide the analysis of results into three sections: Validation, phase-1 analysis and phase-2 analysis.

<u>Validation</u>: In this phase, we simulate the model as per the current variables and parameters and see if the results represent the real life observations. We also perform a logical validation of the model in conjunction with the sponsor (Landry, et al., 1983).

<u>Phase-1 analysis</u>: In this phase, we evaluate the current policy with different hold back levels and then select the most optimal one while stating the trade-offs. This will then be the hold back level used for the next phase of analysis.

Phase-2 analysis: After fixing the value of the hold back level, we evaluate different combinations of the (R,Q) and (s,S) policies, present the findings and interpret the results.

4. Model Development

This section describes the development approach for the simulation model. The model used for this study is based upon a duplication of the current system and calculates the availability of raw materials at different locations in order to trigger replenishment orders.

During the model development, it was necessary to make certain assumptions in the absence of data or for simplification of the process without losing the end result accuracy. The assumptions were made in consultation with the sponsor and are discussed below.

<u>Demand assumptions</u>

We assume that the historical production information is a good representation of the demand distributions expected in the future. This assumption enables us to create a demand distribution that can be used as an input to the model and helps compare the results against previous years in order to validate the model. In addition, the revised demands and true demands, which are improvements upon the long term forecasted demands, are known seven and two days in advance, respectively. This is a close approximation of the realization of demand by the master planners.

<u>Supplier assumptions</u>

Lead times for replenishments remain constant. As experienced by the business, the lead times can be variable but they are generally within acceptable limits and we implement the lead times as constant to simplify the modeling process. Since the lead time deviations average out during the course of one complete period, making this assumption does not affect the results significantly. Also, the supplier's capacity for replenishment is assumed to be unlimited as purchase orders include upside buffers to ensure capacity when demand increases.

Quality assumptions

Supplier service level is assumed to be constant over the period under review. In reality, the supplier service level can change from time to time, but quantifying this variation can be extremely difficult. Making this assumption simplifies this process by taking an average supplier service level to be utilized throughout the modeling time period. This affects the result only slightly as an average and representative value is used.

A quality failure of raw material on the production floor leads to the earliest received batch of raw material getting discarded. This is a close approximation of the current policy that is being followed where the raw materials are used and discarded on a first in first out basis.

Backorder assumptions

Backorders are accommodated in the next day run. In the actual business, a similar practice is followed where the backorders are added to the next day's run if the same product is scheduled for manufacture. There are some variations based on special circumstances but this is a general practice.

The process followed for model development in this research is:

1. Analyze the data and develop probability distributions

2. Identify the trigger points for a shipment decision-making process

3. Devise appropriate computations for dependent variables

4. Implementation details

Below we describe each of these steps in further detail.

4.1. Analyze the data and develop probability distributions

To proceed with the analysis, we needed data from several different business functions. We held discussions with the demand, supply and transportation groups provided the overall picture of sponsor operations and once the linkages between functions were known, appropriate data from the key stakeholders was obtained. The data we used are: yearly sales data, production run data and raw material shipment historical data. The sales information and the production information are decoupled by the finished goods inventory (e.g. if finished goods are on hand at the plant, production quantity might not equal sales quantity for a certain order). For this research, it is better to use the production information as it is more closely related to the raw materials' sourcing. The sales data is used to confirm that the production run information is correct.

The first actions included studying the demand patterns over the calendar year 2014. This analysis enabled matching of SKUs to production requirements and scheduling cycles. Identifying and correcting the initial production data was a primary concern during initial data manipulation. Production date-time stamps were a particular problem because of the way they were captured. In order to properly sort the data, it was necessary to extract date and time information and to determine production run length.

While developing the probability distributions, we decided to concentrate on the top selling SKUs as they account for a large portion of the revenue and better strategy will result in more savings for the sponsor. In addition, the data availability is more reliable for these top selling SKUs as they are produced almost every week.

The results of the exploratory analysis are presented in the Figure 4-1. We clubbed the daily data into weekly data in order to reduce the variation and arrive at a smoother distribution. Judging from the histograms presented in the above figures, assuming demand follows a Normal distribution seems reasonable. The deviations from an exact normal curve can be attributed to limited production data for one year which itself has several timestamp issues.

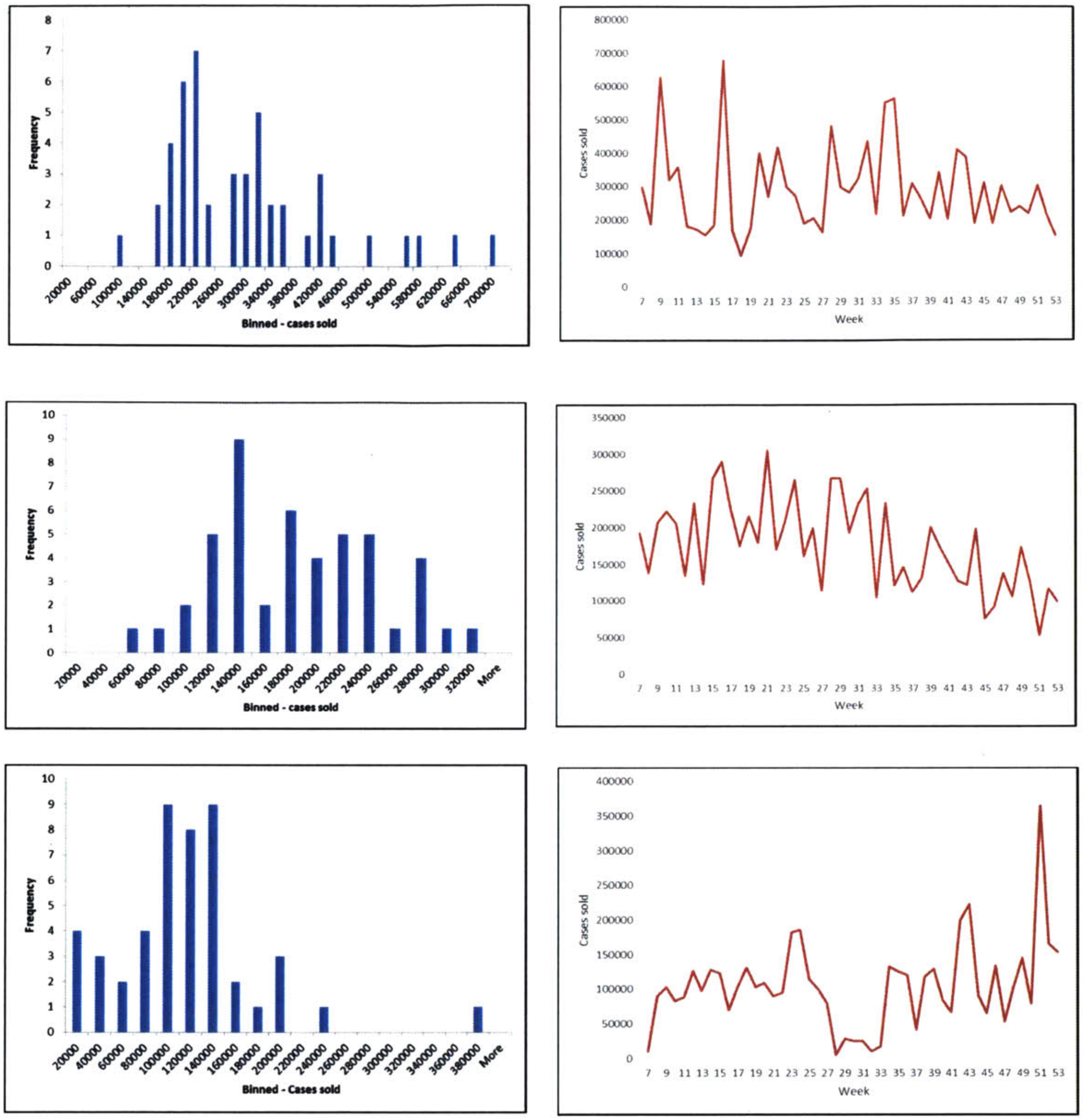

Figure 4-1 Demand distributions - Histogram and time series - Top 3 SKUs

4.2. Identify the trigger points for shipment decision making process

The sponsor's current decision making is dependent upon several scenarios for the raw material shipment. These in turn are based upon the material availability and geographic locations for the shipment. We identified three separate shipment types: regular replenishment, expedited replenishment and transshipment for which the trigger points are 15 DOH, 8 DOH and 5 DOH availability.

4.3. Devise appropriate computations for dependent variables

Raw material availability at all times is a function of safety stock policy. For a given plant, this depends on the availability of raw materials both at the plant and consignments in addition to another plant from where it can be replenished quickly. Hence, the computations are focused on demand and inventory availability shown in Table 4-1.

Table 4-1 Parameters and dependent variables

Parameters and dependent variables	Value
Starting inventory at consignment(t)	Ending inventory(t-1) + Ordered shipment(t-30)
Ending inventory at consignment(t)	Starting inventory at consignment(t) – Requested shipments to plant(t)
Average demand for next 45 days(t)	True demand(t to t+2) + Revised demand(t+3 to t+7) + forecasted demand(t+8 to t+15)
Consignment replenishment required	1, if Ending inventory < 45 DOH ; else 0
Demand at plant	Stochastic, random number
Starting inventory at Plant(t)	Ending inventory at plant(t-1) + Regular shipment(t-7) + expedited shipment(t-4) + transshipment(t-2)
Ending inventory at Plant(t)	Starting inventory at plant(t) – fulfilled demand(t) – Transshipped to another plant(t)
QA	1, if random number greater than threshold
Backorder(t)	Demand(t) + backorder(t-1) if QA = 0

4.4. Implementation details

To implement the simulation model, we chose Microsoft Excel software. It is the software used by the sponsor for the current numerical analysis and is licensed for use within the organization. Undertaking the implementation using a statistical software would require the purchase of licenses which is not probable in the foreseeable future. Moreover, the sponsor intends to use this model with modifications for their own purposes later on and hence it makes sense to use it on the same platform. In addition, widely available spreadsheet software can adequately handle the complexity of the model. On the other hand, the spreadsheet model is limited in scalability and can only be used for one SKU at one time. This imposes constraints on how many different SKUs it can be used to analyze.

5. Results

The results of the model under different inventory policies and their policy specifics were studied by calculating the KPI values in order to provide an understanding of the effect of implementing the policies. This result provides management the guidance to choose an appropriate course of action and to set its parameters while considering the associated trade-offs.

Based on conversations with the sponsor, we chose Production Fill Rate (PFR) as the KPI against which we measure other KPIs in order to show the changes that take place in the system when different policies are implemented.

We selected four different supplier service levels to test the simulation. This range of service levels provides us with a more complete picture of the results and is of particular interest to the manufacturer given that supplier service levels have been declining in recent years. We also compared the current policy and show how different combinations can result in improved PFR and at what cost to the company.

Since there is variation in demand for different SKUs, we also perform a sensitivity analysis to understand the effects different standard deviations of demand on a given policy.

The results are presented as per the steps outlined in section 3.2.6.

5.1. Validation

The results of the simulation model for the current process being followed are close to the actual values that are observed. The current policy is an (R,Q,H) with policy variables' values set at (15,15,15). The values for regular, expedited and transshipments at 68, 2 and 1 are close to the actual number of replenishments seen. Expedited shipments and transshipments are not very common cuurently and the results show that as well. In addition, the PFR value of 96.16% provided by the model is close to the actual value of 96%. Also, the model was logically validated where we verified that the simulation model is constructed as intended.

5.2. Phase-1 results

Under the analysis framework, we first determine the transshipment holdback level. For this, we run the simulations for different policies using different quality levels as well as standard deviation levels. The results can be shown graphically as below.

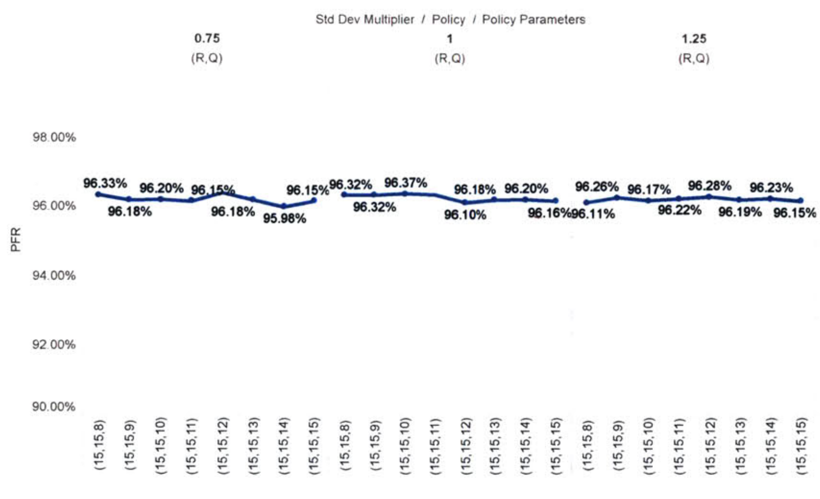

Figure 5-1 PFR vs hold back level for (R,Q,H), SSL 97%

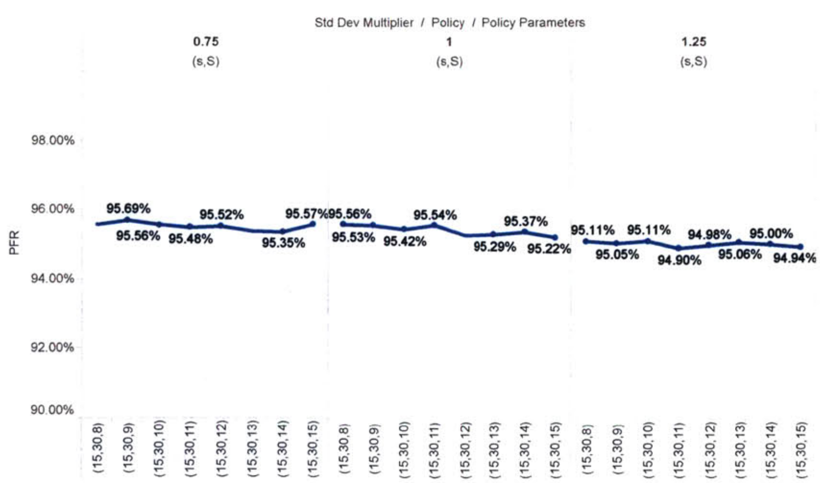

Figure 5-2 PFR vs hold back level for (s,S,H), SSL 97%

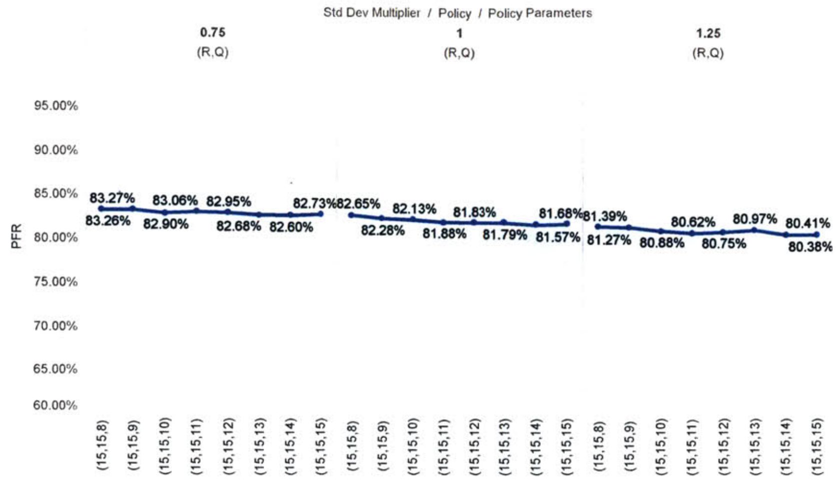

Figure 5-3 PFR vs hold back level for (R,Q,H), SSL 91%

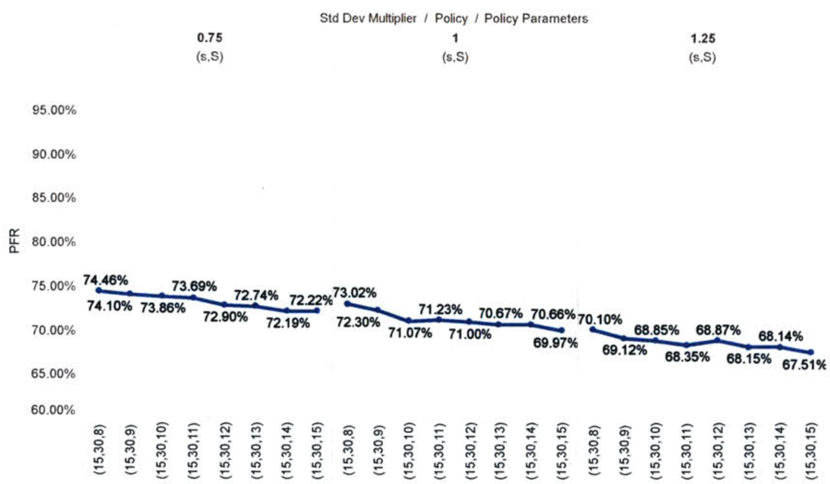

Figure 5-4 PFR vs hold back level for (s,S,H), SSL 91%

At the highest supplier service level and with low standard deviation, the effect of hold back level on PFR is largely unnoticeable (Figures 5-1, 5-2) but becomes markedly noticeable with lower SSL and high SD (Figures 5-3, 5-4). The PFR is considerably higher with lower hold back levels. However, this increase in PFR does come at additional cost in terms of extra transshipments. The increase in number of transshipments when changing the hold back level from 15 days to 8 days was on average 10 transshipments a year. The effect on other KPIs are minor. The gains in PFR are considerable at up to 3 percentage points and for the strategic focus of the sponsor on countering PFR loss by transshipments, we will continue with the hold back level value of 8. This selected hold back level will be used in the next phase of determining the appropriate R,Q and s,S values. Theoretically, this holdback value can be lowered further, but other business concerns regarding how the sponsor handles expedited shipments prevent us from doing so.

5.3. Phase-2 results

The holdback level determined in phase-1 is then employed in the simulation to generate results using different combinations of the R,Q and s,S policies and to compare the KPIs. For the R,Q policy, we chose R values of 12, 15 and 18 and Q values of 12, 15 and 18. For s,S policy, we chose s values of 12, 15 and 18 and S values of 25, 30 and 35. These values represent a fair range of possibilities that the sponsor may choose and is based on their current policy. While not providing a complete set of possible policy specific values, these give a sense of direction towards which the inventory policy must be modified in order achieve required results. Given the number of variables, both (R,Q) and (s,S) policies have nine possible combinations. These different combinations were simulated for three standard deviation levels and four different SSL levels. We chose 97% SSL and an unchanged standard deviation to evaluate the policies. We discuss the impact of changing the SSL and standard deviation under the sensitivity analysis. We first evaluate the R,Q and s,S policy with different parameters for the current SSL and graphically represent the KPIs. The KPIs are then compared to understand the effects.

Regular shipments vs. PFR:

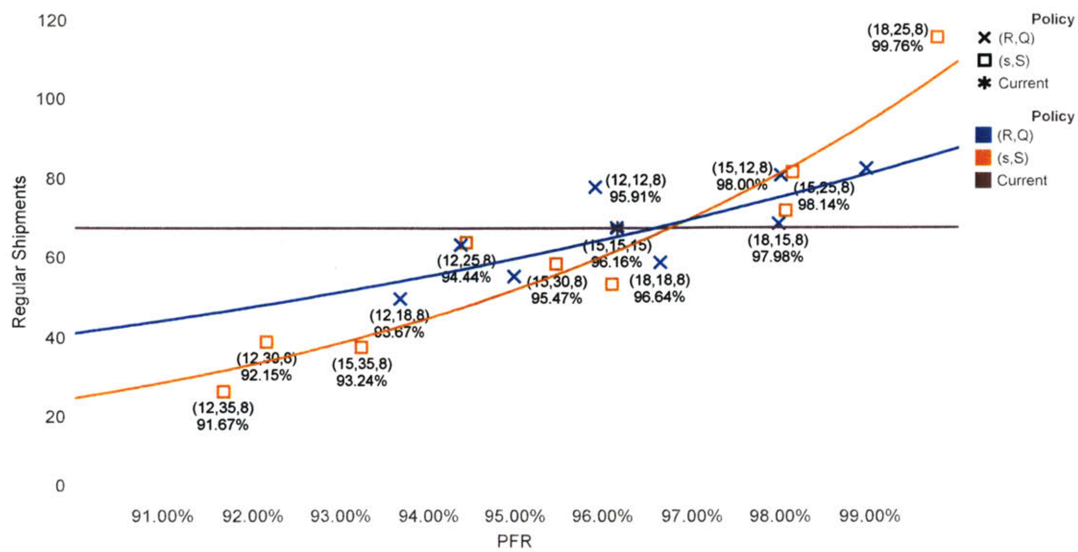

Figure 5-5 Regular shipments vs PFR (SSL 97%, Std Dev Mul. 1)

We see from Figure 5-5 that for regular shipments, there are several policies that provide better PFR values for a relatively small number of extra regular shipments or some that provide the same PFR for a lesser number of regular shipments. As PFR begins reaching the 99% mark, however the number of shipments required increases dramatically. This increase in shipments is observed with the (s,S), (18,25,8) policy which requires nearly 115 regular shipments compared to 68 shipments in the existing policy at the manufacturer. As number of a certain type of shipments increases (e.g. regular shipments), it comes at the expense of other types of shipments (e.g. expedited shipments). These tradeoffs in are compared next.

Expedited shipments vs. PFR:

The number of expedited shipments show an exponential decline (Figure 5-6) as the PFR increases. The inference can be made that a policy that aims to increase the PFR will result in a higher number of regular shipments, but a lower number of expedited shipments. This implies there is a need to maintain more safety stock and to order replenishments more frequently rather than rely on expedited shipments for PFR improvements. In addition, the chart shows that are better policies than the current policy and do not incur excess costs in terms of many extra expedited shipments.

<u>Transshipments vs. PFR:</u>

Transshipments show a similar relationship with PFR in line with that of expedited shipments (Figure 5-7). Thus, a better PFR rate is achieved by minimizing the occurrence of transshipment, which, in turn, is realized by requiring more regular shipments to maintain a higher safety stock. Again, to achieve a better PFR it is not paramount that there needs to be an increase in transshipments.

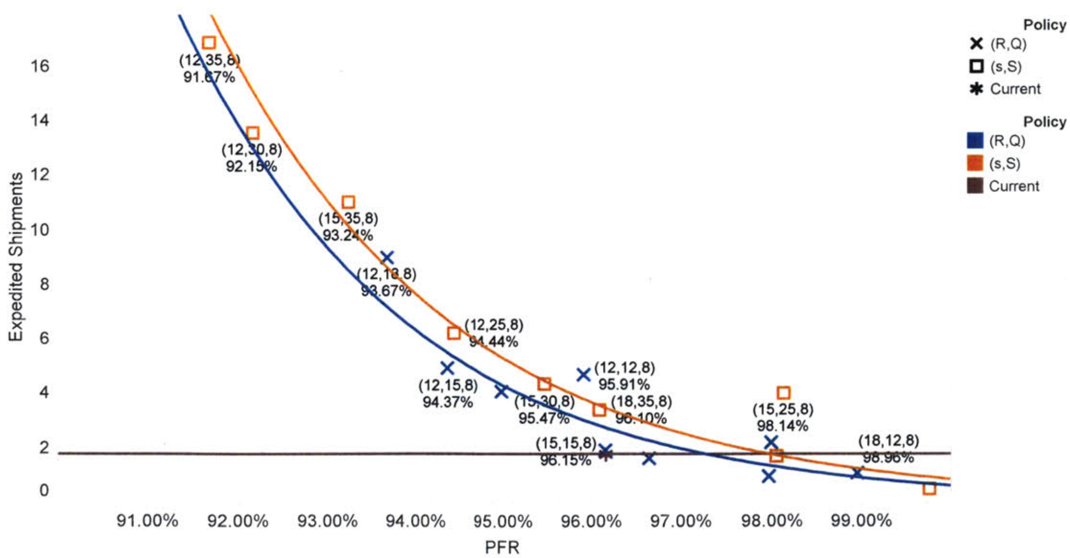

Figure 5-6 Expedited shipments vs PFR (SSL 97%, Std Dev Mul. 1)

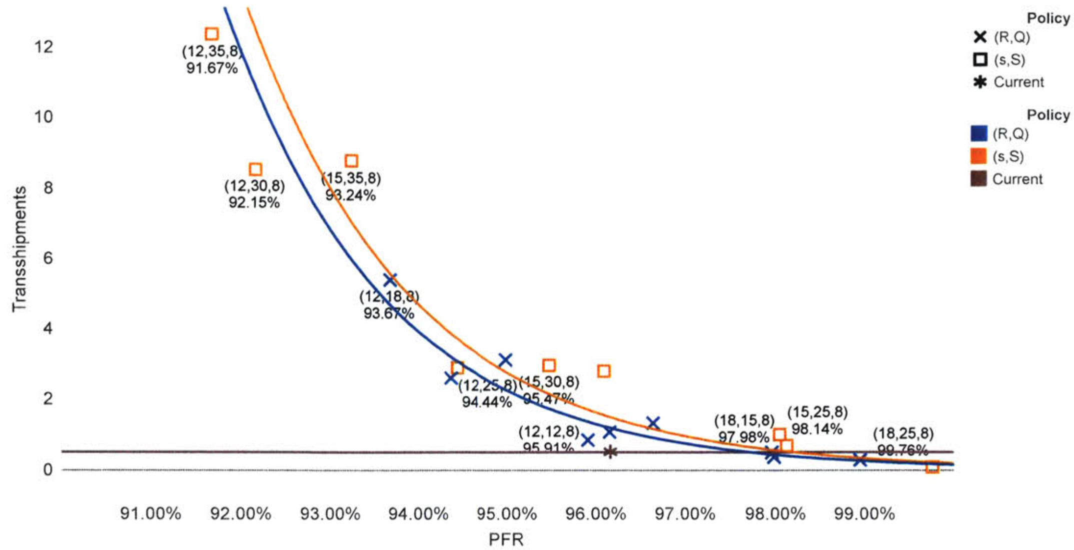

Figure 5-7 Transshipments vs PFR (SSL 97%, Std Dev Mul. 1)

Total shipments vs. PFR:

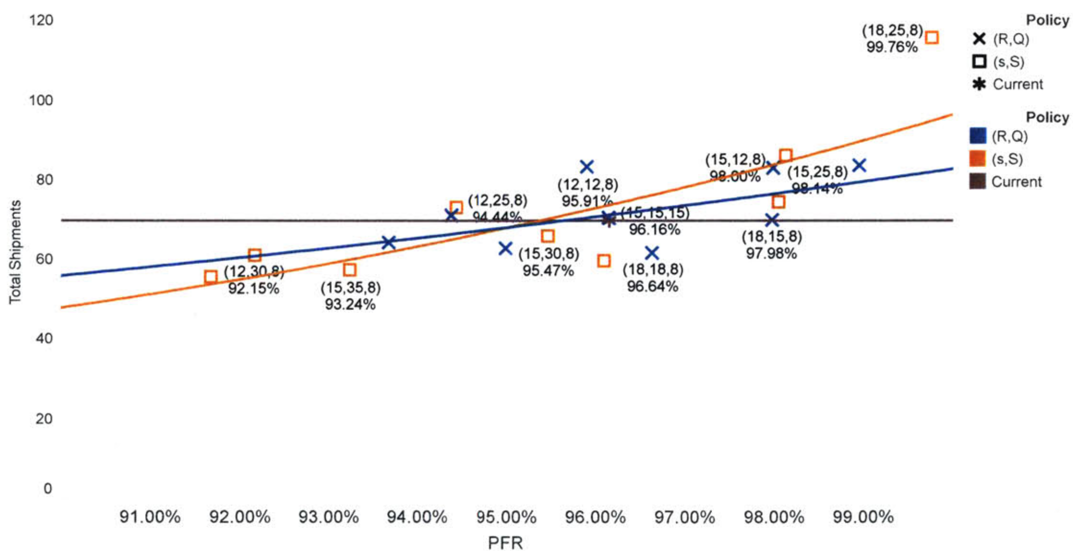

Figure 5-8 Total shipments vs PFR (SSL 97%, Std Dev Mul. 1)

The chart above (Figure 5-8) shows an expected increase in the total number of shipments in order to achieve higher PFR. There is a decline in expedited shipments and transshipments, but this decrease is more than offset by the increase in regular shipments. Again, this confirms that more safety stock is needed to improve the PFR level, but there are options available to management where the total cost increase due to extra shipments is only marginally higher and results in improved PFR.

Average inventory vs. PFR:

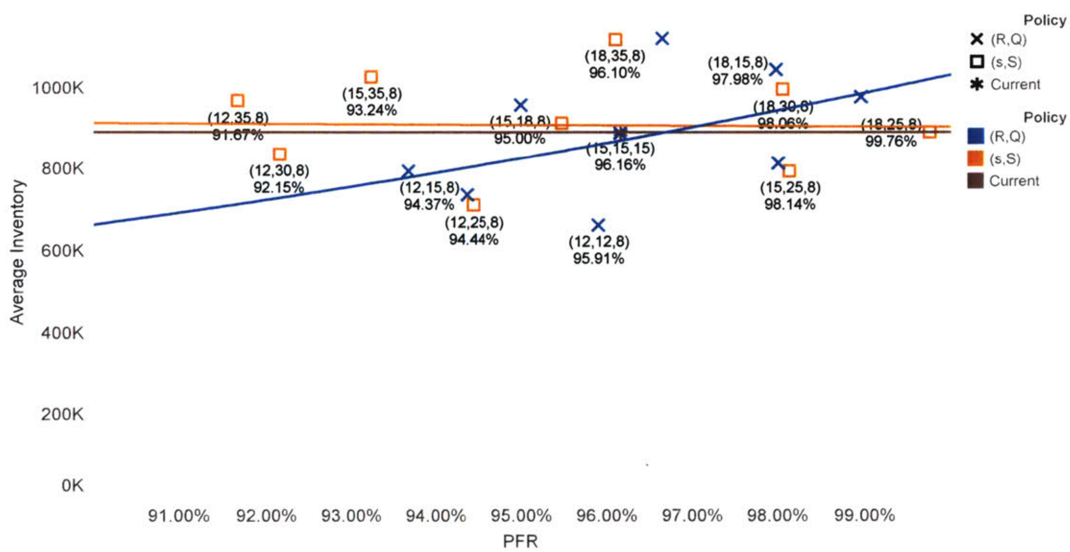

Figure 5-9 Average inventory vs PFR (SSL 97%, Std Dev Mul. 1)

There is an interesting disparity between the (R,Q) and (s,S) polices when it comes to average inventory (Figure 5-9). With the (R,Q) policy, the average inventory keeps on increasing, but for the same levels of PFR, the average inventory under (s,S) policies remains virtually flat. There are some significant variations, but over a larger experiment scenario, this can be used to determine the holding cost and determine complete trade-offs between PFR, the shipments and the holding costs.

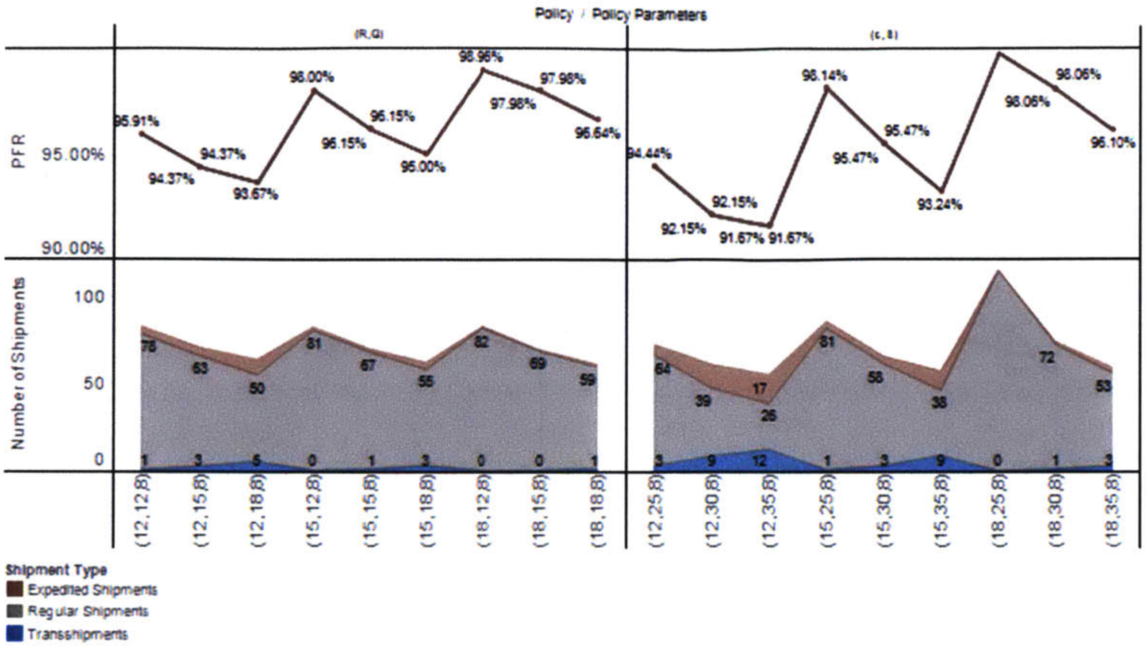

Figure 5-10 PFR, shipments and inventory policy (SSL 97%, Std Dev Mul. 1)

In Figure 5-10, a comparison of the PFR rates against total shipments shows a correlation between the number of shipments and PFR rates. This correlation confirms what we have already showcased in previous graphs. It also shows that as the PFR rates start to fall due to lower SSLs, expediting and transshipments increase in order to ensure raw material availability in the event of raw material failure on the plant floor. This chart can be utilized to understand the impact of various policies on PFR as well as transportation costs.

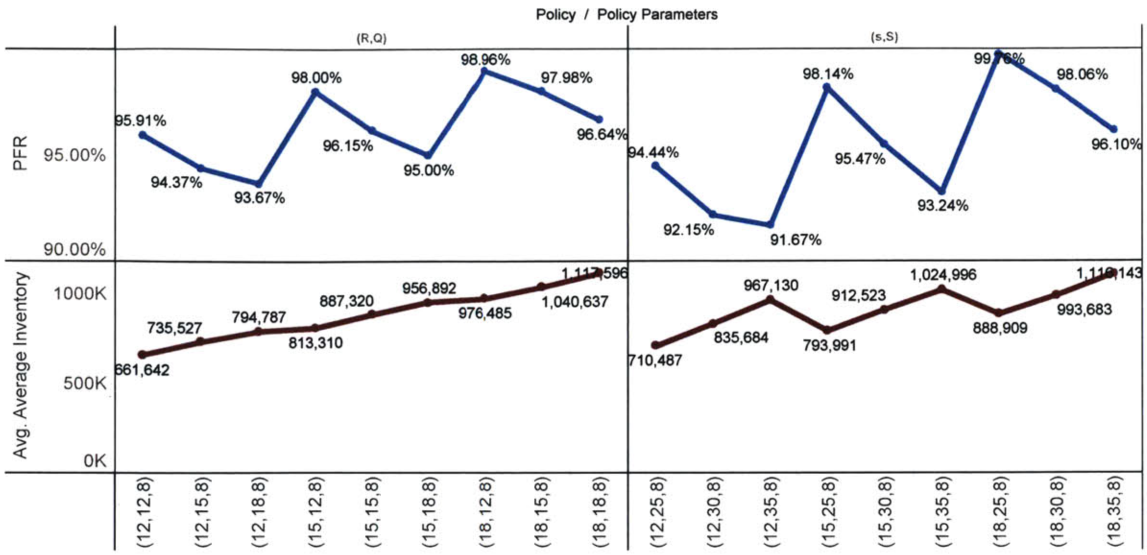

Figure 5-11 PFR, avg inventory and inventory policy (SSL 97%, Std Dev Mul. 1)

The relationship between PFR and average inventory in the system is more a function of the safety stock policies than any other factor as seen in Figure 5-11. Increasing the average inventory in the system alone does not produce a better PFR, as it must be coupled with the ordering of smaller replenishments in order to realize any gains. With the possibility of material quality failures not being discovered until product reaches the factory floor, it seems reasonable to decrease replenishment size. In this way, the amount of raw material that would be rejected from a certain batch declines as the size of replenishments declines.

5.4. Sensitivity Analysis

<u>Sensitivity with SSL</u>

We perform the sensitivity analysis for changes in SSL by the keeping standard deviation multiplier at one. The results for regular shipments vs PFR are shown in Figure 5-12.

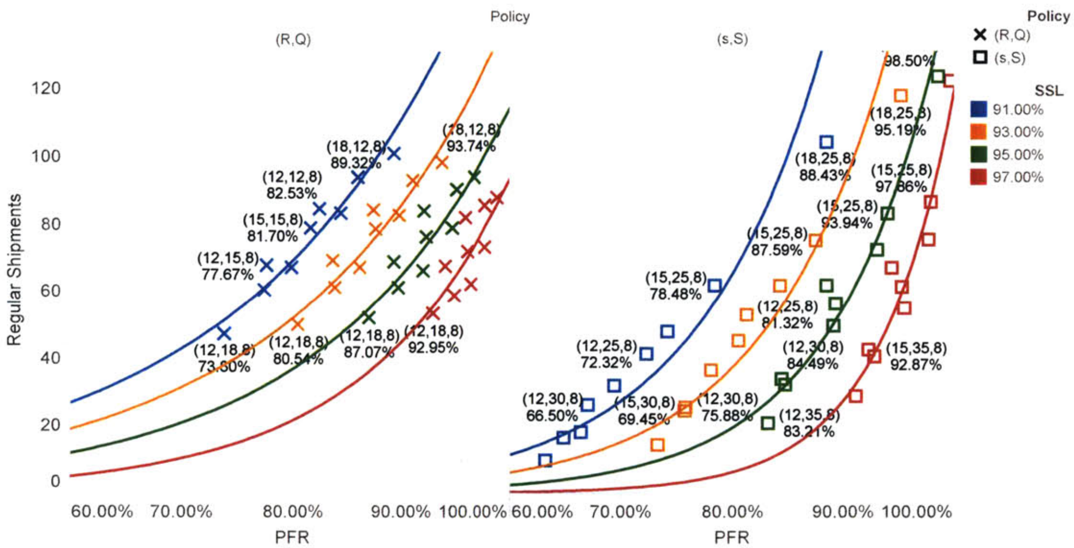

Figure 5-12 Sensitivity - regular shipments vs. PFR - SSL

With decreasing supplier service levels, the PFR decreases. This is an expected response of the system where a lower SSL means more failures (and raw material removed from inventory) and thus a higher number of replenishments as the re-order point is reached more often.

The decline in expedited shipments that we observed earlier with increasing PFR continues to be the case with different SSLs (Figure 5-13). However, the rate of decline slows with lower SSLs, implying that expedited shipments become more important and more frequent raw material failures cause the expediting trigger point to be reached more quickly.

Transshipments show a similar trend to expedited shipments (Figure 5-14), and imply that the raw material shortages become more prominent as the SSL declines, thus triggering more transshipments.

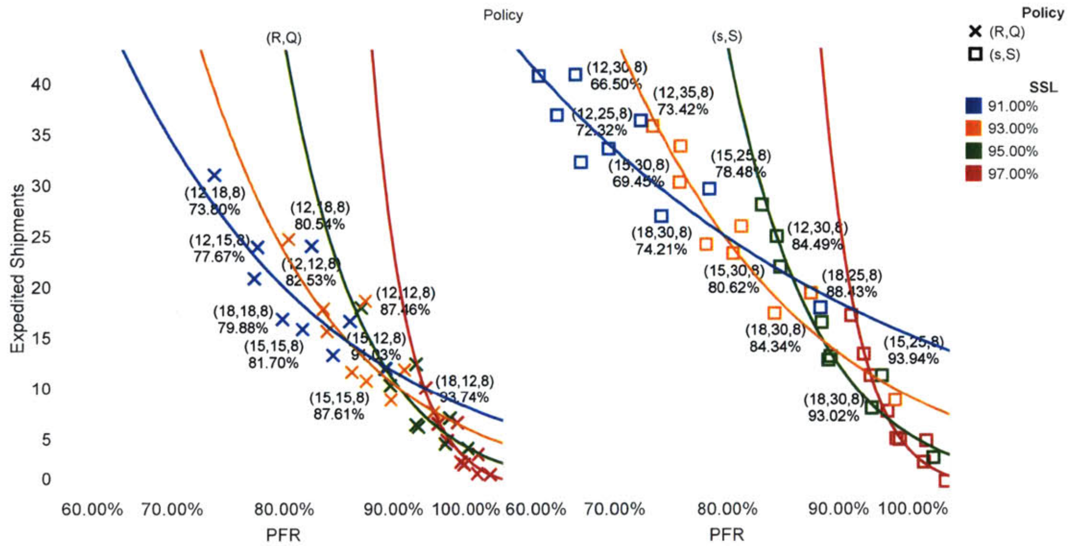

Figure 5-13 Sensitivity - expedited shipments vs PFR - SSL

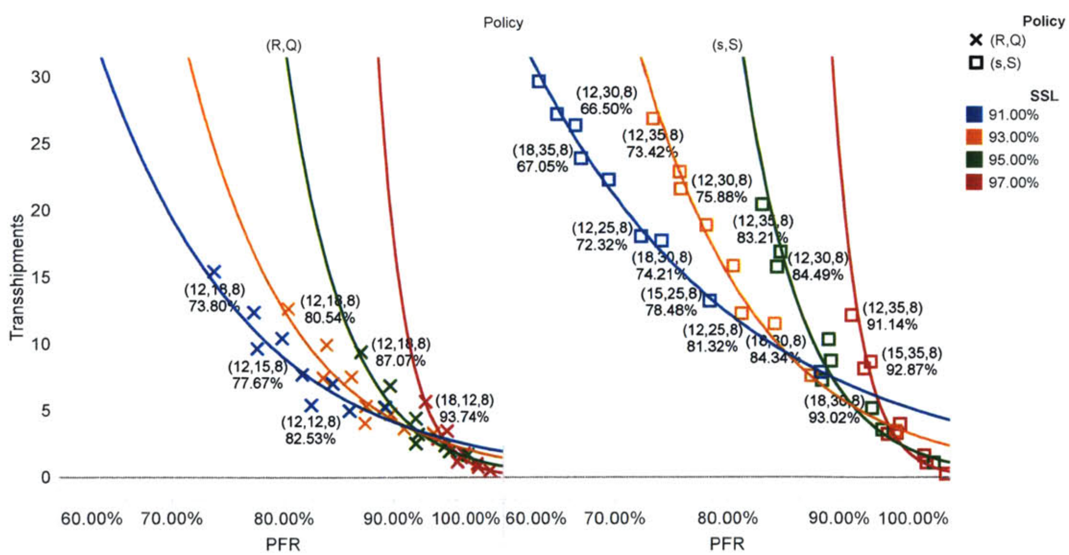

Figure 5-14 Sensitivity - transshipment vs PFR - SSL

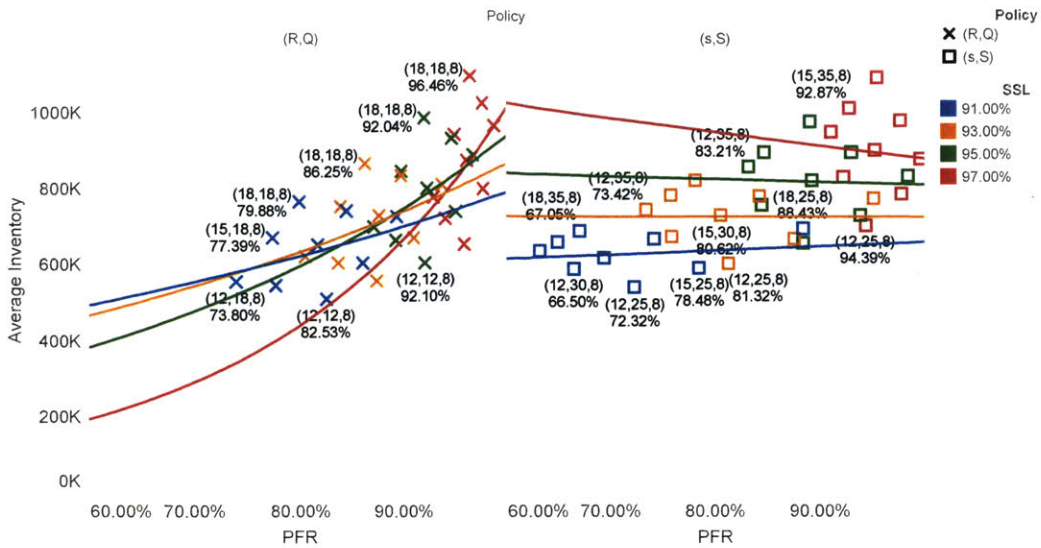

Figure 5-15 Sensitivity - avg inventory vs PFR - SSL

The average inventory in the system continues to decline as the SSL decreases (Figure 5-15). This phenomenon occurs despite ordering more frequently as a portion of the raw material is invalidated more frequently, leaving an entire shipment unusable and contributing to an overall decline in the system.

From the sensitivity analysis with changing SSL levels, we see that PFR is highly influenced by changes in SSL and a drop of just two percentage points in the SSL can cause the PFR to go down by 5 or more percentage points. Hence, the inventory policy revision is extremely important when a decline in SSL is observed.

Sensitivity with standard deviation

We perform the sensitivity analysis for changes in standard deviation by the keeping supplier service level at 91% as more prominent changes can be observed at lower SSLs. The results are as below.

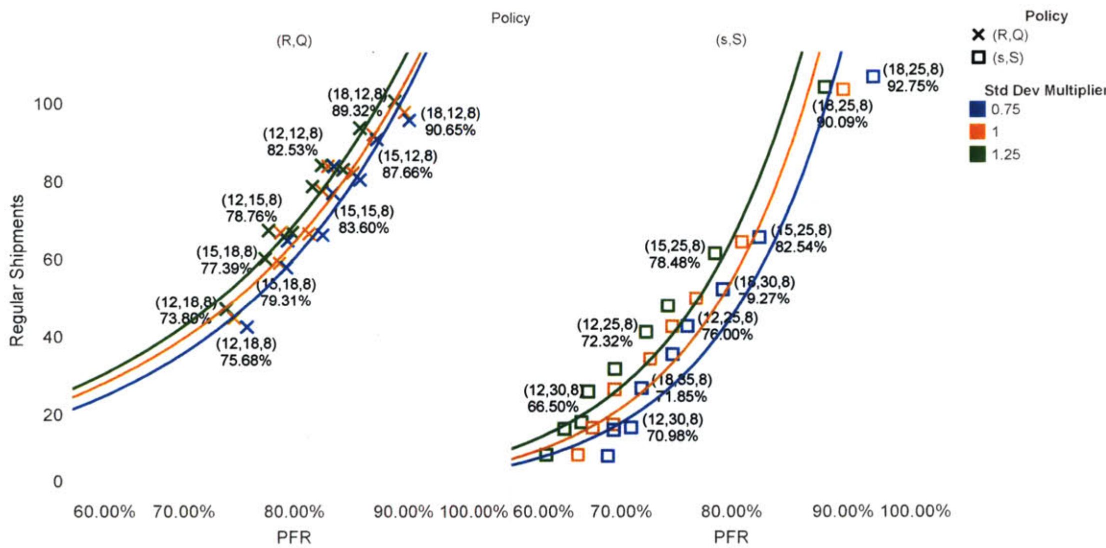

Figure 5-16 Sensitivity - regular shipments vs PFR - std dev

Higher standard deviation implies more volatility in the system with respect to daily demand. The plot (Figure 5-16) above confirms that as the standard deviation decreases, the number of shipments declines and vice-versa. This holds true for both (R,Q) as well as (s,S) policies.

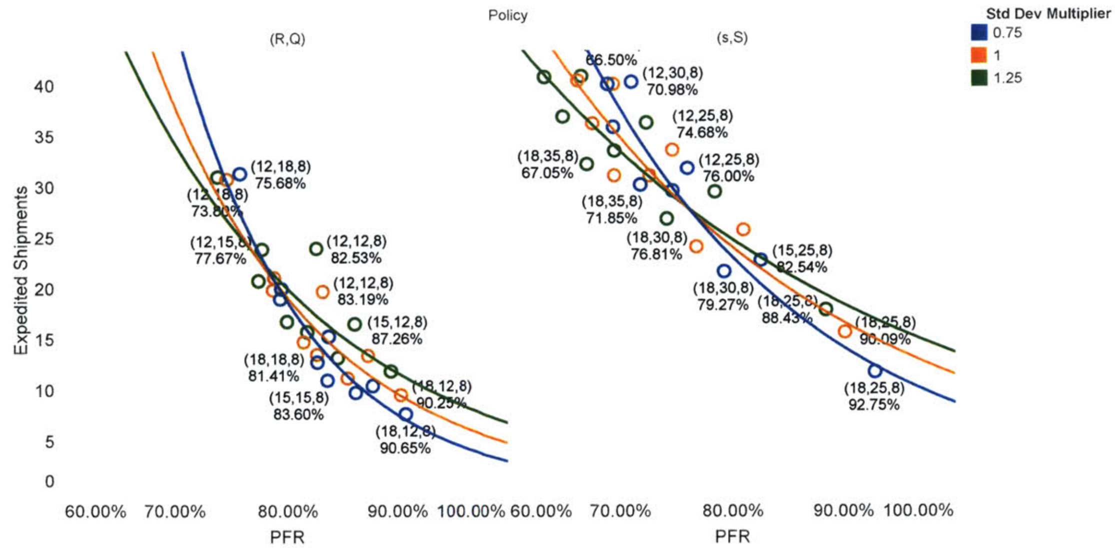

Figure 5-17 Sensitivity - expedited shipments vs PFR - std dev

The different standard deviations show a decline in expedited shipments and transshipments (Figures 5-17, 5-18) as the demand becomes more stable. This is again an expected behavior and the plots can be used to determine the level of impact of the changes of changing standard deviation.

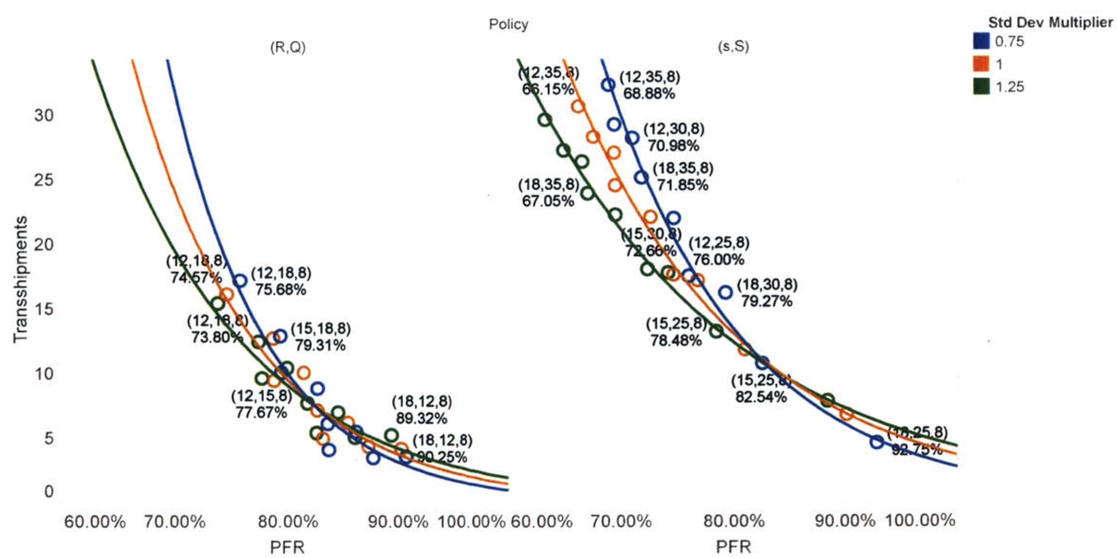

Figure 5-18 Sensitivity - transshipments vs PFR - std dev

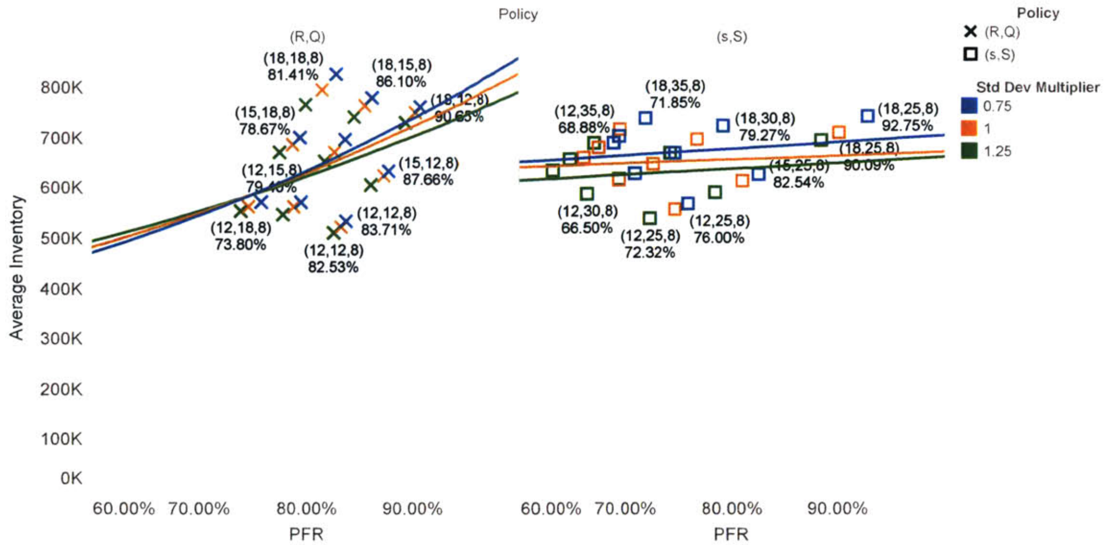

Figure 5-19 Sensitivity - avg inventory vs PFR - std dev

The average inventory in the system increases as the demand becomes more stable. It can be seen in both the (R,Q) and (s,S) case (Figure 5-19). This is expected as lower demand means lower shipment sizes and hence less risk of losing a shipment to quality issues.

A key observation is that the various policies are very stable in the face of different standard deviations. This stability should allow a given policy to work well over a wide range of standard deviations unless there are radical changes in this parameter.

6. Discussion and Insights

The system studied has several constraints that make it difficult to calculate appropriate re-order points and replenishment quantities in terms of traditional measures of cost and service level. The current system uses the same policy of all SKUs, a practice that has been followed for its ease of understanding and implementation. Additionally, the IT systems supporting the manufacturing operations can be then made uniform for all SKUs. However, this comes at an overall efficiency loss, especially when supplier service levels are falling.

The results of the analysis show different effects of the policies in terms of number of events. The costs associated with these events will decide the path that has to be followed in order to reduce cost while maintaining the service levels. The assumptions that have been made while developing this model also are an important consideration as these are close approximations of the business policies.

Policy Selection

The evaluation tool developed can be used to compare several policies and determine the trade-offs to arrive at a particular policy. The charts from Figure 5-10 and Figure 5-11 can be used to enable comparison between few selected policies which appear to give better PFR at not much of a higher expense in terms of other KPIs. In the comparison made in Figure 6-1 and 6-2, it can be seen that better PFR values at similar number of shipments can be reached using policies (18,15,8) and (18,30,8). The cost that these policies incur in terms of average inventory value maintained can then be compared and a decision can be arrived at as to whether it is worth implementing the policy.

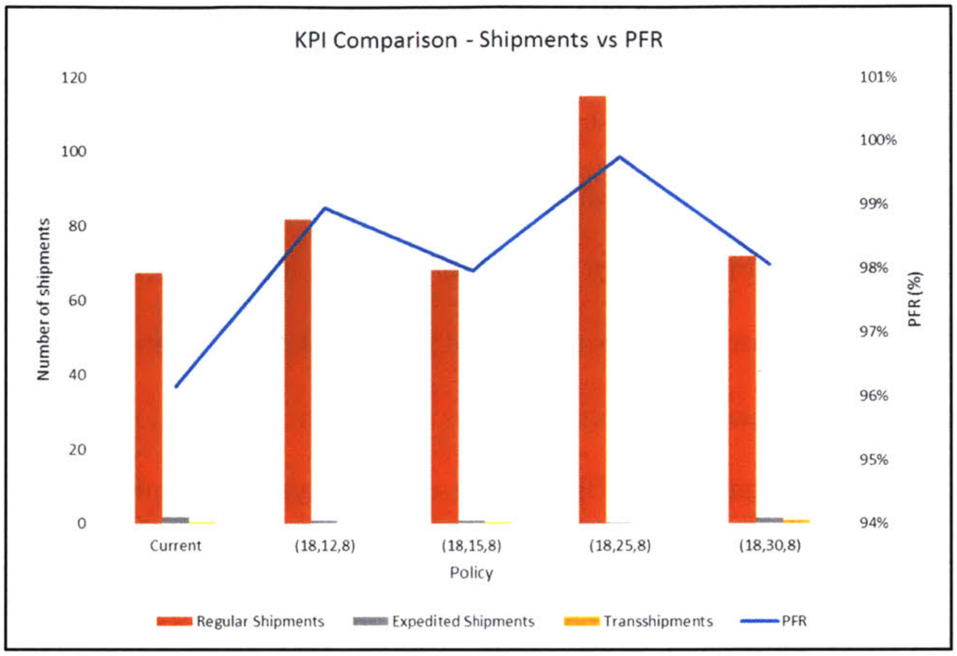

Figure 6-1 KPI Comparison – PFR vs Shipments

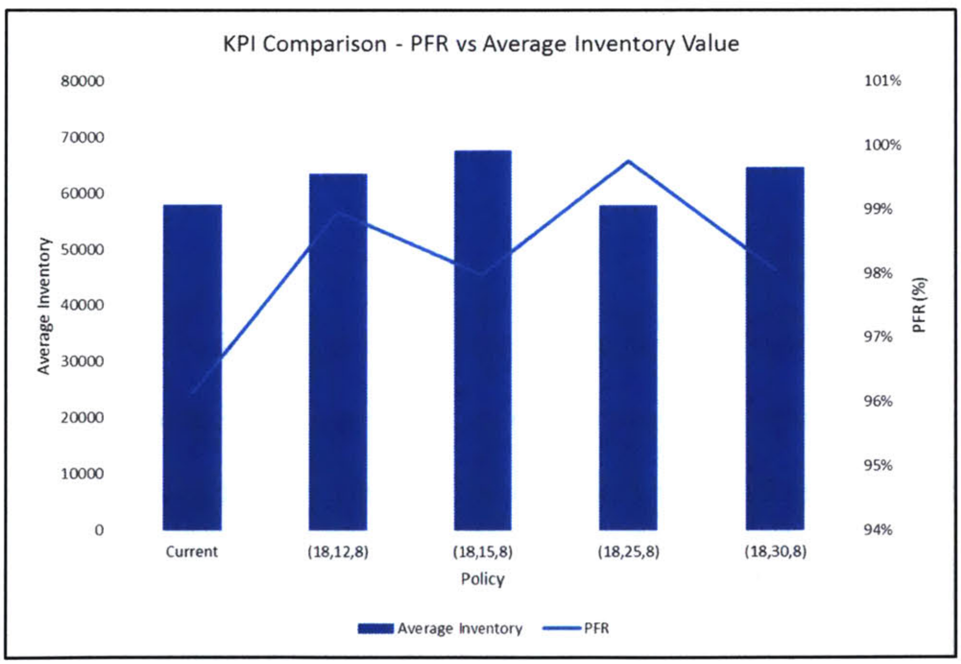

Figure 6-2 KPI Comparison – PFR vs avg inventory

Safety Stock and Cycle Stock

The findings of the research emphasize that with falling supplier service levels, safety stock should be increased and cycle stock should be decreased. However, these come at an additional cost of increasing the number of shipments. Hence the management must make a decision on what costs it is ready to bear for a particular SKU to improve its production fill rate when switching to another supplier with better service levels is not a practical solution.

At any point, the safety stock on the floor can be an aggregation of different shipments that have been received. Hence, the risk of losing entire stock to quality failure declines. Additionally, a higher safety stock means a higher re-order point implying a more pro-active measure to counter stock out situations. Hence, the findings of the research are consistent with the current business processes being used. These findings provide the management with costs in terms of number of events and average inventory on floor to leverage these findings to set appropriate safety stock and cycle stock levels.

Transshipments

The initial hold back level of 15 DOH for transshipments is not an effective solution to overcome inventory depletion issues. This discourages transshipments and considerable relaxation of this rule is necessary. We recommend relaxations of the 15 DOH constraint to a lower value of 8 DOH, which gives significantly better PFR values by making transshipments more likely and allowing better distribution of raw materials where they are needed. In particular, transshipments are important for high standard deviation SKUs and give better overall PFR as the supplier service levels falls. It must be noted that transshipments only reduce the impact of raw materials shortages and stock outs as a last resort. They should be used in conjunction with a better over-arching inventory policy which can reduce the chances that transshipments will be needed often.

Average inventory

From the results, we see that the average inventory in the system goes down as the safety stock is reduced, but this decrease in average inventory comes at the cost of increased transportation. Hence, a management decision needs to be made on what is more important from a financial as well as viability point of view. This means a comparative analysis of costs of holding the inventory and the cost of transporting the raw materials. A middle ground solution can also be reached and our evaluation tool can be used to measure the impact of such a solution.

Cycle stock appears to a have much a bigger impact on the average inventory in the system, especially with higher SSL. This is to be expected as the average size of the shipment arriving in each replenishment increases, meaning the overall inventory levels rise.

Supplier Service Level

A significant learning from this research is the correlation between falling supplier service levels (SSL) and the drop in PFR. A decline in SSL can result from poor quality control which forces the manufacturer to reject a shipment from a vendor or from a vendor failing to meet that appropriate delivery date for an order. The research shows that while adjusting inventory policy under a given SSL can help increase PFR, there is no policy which can compensate for falling SSL. These findings stress the importance of vendors adhering to SSLs and show management the importance of including SSLs in contracts and closely monitoring vendor performance.

We also recommend incentivizing the suppliers to increase their service levels, especially for SKUs with higher standard deviations. The incentives can be in terms of additional business or monetary pay offs. The monetary aspect can be determined using our evaluation tool by understanding the PFR improvements and putting a financial figure to the improvement. Hence, management need not always resort to changing inventory policies to overcome the SSL issues and can incentive the suppliers instead to increase the SSL in order to increase PFR.

7. Limitations

It is important to note that this research is an evaluation of current raw material policy and provides a tool with which future policies can be tested prior to implementation. As shown in the Results section, there are correlations between pairs of KPIs such as the number of shipments and PFR. The tested parameters are not meant to be exhaustive, but to provide company management with approximations of anticipated performance. Additional simulation iterations beyond those shown were not conducted due to diminishing marginal gains as PFR approaches 100%.

As noted early in this research, several KPIs used in this simulation are event based and do not actually contain cost data. This event-based method allows company management to make decisions based on actions that may have either dynamic or proprietary costs. Additionally, the event based method builds in flexibility to the simulation and allows it to evolve and remain relevant over time.

The term "best" is not used in describing any particular policy simulated in this research, this be done because the "preferred solution" is dependent upon company priorities at the time the decision is made. A company may opt for a policy maximizing PFR for one customer while in a growth phase; on the other hand choosing a policy with a lower PFR and fewer shipments during a cost minimization push. By varying input data on a SKU, plant and regional level, the users of this simulation will not only benchmark their current performance, but understand the gap to next desired level of performance. This then allows the procurement personnel to easily evaluate the options.

For the manufacturer in this study, which has a large number of SKUs and a large variance between SKU volumes, the simulation allows for tailoring of inventory policy to specific SKUs. An exhaustive simulation for all the SKUs is not advisable as it might be redundant or practically infeasible. Instead, the tool should be used to create buckets of SKUs for implementing similar rules based on similar SKU characteristics.

8. Further Research

There are aspects of our research that can be expanded upon to make it more inclusive. There are several business practices being followed at a granular level which are important to the organization but don't affect the outcome of this research much and were removed from the scope. However, they can be accommodated to further improve the accuracy of this research. This research does not allow for a flexible lead time to test different scenarios but in certain scenarios, the lead times can be very volatile and hence have an impact on the safety stock. In addition, there are two important enhancements that can be made. First, changes in consignment inventory policy are not part of this research and hence incorporating the tool to select an appropriate policy at consignment can improve the overall system. Secondly, addition of supplier capacity constraints to the simulation can give a more realistic picture of the business practice at consignment. We believe that the above mentioned additions will make the inventory policy evaluation tool developed in this research even more compelling and can be used organization wide to evaluate inventory policies more accurately despite the absence of cost and service level information.

9. References

Axsäter, S. (2003). A New Decision Rule for Lateral Transshipments in Inventory Systems. Management Science, (9). 1168.

Chung, C. A. (2004). Simulation modeling handbook : a practical approach. Boca Raton : CRC Press, c2004.

Churchill, N.C., and Lewis, V. (1983). "The Five Stages of Small Business Growth - Harvard Business Review." Harvard Business Review Case Studies, Articles, Books. N.p., May. 1983. Web. 7 Apr. 2016.

Das, C. (1975). Supply and redistribution rules for two-location inventory systems: One period analysis. Management Science, 21(7), 765-776.

Gross, D. (1963). Centralized inventory control in multilocation supply systems. In: Scarf, H.E., Gilford, D.M., Shelly, M.W. (Eds.), Multistage Inventory Models and Techniques. Stanford University Press, Stanford, California, pp. 47–84.

Hoadley, B., & Heyman, D. P. (1977). A two-echelon inventory model with purchases, dispositions, shipments, returns and transshipments. Naval Research Logistics Quarterly, 24(1), 1. doi:10.1002/nav.3800240102

Jönsson, H., & Silver, E. A. (1987). Analysis of a two echelon inventory control system with complete redistribution. Management Science, 33(2), 215-227.

Landry, M., Malouin, J., & Oral, M. (1983). Model validation in operations research. European Journal Of Operational Research, 14(3), 207-220.

Lee, H. L. (1987). A multi-echelon inventory model for repairable items with emergency lateral transshipments. Management Science, 33(10), 1302-1316.

Olsson, F. (2009). Optimal policies for inventory systems with lateral transshipments. International Journal Of Production Economics, 118(Special Section on Problems and models of inventories selected papers of the fourteenth International symposium on inventories), 175-184.
doi:10.1016/j.ijpe.2008.08.021

Robinson, L. W. (1990). Optimal and Approximate Policies in Multiperiod, Multilocation Inventory Models with Transshipments. Operations Research, (2). 278.

Rudi, N., Kapur, S., & Pyke, D. F. (2001). A Two-Location Inventory Model with Transshipment and Local Decision Making. Management Science, (12). 1668.

Willems, S. (2016). 15.762: Supply Chain Planning class notes. Cambridge Massachusetts: Massachusetts Institute of Technology.

Xu, K., Evers, P. T., & Fu, M. C. (2003). Production, Manufacturing and Logistics: Estimating customer service in a two-location continuous review inventory model with emergency transshipments. European Journal Of Operational Research, 145569-584. doi:10.1016/S0377-2217(02)00158-3