Inventory Optimization as a Business Advantage

by

Rajesh Kella
B.Tech., Mechanical Engineering, Indian Institute of Technology Madras, India

and

Christos Agrogiannis
MSc. Project Management and Operational Development, Royal Institute of Technology, Sweden

Submitted to the Zaragoza Logistics Center in Partial Fulfillment of the Requirements for the Degree of

MASTER OF ENGINEERING IN LOGISTICS AND SUPPLY CHAIN MANAGEMENT

in the

MIT-ZARAGOZA INTERNATIONAL LOGISTICS PROGRAM

at the

ZARAGOZA LOGISTICS CENTER,
A RESEARCH INSTITUTE ASSOCIATED WITH THE UNIVERSITY OF ZARAGOZA

May 2016

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Signature of Author(s)

MIT-Zaragoza International Logistics Program
Zaragoza Logistics Center
May 13, 2016

Certified by

Mustafa Çagri Gürbüz
Professor of Supply Chain Management
Thesis Supervisor

Accepted by

María Jesús Sáenz
Zaragoza Logistics Center/ Universidad de Zaragoza Program’s Coordinator
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ABSTRACT

This thesis addresses the performance optimization of supply chain network for a chemical company that has the manufacturing base in Europe and serves the customers of the Latin America region. In this sense, the overall target of this project is to enable the business to take robust decisions on how much and where to place inventories that would provide a business advantage both in financial terms and long term sustainability. Moreover, the research work in this document will be utilized in a key value chain of a pilot business unit within the sponsor company.

With an objective to achieve the right balance between net working capital and speed of response, this thesis studies the interactions between various factors that affect the safety stock and inventory placement. The scope of the work includes studying the segmentation strategy, optimizing the inventory policy and validating the benefits of modifying the supply chain network configuration.

In order to tackle the business problem, we outlined a multi-stage roadmap that includes: data collection and statistical analysis; Pareto analysis to downsize the scope in a manageable way without loss of generality; and Discrete Event Simulation (DES) to both optimize and test the performance of the inventory policy and network configuration. Although these tools are not the core of the study, they are the platform over which the thesis is built in order to assure the accuracy of the models. This thesis examines the past 4 year trends of demand and forecast and includes the benefits of implementing an inventory policy based on three approaches – Normal distribution, Stationary and Evolutionary optimization of the safety stock. Given the demand and forecast trends, while the policy based on Normal distribution showed marginal improvements in costs and inventory, Stationary & Evolutionary optimization yielded more than 25% reduction from current inventory levels.

Finally, it is important to mention that this thesis aims to prove the real value that the academia-business relationship has for both parties. On one hand, strengthening technical skills and developing new study frame works; and on the other hand, making the supply chain more efficient offering business advantage by managing net working capital better.
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1 Introduction

“Before Galileo’s death nearly 400 years ago, Conventional Wisdom held that the earth-and not the sun-was the center of the universe. More recently, Conventional Wisdom held that smoking, drinking, stress, and diet caused peptic ulcers. Then, two Australian scientists, Robin Warren and Barry J. Marshall, showed that bacteria caused ulcers. Meanwhile, The Wisdom of Crowds, a book by James Surowiecki, contends that the collective conclusions by groups of individuals are often better than those made by any single member of the group. Well, maybe; maybe not. Remember that Galileo’s belief that the sun was the center of the universe was ultimately proved correct. Maybe conventional wisdom isn’t always correct.”

- Steven A. Melnyk and Colin M. Seftel (2016)

1.1 Reality of Supply Chain in Today’s Business

Emanating from the business practice field, supply chain management has undergone a series of transformations. First, disengaged from a purely transactional function responsible only for cost-reduction towards a strengthening role through seizing unforeseen benefits supporting proactive business practices. Second and equally important, it is transcending from the state of art-something that is learned through experimentation and experience-to a science where continuous testing of commonly held beliefs takes place. As such, answers need to be congruent with practitioners’ needs.

In the meantime however, this means that we might dream of a perfect world. A world of supply chain management Utopia might be a pretty straightforward matter where the supply chain manager plans and executes the sourcing process and the respective tasks within clearly delineated boundaries with well-defined criteria accompanied by control mechanisms and with subsequent success already secured. In the supply management Utopia, managers would always predict requirements, possess ample capacity and utilize co-ordination actions in a seamless manner in order to meet business needs through the procured semi-finished products and/or components. Unfortunately, this kind of Utopia is a myth. The truth of today’s market of supply and demand is quite different and lessons taught coincide with the assertion that buying semi-finished products and/or components and subsequently offering final products to market customers poses a far more vexed question to organizations; a question that remains to be answered. This has also become a mainstay in both business management and operations management research.

Reminiscent of the supply chain management Utopia is the conceptualization of supply chain networks as complex adaptive systems. According to (Choi, T.Y., K.J. Dooley and M.Rungtusanatham, 2001) these adaptive supply chain systems can be managed directly only to a certain extent, because some part of the organization is always dynamically changing over time. Furthermore, the behavior of one organization will have impact on both types of its trading partners, those that are direct trading organizations and those that are peripherally related. Equally important is the unjustified confidence of predictive accuracy in foreseeing forthcoming demand and securing a correspondingly sufficient and
efficient supply upstream in order to serve the downstream channel. The drawback emanating from uncritically accepting such views is twofold. On one hand, what might constitute reality in one aspect becomes a myth in another. On the other hand, myths become mental prisons and this might discourage us from challenging commonly held beliefs and therefore silently abiding by one of the two (or both) schools of thought. The common denominator in both cases resides upon the prescriptive implications; myths and utopia envision ‘best practices’ which might actually serve as bad advice. However, relying solely on myths might entail compromises in the sense of grasping the complexity of contemporary supply chains.

1.2 Supply Chain Operations as ‘Investors’

Heeding the calls for a more collaborative and encompassing treatment of supply chain functions, supply chain finance has become a central concern reverberating issues of supply chain policy. Furthermore, it has been witnessing a growing resurrection during the last years. Its aspirations are aligned with the ongoing debate in academia and the implications posed on supply chain management professionals towards prompting responsible business behaviour for the longer term sustainability. In the wake of the collapse of Lehman Brothers in 2008 and the subsequent economic crisis, the nature of supply chain planning (inventory stocks, in-transit inventory and free-up of working capital) and buyer-supplier relationships is at a center stage as never before. Recent failures did not only eradicate equity wealth for unlucky or irresponsible shareholders but also imposed system-wide risks for entire supply chain structures due to diminishing available liquidity. The financial downturn of 2008-2009 led to an unprecedented credit crisis which in turn dried up available liquidity (Ellingsen, 2009) where companies adopted a dual-directional attitude, the one of postponement stance, regarding the upstream channel, pushing back supplier payments and consequently small and medium sized enterprises had to deal with limited access to capital and high interest rates (Chauffour, J. P. and Farole, T.,, 2009) and the other of focusing on inventory management that is of crucial importance to the performance of the supply chain (Musalem, E.P., R. Dekker, 2005) in order to free-up working capital that is tied in inventory and can smoothen the lack of liquidity from traditional lending institutions.

Against this backdrop, supply chain finance has now transcended from one of the most arcane aspects of corporate supply chain life down to the subject of direct intervention since previous poorly exercised finance and operations practices have irrefutably amplified the repercussions of the recession. Following this turmoil, the financial crunch has acted as an eye-opener and a new market reality expectation seems to be gaining popularity; towards a proper utilization and development of company’s financial resources to generate long term value under a sustainable basis.

Following this line of reasoning, conceptualizing supply chain management through the effectuation of capital flows taking place among business partners, both upwards and downwards from sourcing necessary materials and components to delivering and managing the final products, is
inescapable. This need of simultaneous integration of financial flows along with material flows and information has been lately recognized within the supply chain finance literature (Protopappa-Sieke, M. and Seifert, R. W, 2011) (Protopappa-Sieke, M. and Seifert, R. W, 2010) and indeed some firms have responded to this call by considering it an inextricable part of their business model (Mullins, J. W. and Komisar, R, 2009). The decisive significance and alleged benefits that result from becoming attentive to capital flows in the supply chain management framework, were outlined first by (Hofmann, E, 2005). He called for treating the relevant cash flows as equally important due to the potential impact of the financial side of business activities on jointly planning, steering and controlling financial resources from an inter-organizational perspective. To this end, (Hofmann, E. and Belin, O., 2011) state that the operational side of supply chains has become as efficient as possible and doing so they intended to put emphasis on the importance of the supply chain’s financial aspect. As such, we have seen several firms tapping into the field of supply chain finance since it provides a pathway not only out of short-term liquidity dilemmas but also towards the alleviation of the long-term financial burden (Wuttke, D. A., Blome, C., Foerstl, K. and Henke, M, 2013). To substantiate our argument, we refer to the work of Roubert (2013), cited in (Steeman, M, 2014), which demonstrates an excess of working capital of 200 million USD due to poorly managed inventory, inappropriate payment terms and delays and inter-firm processing inefficiencies. The main point emanating from the foregone discussion, is that supply chain integration raises the need for considering the financial flows of all of its supply chain partners. An effective supply chain management system presupposes the concern of the upstream flow of money along with the downstream flow of goods (Gupta, S. and Dutta, K., 2011).

1.3 Problem Statement and Research Questions

An immediate perspective that comes to the fore, calling for investigation, is the role that inventory management can play in terms of the financial impact that operations generate. This view resides upon the saying that ‘cash is king’ and working capital optimization receives central stage. To this end, companies are advised to focus attention on the operational side of the supply chain as an effort of increasing their available working capital. A prominent means to achieve this is situated within the area of inventory management. Typically, a considerable amount of working capital is locked in current inventories due to forecast inaccuracies and oversized service level targets. This in turn unveils the criticality of effective inventory management in securing working capital and synchronizing product flows in light of demand and supply variability. As such, working capital is inextricably connected to having the right amount of inventory in the right place at the right time. Within this setting, inventory management seems not only promising to strengthen the working capital but also acting as a safeguard for customer satisfaction, supply continuity and financial growth.

The sponsoring company of this thesis project is a leading manufacturer in chemical industry with Business-to-Business (B2B) worldwide operations. It consists of several different Business Units
(BUs). The focus of this thesis project is on their operations in Latin America of one specific BU. While it is relatively easier to establish supply chain in stable and well-established markets, it becomes more complex to take similar supply chain decisions in a new or unexplored market with a lot of uncertainty. The business path of introduction to a new market, the sequential growth gaining increased market share until the establishment and maturity of this process with all the dynamic reality around makes the decision-making about how to go through this, in an optimized way, a complex issue with a lot of uncertainty involved. For example, this thesis addresses the uncertainty due to forecast inaccuracy as lack of historical data or relationship makes it difficult to forecast and assess financial stability in new markets.

The problem that the company anticipates is that the replenishment process of the warehouses in all the regions lacks transparency and differs from region to region. This leads to firefighting situations and requires a lot of manual and time-consuming efforts from the Demand & Inventory Managers (DIMs), supply chain management coordinators and other planners. Optimal inventory levels are not known in every location.

Central to the above is the underlying assumption that working capital is a fundamental component of successful market competition and firm’s profitability. This in turn lends credence to the need of scrutinizing different methods available in order to preserve or even increase the margin. To this end, our two guiding research questions are as follows:

a) What are the key factors influencing safety stock placement in a single/multi-echelon network?

b) What is the right balance between Net Working Capital (NWC) and the speed of response?

As per the current business dynamics in B2B environment, customer orders are either fulfilled on-time from available stock or with the arrival of the next replenishment shipment. While the former constitutes a faster speed of response, the latter represents a slower speed of response and might lead to customer dissatisfaction in the short term and potential loss of customer in the long term. In other words, speed of response is measured by the customer service level met for on-time in-full fulfillment of the customer’s orders. The overarching treatment will materialize through a three-step process. First, what is the current landscape in terms of academic and business practice knowledge? Second, what is the current business environment like and what are the issues at stake? To what extent does a coherent framework exist for safety stock optimization? These questions are answered in Chapter 2 where we provide a summative account to the reader concerning a comprehensive and yet elaborate snapshot. It serves as the springboard for establishing our objectives and research contributions. In Chapter 3, we further elaborate on our research questions and explicate our methodology and research approach. This refers to our part in specific delineating the overall theoretical basis for our project. Last but not least, the penultimate Chapter 4 includes our case analysis. This involves analytical justification as well as the simulation results supplemented with scenario analysis.
2 Literature Survey

“Supply Chain management is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandize is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system wide costs while satisfying service level requirements.” (Simchi-Levi, D., Kaminsky & Simchi-Levi, E., 2007). Supply Chain Management is a key driver of businesses in the globalized world. Furthermore, the companies’ configuration of how they manage their supply chain network and how they allocate their resources are crucial towards long term profitability and sustainable growth.

The financial crisis aftermath puts a tremendous pressure on the businesses due to lack of cash and access to loans, and dictates improvement actions on their operations in order to improve the available money to run the business while keeping the customer satisfaction on the same or higher level. To be able to respond to this new stringent business environment, companies have started to look towards reconfiguring their supply network configuration in order to achieve economies of scale and gain ‘net’ cash flows from their own operations in order to balance the money that is not ‘available’ from the external sources (Steeman, M, 2014).

Inventory management is one of the key methods to assess the efficiency of any operations (Arnold, T., Chapman, S., & Clive, L., 2008). Safety stock is inventory carried to satisfy demand that exceeds the forecast for a given period. Safety stock is carried because demand is uncertain, and a product shortage may result if actual demand exceeds the forecast. While raising the level of safety stock increases product availability and thus the margin captured from customer purchases, it also increases inventory holding costs. The optimal deployment of inventory is a vital business function for an enterprise. There are well-documented benefits of running a manufacturing, distribution or retailing operation with leaner inventory range from a permanent reduction in working capital to increased sales and higher customer satisfaction. Managing inventory can be a daunting task for an enterprise with tens of thousands of products that are located in hundreds of locations. The challenge is even greater when the locations are situated in different tiers or echelons of the enterprise’s distribution network and even more when dealing with products of short life-cycles in markets with a lot of demand uncertainty. A central question in the supply chain management is how to coordinate activities and inventories over a large number of stages and locations, while providing a high level of service to end customers. This question is not only of great practical importance but also well suited for theoretical analysis. A multi-echelon supply chain network is so complex that one cannot hope to incorporate every conceivable cost, benefit, action and activity into a single, all-inclusive model. Rather, researchers and practitioners focus on more limited problems within different frameworks - sets of “ground rules” and shared assumptions. During the past decades, numerous investigations within several different frameworks have thus resulted in a rich literature detailing theories, models, and empirical experiences of various supply chain
problems and solutions. Nevertheless, many questions remain unanswered, and others are worth revisiting for a deeper examination (Chopra, S. and Meindl, P., 2007).

One model that is used extensively in the literature is the joint replenishment policy (JRP), where a multi-item inventory portfolio is examined under the action of coordination of the individual replenishments. It is proven, that using a periodic review policy to tackle the challenge of the multi-item inventory replenishments is superior than using continuous review policy (Viswanathan, S., 1997). The main reason that this happens is that under continuous review policy and due to the stochastic demand of the items, the inventory levels cannot be synchronized. The JRP problem has been analyzed by many researchers such as (Starr, M.K., Miller, D.W, 1962), (Shu, F.T, 1971) and (Atkins, D.R., Iyogun, O., 1988) and a literature review is done by (Khouja, M., Goyal, S., 2008).

Two models that are frequently used in the literature for multi-echelon stock placement (Graves, S. C., P. Willems, 2003) are stochastic-service model and guaranteed-service model. The fundamental difference between the two approaches stems from the way of modeling interactions of demand and supply at a stage with ones at its adjacent stages in the supply chain. It appears in different formulations of demand propagation and replenishment lead-times. Guaranteed-service model for multi-echelon supply chain first appeared in (Simpson, K. F., 1958) where stock placement problem for a serial process is successfully converted into allocation problem of service time to stages in the process. (Graves, S. C., 1987) developed an optimization algorithm with dynamic programming for Simpson’s model. All of them optimize safety stock placement by dynamic programming with stage definitions according to specific network structures.

Additionally, supply chain network design is one of the classical problems in operations research, and therefore there has been vast research in this area. Since safety stock formulation goes nonlinear in nature and its allocation to multi-echelon stages is itself a combinatorial problem, efforts to combine safety stock placement with supply chain network design have been made either in empirical or in rigorous theoretical way. Typical empirical method is to formulate safety stock level by a function of shipment volume. (Baumol, W., Wolfe, P., 1958) introduced a polynomial of degree q as cost function including inventory holding cost based on their observation in practice of inventory analysis. Empirical studies by (Ballou, R., 1984) showed that the average inventory level including safety stock can typically be expressed by a power function of throughput. Following this result, (Shapiro, A. Philpott, A., 2007) provided supply chain network optimization model with power function base safety stock model and converted it into Multiple-Integer Programming (MIP) model with piecewise linear functions.

As a half-empirical and half-theoretical approach, (Croxton, K., L., Zinn, W., 2005) used “square root law” in modeling safety stock at multiple parallel facilities. Square root law considers risk pooling effect by inventory centralization, so safety stock level spread over n parallel facilities is calculated by
S*√n where S is required safety stock level when safety stock is centralized at a single facility. Although this model is easy to be embedded into network optimization model and requires less additional computing power, it is based on strong assumption that replenishment time to all facilities is identical regardless of number of facilities and their locations. (Miranda, P., A., Garrido, R., A., 2004) incorporated safety stock model with constant replenishment time together with cycle stock model by EOQ modeling into network optimization problem, where safety stock is placed only at warehousing sites.

The decision of where to place inventories has tremendous impact in Net Working Capital (NWC) as well as the ability to absorb fluctuations of demand in the short term. According to (Vitasek, K., L., Manrodt, K. B., and Kelly, M., 2003) inventory performance can be improved by analyzing the demand under two dimensions, considering both the volume and the variability of the demand. While the aforementioned research helped us understand the quantitative perspective to tackle the thesis problem, an additional qualitative research perspective is necessary to understand various factors that impact critical decisions like how much, when and where to place inventories. We’ve identified the following factors from research and interviews with Sponsor Company. The ones that are italicized have been considered in our simulation models and will be explained in more detail in following pages.

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<th>Ownership of Supply Chain stages – Sponsoring Company or TPL</th>
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<td>Local Government Legislation</td>
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Table 2-1: Factors to be considered for Inventory management

Quite often, it is a trade-off between these factors in order to serve customers in the best possible way. In broad terms, the purpose of this project is to enable the business to make robust decisions in both financial terms and also regarding the long term sustainability of the business depicted in customer service level. The nature of the sponsor company’s business necessitates the need of intense cost reduction initiatives across their whole Supply Chain.
3 Methodology

Due to large scope and multi-disciplinary aspect of the project involving data treatment, statistical analysis, mathematical modeling, stock policy development and simulation, a multi-stage roadmap was developed to tackle this problem and all steps to be followed are presented in the figure below.

![Multi-stage roadmap of the project](image)

3.1 Defining the Scope

First of all, a clear definition of the expectations of the sponsoring company and the respective BU involved was needed in order to plan and define the scope of this thesis. Bi-weekly conference calls and a workshop between the authors and the sponsoring company were fundamental to successfully understand the current scenario, to establish the company’s expectations and to define the methodology to be followed towards meeting the project goals. The sponsor company’s expectation is to find the right balance between net working capital and the speed of response that gives them a competitive advantage. Due to a large extent of this project, the scope has been limited only to Latin American markets, which is relatively small but also the most challenging from supply chain perspective due to fluctuating demand, governmental and macro-economic factors. Apart from optimizing the performance of Latin American supply chain network, the overall target of this project also includes preparation of a generic business model that will be utilized as a key value chain for a pilot business unit within the sponsor company.
3.2 Data Collection & Integration

Having the right information is key to solve the inventory management problem. The following information was requested from the sponsoring company:

- Facility locations: plants, distribution centers, warehouses
- Transportation resources – Road, Ocean, Air – Container information
- Products and product information such as families, SKUs
- Minimum lot size, Pallet size, capacity and costs
- Demand, Forecast & Sales by SKU by location for the defined time horizon
- Transportation costs
- Weighted average cost of capital (WACC)
- Unit costs and Contribution Margin

The data collection flow to consolidate into a master database, which is used later for all modeling and simulation is depicted in the following figure.

![Data collection and consolidation](image)

In this sense, the data collection & treatment was time consuming and required a lot of efforts from both the sponsor company and the authors. Large organizations often have multiple sources of information in different platforms which consumes a lot of efforts to put these datasets together into a useful and readable form in order to have full visibility. This activity is very critical and important as any incoherence at this stage would lead to inaccurate modeling and analysis moving forward. For instance, forecasts tend to change on a periodic basis as new information is taken into account. But there exists a frozen period, beyond which the forecast is not updated. The supply chain decisions like
initiating a replenishment order are taken with this frozen forecast. Usually frozen period is longer than the lead time to ensure smooth decision making and all the KPIs such as Demand accuracy are measured against the frozen forecast. A lot of time went into deciphering the forecast files to extract the frozen forecast for a given combination of SKU, warehouse and time period. We base the analysis of modeling and simulation on the real data - historical sales and forecast data of the past 4 years, i.e. 2012 to 2015.

### 3.3 Latin American Supply Chain Network

The current supply chain network for the sponsor company that caters to LatAm markets is shown in the Figure 3.3. Supply and manufacturing footprint for all the SKUs is in Europe. There are 16 affiliate warehouses in 8 countries spread across Latin America to cater to demand from the respective region. There also exists Global DCs in Europe which serve replenishment shipments according to the orders from affiliate warehouses in Latin America. The orders from the end-customers are directly shipped from the closest affiliate warehouse in Latin America.

At this point, it is also worth mentioning that the scope of the project is confined to the replenishment strategy between Global DC in Europe to Affiliate warehouse in LatAm. This means, it is assumed that the manufacturing capacity is unconstrained within the scope of the project. Due to lack of historical service level information from the sponsor company, it is assumed the sales information is the best indicator for demand and hence sales data is used as a reference for demand in the modeling and simulation moving forward.

*Figure 3.3: Latin America Supply Chain Network*
3.4 Modeling

Since the main objective is to find the right balance between NWC and Speed of response, a study was done to understand the interaction between the factors that impact NWC and Speed of Response. The factors considered are namely – Forecast accuracy, Inventory level, Transit Inventory, Target service level and Lead time. The complex interactions between these factors are depicted in the Figure 3.4, which is the result of brainstorming sessions with supply chain experts. The arrow head indicates the impact of the preceding factor on the succeeding factor and the symbol on top of the arrow head depicts the nature of impact. For example, improving forecasting system leads to higher forecast accuracy, which in turns reduces the uncertainty and hence the need to hold higher safety stock. Lower safety stock would lead to less capital tied in inventory thereby reducing NWC.

Based on this study, we reached a conclusion that these factors can be directly controlled by three aspects of the Supply Chain – namely Segmentation Strategy, Inventory Policy and Network Design. These three aspects are studied in detail in subsequent sections of the thesis.

3.5 Segmentation Strategy

In industries that operate with a large number of SKUs, the overall supply chain can get complex from planning to logistics because of varying supply chain trends for each SKU and having a different plan for every SKU can be difficult to implement in a large global organization. The goal with supply chain segmentation is to move from a “one-size-fits-all” approach to a portfolio of supply chain execution options. About 98 percent of supply-chain leaders conduct some level of segmentation,
although the word can mean many different things, said Dave Powell, a partner in the Consumer Goods Practice of A.T. Kearney, Inc.

Due to inherent variability in the demand and supply streams at any supply chain node, the ability to service demand directly depends on the safety stock. The relationship between the two is exponential that means that a 100% guarantee to fulfill demand will, in theory, require an infinite amount of safety stock to be maintained. This feature is depicted in the below Figure 3.5. This depicts the criticality to define the target service levels from an inventory stand-point.

![Figure 3.5: Safety stock vs Target Service Level](image)

In order to differentiate the replenishment process for each SKU, the two factors which are considered are - importance of the SKU in sales and the predictability of demand. In order to study the importance of a product in a region, all SKUs are sorted by their Contribution Margin (CoMa) and classified into three categories – A, B & C- based on their profitability. While ‘A’ class SKUs are highly profitable, ‘C’ class represents the least profitable. Similarly, all SKU’s are classified into three categories – X, Y & Z – based on their forecast accuracy. While ‘X’ class represents most predictable SKUs, ‘Z’ class represents least predictable SKUs. The combination of these two classifications (A, B, C) & (X, Y, Z) results in 9 categories and their target service levels are present in Table 3.1.

<table>
<thead>
<tr>
<th>TARGET SERVICE LEVELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>Y</td>
</tr>
<tr>
<td>Z</td>
</tr>
</tbody>
</table>

*Table 3.1: ABC-XYZ Segmentation and Target service levels*

The rationale behind these target service levels is to increase the net margin by increasing product availability for highly predictable SKUs while not holding too much of inventory as buffer
stock for uncertainty. Hence, higher service levels are assigned to highly profitable and highly predictable (For example AX category) SKUs to generate higher net profits while lower service levels are assigned to least profitable least predictable SKUs to reduce working capital (For example, CZ category). It was learnt during the interviews with Sponsor Company personnel that, backorders do not become lost revenue and usually all backorders are fulfilled at a later date. The only risk is to lose the customer due to repeated delay in fulfillment of orders. Hence, within a profitability category (for example, Category A), precedence is given to the holding costs over underage costs (such as lost sales) – leading higher target service levels for AX when compared to AZ.

3.6 Inventory Policy

The inventory planning process establishes the optimal inventory levels that must be maintained at affiliate warehouse to meet expected service levels for demand fulfillment. In doing so, we will also establish the decision parameters for an inventory planning process that provides for the replenishment to work at its most optimal levels.

This process requires two decision variables - review period for reordering, and an ordering quantity. Then it needs the inventory parameters to determine whether an order for replenishment should be placed at the time of review or not. Based on the above two parameters, the reordering process can be deployed in the four basic ways:

- Periodic Review – Fixed Order Quantity at Order-point
- Periodic Review – Order-up-to Level
- Continuous Review – Fixed Order quantity at Order-point
- Continuous Review – Order up-to level

The model used for modeling and simulation is the Order up-to level with a periodic review. Not only this is the best policy for a joint replenishment inventory systems (Viswanathan, S., 1997), but also the preferred mode of inventory policy from the sponsor company due to practical constraints on human resources and IT infrastructure. Under periodic review, the inventory levels are reviewed at a set frequency. At the time of review, an order for replenishment is placed to raise the inventories to order-up-to level. This makes it easier to manage when the process is manual, or the number of items involved is extremely large, or when constraints on ordering-day exist. The actual order quantity is determined as the difference between the sum of on-hand stock and transit stock on the review day, and the “Order Up-to Level (OUL)”. These parameters control two of the most critical factors in a supply chain, the amount of inventory, and the ability to maintain favorable service levels. Both of these are defined by the inventory planning process. As the demand and supply patterns change, the optimal inventory levels required to guarantee desirable service levels also change. This means a SKU which is in AX category now can jump into AY category next year if there is significant difference in its predictability over a period of time. The value of dynamic segmentation is discussed in more detail in chapter 4. A good
inventory planning process helps define these levels, discriminating between products that require higher service levels versus those that don’t. It also reviews them frequently to make changes to the safety stock recommendations in order to adjust to the new demand/supply scenarios. Here is a brief overview of the inventory planning optimization process that determines the optimal inventory levels to meet a desired service level.

3.6.1 Inputs to Inventory Optimization

- Desired Service Level -- this is a result of the segmentation strategy. The desired service level depends on the profitability and predictability.
- Demand -- this is the historical demand for the item at the location. Note that the demand that is considered in the modeling & simulation is the historical point of sales information at the affiliate warehouse. This is due to lack of information of lost sales or historical service levels.
- Forecast -- this is the projected demand at a given location. Though forecasts change over time as we learn new information, the forecast used in the modeling & simulation is the frozen forecast which is used to decide replenishment order decisions.
- Supply Lead-time -- this is the historical lead-time of the supplies. The lead-time may vary for every transfer order that is fulfilled even for the same item/affiliate warehouse/distribution center combinations. The lead times in this particular project are often long due to the distance and the mode of transportation. For the sake of simplicity, buffer lead time has already been incorporated into the lead times provided by the transportation department of the sponsor company based on the historical trends. Hence, variability in supply lead time is not considered into the modeling & simulation.

3.6.2 Process of Inventory Optimization

The current supply chain network configuration has been modeled in ARENA Simulation software.

- Review Period – Monthly
- Order up-to level (OUL) = Sum of Frozen forecast for (Lead Time + Review Period) months + Safety Stock
- Order quantity = OUL – On-hand Inventory – Transit Inventory + Unfulfilled demand
- Every SKU has a pre-defined set of quantity required to fill one pallet. Order quantity is rounded off to nearest integer multiple of pallet(s).
- Inventory Holding Cost = WACC * Average On-hand inventory * Unit Cost
- Transportation Cost = # Shipments * # Container/shipment * Container price
- The performance of supply chain is measured in model against as real demand(Historical point-of-sales information) arrives

3.6.3 Safety Stock Calculation

One of the outputs of the modeling or simulation is the amount of safety stock. Three different approaches to arrive at safety stock are introduced here but are discussed in more detail in chapter 4.
Using Normal distribution

Here another parameter of frequency of sales is used to decide the amount of safety stock. The usage of continuous and periodic review systems have their separate advantages. While continuous review system permits greater overall inventory and item cost control at higher levels of customer serviceability, periodic systems help plant resources and budgets better for inventory review at a minimum cost because review cycle is fixed. With regard to item control, continuous system is best used to control fast-moving products, whereas periodic review is best used for slow-moving products.

A SKU is considered a

- **Fast-moving product:** If a one full-container load (FCL) worth of shipments is sufficient to cover less than 90 days of demand on an average. The amount of safety stock is equal to that of a continuous policy
- **Medium-moving product:** If a one full-container load (FCL) worth of shipments is sufficient to cover between 90 to 180 days of demand on an average. The amount of safety stock is equal to that of a continuous policy
- **Slow-moving product:** If a one full-container load (FCL) worth of shipments is sufficient to cover more than 180 days of demand on an average. The amount of safety stock is equal to that of a periodic policy

This has been explained in detail in the below Figure 3.6. Here, PPC has equivalent meaning of Stock-keeping Unit (SKU) as per nomenclature of the sponsor company.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Predictability</th>
<th># PPCs</th>
<th>CSL</th>
<th>Sales Rate (Inventory Policy)</th>
<th># PPCs</th>
<th>Safety Stock</th>
</tr>
</thead>
</table>
| A X    | Stat MAD of Forecast $\sigma_f$ 46 90% $<90$ Continuous 15 $z \times (\sigma_f + 1.25 \times \sqrt{L})$  
$>180$ Periodic 31 $z \times (\sigma_f + 1.25 \times \sqrt{L})$ |
| Y Stat + Manual MAD of Forecast $\sigma_f$ 16 85% $<90$ Continuous 3 $z \times (\sigma_f + 1.25 \times \sqrt{L})$  
$>180$ Periodic 13 $z \times (\sigma_f + 1.25 \times \sqrt{L})$ |
| Z Manual Sales Standard Deviation $\sigma_d$ 9 80% $<90$ Continuous 0 $z \times (\sigma_d + 1.25 \times \sqrt{L})$  
$>180$ Periodic 9 $z \times (\sigma_d + 1.25 \times \sqrt{L})$ |
| B X Stat MAD of Forecast $\sigma_f$ 28 75% $<90$ Continuous 0 $z \times (\sigma_f + 1.25 \times \sqrt{L})$  
$>180$ Periodic 28 $z \times (\sigma_f + 1.25 \times \sqrt{L})$ |
| Y Stat MAD of Forecast $\sigma_f$ 23 70% $<90$ Continuous 0 $z \times (\sigma_f + 1.25 \times \sqrt{L})$  
$>180$ Periodic 23 $z \times (\sigma_f + 1.25 \times \sqrt{L})$ |
| Z No Plan Sales Standard Deviation $\sigma_d$ 9 65% $<90$ Continuous 0 $z \times (\sigma_d + 1.25 \times \sqrt{L})$  
$>180$ Periodic 9 $z \times (\sigma_d + 1.25 \times \sqrt{L})$ |
| C X No Plan Sales Standard Deviation $\sigma_d$ 25 60% $<90$ Continuous 0 $z \times (\sigma_d + 1.25 \times \sqrt{L})$  
$>180$ Periodic 25 $z \times (\sigma_d + 1.25 \times \sqrt{L})$ |
| Y No Plan Sales Standard Deviation $\sigma_d$ 16 55% $<90$ Continuous 0 $z \times (\sigma_d + 1.25 \times \sqrt{L})$  
$>180$ Periodic 16 $z \times (\sigma_d + 1.25 \times \sqrt{L})$ |
| Z No Plan Sales Standard Deviation $\sigma_d$ 14 50% $<90$ Continuous 0 $z \times (\sigma_d + 1.25 \times \sqrt{L})$  
$>180$ Periodic 14 $z \times (\sigma_d + 1.25 \times \sqrt{L})$ |

*Figure 3-6: Inventory policy based on Normality*
Stationary & Evolutionary Optimization

In these methods, the amount of safety stock is an output of a non-linear optimization of the simulation model (as an output of Opt Quest module integrated in ARENA simulation software). While stationary optimization assumes that safety stock doesn’t vary with time, evolutionary optimization allows to adjust the value of safety stock with time. This is discussed in more detail in chapter 4.

3.7 Modifying Supply Chain Network Configuration

Network design decisions have a significant impact on performance because they determine the supply chain configuration and set constraints within which the other supply chain drivers can be used either to decrease supply chain cost or to increase responsiveness. All network design decisions affect one another and must be made taking these trade-offs into consideration. These trade-offs are better analyzed through simulation given the complexity in demand scenarios. While benefits include reduction in inventory by virtue of aggregation, it could lead to increased transportation and facility costs. In this project, network configuration problem is analyzed by studying the potential benefits by adding an integrated distribution center (DC) in Latin America to serve the regional warehouses. The aforementioned simulation model is used by varying inputs to investigate the potential benefits of adding a DC. The results before and after adding DC are discussed in more detail in Chapter 4.
4 Analysis and Results

4.1 Data-Scoping: Pareto Analysis

Having the right information per se will not always solve the problem; in many situations we may have too much data that it becomes difficult to handle computationally. Apart from that, lack of visibility of the overall situation can also lead to many roadblocks during the project. Thus, we firstly analyzed the data using Pareto principle in order to narrow down the scope without loss of generality. The representative sample is extracted by working top-down from the end objective. The end objective is to optimize supply chain network performance by reducing Net Working Capital (NWC). The component of supply chain network that directly contributes to NWC is Inventory. Total inventory is an addition of both on-hand inventory (cycle stock & safety stock) and transit inventory. Given that all manufacturing facilities are based out of Europe that supply to Latin American market, lead times are long (of the order of 2 - 3 months) and in turn that leads to very high transit inventory and safety stock. Both on-hand and transit inventory are a function of demand volume. We identified about 10 SKUs of 122 SKUs that add up to 70% of the total volume and that contribute to majority of NWC of the sponsor company within this BU’s Latin American markets. This is presented in the Figure 4.1. Detailed information for these 10 SKUs that was gathered from multiple databases of the sponsoring company include - Demand (all affiliate warehouses from 2012 to 2015); Frozen Forecast (all affiliate warehouse from 2011 to 2016) and SKU characteristics – Unit cost, pallet size, capacity of a 40 ft. container etc.

These 10 SKUs are shipped to 12 LatAm affiliate warehouses. Thus, there are 57 SKU-warehouse combinations since not all SKUs have customer base around all affiliate warehouses.

![Figure 4-1: Pareto Principle – Volume](image)
57 SKU-Warehouse combinations still represent a large number to continue our in-depth research in terms of simulations. Hence the scope has been further narrowed down to top 20 of these 57 combinations that contribute to about 60% of total annual volume of 122 SKUs. Moving forward, we share the results of these 20 SKU-Warehouse combinations.

4.2 Characterizing the Demand

The point of sales information for the top 20 SKU-warehouse combinations from Jan-2012 to Dec-2015 have been analyzed. The chosen tool for performing the analysis was the Input Analyzer – a module of Rockwell ARENA Simulation software. It is observed that demand behavior for most of the combinations do not follow Normal distribution within a confidence interval of 90%. We’ve noticed a range of distributions like Beta, Weibull, Gamma and Triangular etc. that best explains the demand patterns for different combinations. It is also worth mentioning that these distributions also change with time period for any given combination. This means that the distribution for 2012 to 2014 data is different from the distribution of 2012 to 2015 data. As an example, we present the analysis of daily sales information of one combination, where we can see a full pack of descriptive statistics including Chi Square test and Kolmogorov-Smirnov Test results. The results also include the square errors when the data under consideration is fit to various distributions. In this particular case, Beta distribution best explains the daily demand behavior for this combination.

![Graph showing distribution summary](image)

Given the nature of distributions of daily demand for a given combination, the behavior of weekly and monthly aggregated demand have also been analyzed. While weekly aggregated demand for the same combination can be best explained by Triangular distribution, monthly aggregate demand was best explained by Exponential distribution. As we can see, for the same combination, the past demand behavior follows different distributions at different aggregated levels – daily, weekly &
monthly. This makes formulating and implementing the inventory policy difficult in large organizations as the mathematical calculations for these probability distributions (non-normal) can get tedious.

4.3 Theoretical Modeling of Inventory Policy - Normality

As explained in section 3.6, the Inventory policy followed by the sponsor company is Order up-to level with a periodic review. Despite the fact that, the demand behavior doesn’t follow Normal distribution in most cases, it might be worthwhile to model the Inventory Policy using Normal distribution, because of the following reasons

- Normal distribution is a widely used distribution and a lot of research and literature is available
- Normality can be applied to situations in which the data is distributed very differently, by virtue of Central Limit Theorem, which states that regardless of the distribution of the population, the distribution of the means of the random samples approaches normal distribution for a large sample size.
- Easy to calculate and implement consistently across large organizations at scale

Assuming the demand follows Normal distribution, the safety stock and expected on-hand inventory, expected transit inventory and expected backorder can be calculated as given below and the results are tabulated in table 4.1

\[
\begin{align*}
\sigma_{L+T} &= \sigma_f \cdot \sqrt{(L+T)} \\
SS &= F^{-1}(CSL;0;1) \cdot \sigma_{L+T} \cdot 1.25 \\
OUL &= D_{T+L} + \sigma_{L+T} \\
\text{Expected Transit Inventory} &= D_{T+L} + \text{Expected Backorder} \\
\text{Expected Backorder} &= \sigma_{L+T} \cdot L \cdot F^{-1}(CSL;0;1) \\
\text{Expected On-hand Inventory} &= OUL - D_{T+L} + \text{Expected Backorder}
\end{align*}
\]

- F^-1 stands for inverse normal cumulative distribution
- Standard deviation is estimated by multiplying MSD with 1.25 when random component in case of normal distribution (Chopra & Meindl, 2015)
- \(L(z)\) is the standard normal loss function, i.e. the expected number of lost sales as a fraction of the standard deviation.

<table>
<thead>
<tr>
<th>SKU-Warehouse Combination</th>
<th>Safety Stock</th>
<th>Expected On-hand Inventory</th>
<th>Expected Transit Inventory</th>
<th>Expected Total Inventory</th>
<th>Expected Holding Cost</th>
<th>Expected Transportation Costs</th>
<th>Expected Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12,353</td>
<td>22,353</td>
<td>16,550</td>
<td>38,903</td>
<td>CHF 8,489</td>
<td>CHF 18,836</td>
<td>CHF 27,326</td>
</tr>
<tr>
<td>2</td>
<td>4,689</td>
<td>11,889</td>
<td>14,243</td>
<td>26,132</td>
<td>CHF 9,670</td>
<td>CHF 17,002</td>
<td>CHF 26,672</td>
</tr>
<tr>
<td>3</td>
<td>7,405</td>
<td>6,967</td>
<td>12,934</td>
<td>19,902</td>
<td>CHF 6,847</td>
<td>CHF 15,556</td>
<td>CHF 22,404</td>
</tr>
<tr>
<td>4</td>
<td>5,258</td>
<td>15,258</td>
<td>15,393</td>
<td>30,651</td>
<td>CHF 10,122</td>
<td>CHF 14,678</td>
<td>CHF 24,800</td>
</tr>
<tr>
<td>5</td>
<td>10,964</td>
<td>18,464</td>
<td>24,433</td>
<td>42,897</td>
<td>CHF 12,946</td>
<td>CHF 13,484</td>
<td>CHF 26,430</td>
</tr>
<tr>
<td>6</td>
<td>6,834</td>
<td>16,834</td>
<td>18,519</td>
<td>35,354</td>
<td>CHF 9,048</td>
<td>CHF 13,631</td>
<td>CHF 22,680</td>
</tr>
<tr>
<td>7</td>
<td>4,341</td>
<td>9,341</td>
<td>11,390</td>
<td>20,731</td>
<td>CHF 5,554</td>
<td>CHF 12,463</td>
<td>CHF 18,017</td>
</tr>
<tr>
<td>8</td>
<td>5,723</td>
<td>12,923</td>
<td>13,592</td>
<td>26,515</td>
<td>CHF 16,268</td>
<td>CHF 12,431</td>
<td>CHF 28,699</td>
</tr>
<tr>
<td>9</td>
<td>5,839</td>
<td>10,839</td>
<td>8,351</td>
<td>19,190</td>
<td>CHF 5,364</td>
<td>CHF 11,104</td>
<td>CHF 16,468</td>
</tr>
<tr>
<td>10</td>
<td>6,516</td>
<td>11,516</td>
<td>11,554</td>
<td>23,070</td>
<td>CHF 6,166</td>
<td>CHF 11,493</td>
<td>CHF 17,659</td>
</tr>
<tr>
<td>11</td>
<td>6,549</td>
<td>11,549</td>
<td>10,388</td>
<td>21,936</td>
<td>CHF 5,338</td>
<td>CHF 10,933</td>
<td>CHF 16,271</td>
</tr>
<tr>
<td>12</td>
<td>6,734</td>
<td>11,734</td>
<td>12,027</td>
<td>23,761</td>
<td>CHF 6,326</td>
<td>CHF 9,762</td>
<td>CHF 16,088</td>
</tr>
<tr>
<td>13</td>
<td>10,012</td>
<td>8,618</td>
<td>15,660</td>
<td>24,277</td>
<td>CHF 9,940</td>
<td>CHF 9,650</td>
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</tr>
<tr>
<td>14</td>
<td>4,295</td>
<td>7,895</td>
<td>9,181</td>
<td>17,076</td>
<td>CHF 8,409</td>
<td>CHF 7,801</td>
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<tr>
<td>15</td>
<td>4,938</td>
<td>14,962</td>
<td>10,689</td>
<td>25,651</td>
<td>CHF 14,556</td>
<td>CHF 6,622</td>
<td>CHF 21,177</td>
</tr>
<tr>
<td>16</td>
<td>2,641</td>
<td>2,821</td>
<td>6,242</td>
<td>9,063</td>
<td>CHF 3,115</td>
<td>CHF 5,852</td>
<td>CHF 8,967</td>
</tr>
<tr>
<td>17</td>
<td>9,611</td>
<td>18,611</td>
<td>13,032</td>
<td>31,642</td>
<td>CHF 33,264</td>
<td>CHF 5,293</td>
<td>CHF 38,558</td>
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<td>2,972</td>
<td>4,004</td>
<td>3,209</td>
<td>7,212</td>
<td>CHF 1,760</td>
<td>CHF 4,587</td>
<td>CHF 6,347</td>
</tr>
<tr>
<td>19</td>
<td>3,996</td>
<td>3,821</td>
<td>3,815</td>
<td>7,636</td>
<td>CHF 3,249</td>
<td>CHF 4,065</td>
<td>CHF 7,314</td>
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<tr>
<td>20</td>
<td>2,641</td>
<td>2,886</td>
<td>2,908</td>
<td>5,793</td>
<td>CHF 2,182</td>
<td>CHF 3,537</td>
<td>CHF 5,719</td>
</tr>
</tbody>
</table>

Table 4.1: Results for Normality-based Inventory policy
4.4 Simulation Modeling – Stationary Model

Given the variety of distributions of demand behavior and the difficulty in mathematically calculating the relevant supply chain parameters with those distributions, we resorted to simulation to optimize the total cost in the given supply chain set-up. The chosen tool for simulation is Rockwell ARENA Simulation software. The simulation is set to run for 4 years from 2012 to 2015 using the real data. The Order-up-to Level is calculated based on frozen forecast. The objective of the running the Opt Quest module is to arrive at the optimum safety stock while minimizing the Total cost, which is the sum of Inventory holding cost and Transportation cost subject to meeting target service level and adhering to minimum lot size (pallet size) constraint.

Our Discrete Event Simulation (DES) Model contains 3 tracks:
- Demand Generation & Fulfillment
- Inventory Evaluator & Affiliate Warehouse Replenishment
- Data Logger

In the first track (Figure 4.5), demand order arrives on a specific day with a specific demand order quantity as per the past sales information and the order evaluator checks the demand order quantity against the available on-hand inventory and either fulfills order in full or registers the back-order and fulfills the order partially.

![Figure 4-5 : Track 1 – Simulation Model](image)

In the second track (Figure 4.6), an Inventory evaluator entity arrives once every review period, which is a fixed time interval. The inventory evaluator reads the latest frozen forecast for the (L+T) periods, where L is Lead time for replenishment and T is the review period and calculates the Order-up-to Level (OUL) with a safety stock, which is a fixed quantity throughout the period of simulation, i.e. 4 years. Since the safety stock is fixed for entire time period irrespective of changing demand trends, the model is named as “Stationary Model”.

The third track is a Data Logger, in which a logger comes once every day and keeps track of all relevant parameters – On-hand Inventory, Transit Inventory, Order Quantity, OUL, Backorder quantity etc. on a daily basis. This kind of information is stored on an external file and is very helpful in
debugging the model or understanding some of the results which might be difficult to understand otherwise just by looking at the consolidated results after the simulation is run for 4 years.

Once the simulation model is formulated, we use the Opt Quest, an in-built module of Rockwell ARENA software, to find the optimal safety stock. The solver is based on a non-linear optimization with:

Objective : Minimize Total Cost
Subject To : CSL ≥ Target CSL for that segment for the given period**
Minimum lot size (pallet size) constraint
By changing : Safety Stock (Stationary value throughout the simulation)

** (this is discussed in more detail in the next section on dynamic segmentation)
The result of the optimization, the optimal safety stock, is plugged back into simulation model to capture the average values of On-hand inventory, transit inventory, Holding costs and Transportation Costs. For each combination, the process of running stationary model consists of:

- Data Clean-up – Forecast and Demand
- Configuring model to input respective data of each combination
- Optimization using Opt-Quest module
- Running Simulation with optimized values

This process takes between 60-90 minutes for each combination and the results of 20 combinations are captured in Table 4.2

<table>
<thead>
<tr>
<th>#</th>
<th>On-hand Inventory</th>
<th>Transit Inventory</th>
<th>Total Inventory</th>
<th>SS</th>
<th>Holding Cost</th>
<th>Transportation Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11,226</td>
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<td>34,252</td>
<td>5,712</td>
<td>CHF 7,467</td>
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<td>(621)</td>
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<td>(350)</td>
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<tr>
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<td>11,453</td>
<td>16,465</td>
<td>1,378</td>
<td>CHF 4,396</td>
<td>CHF 10,863</td>
<td>CHF 15,259</td>
</tr>
<tr>
<td>9</td>
<td>6,151</td>
<td>10,080</td>
<td>16,232</td>
<td>(540)</td>
<td>CHF 3,944</td>
<td>CHF 11,221</td>
<td>CHF 15,165</td>
</tr>
<tr>
<td>10</td>
<td>4,847</td>
<td>11,041</td>
<td>15,888</td>
<td>1,978</td>
<td>CHF 4,226</td>
<td>CHF 9,580</td>
<td>CHF 13,806</td>
</tr>
<tr>
<td>11</td>
<td>4,926</td>
<td>10,094</td>
<td>15,020</td>
<td>213</td>
<td>CHF 6,143</td>
<td>CHF 9,395</td>
<td>CHF 15,538</td>
</tr>
<tr>
<td>12</td>
<td>10,753</td>
<td>7,339</td>
<td>18,092</td>
<td>(773)</td>
<td>CHF 8,901</td>
<td>CHF 7,713</td>
<td>CHF 16,615</td>
</tr>
<tr>
<td>13</td>
<td>6,049</td>
<td>5,961</td>
<td>12,011</td>
<td>59</td>
<td>CHF 6,810</td>
<td>CHF 6,980</td>
<td>CHF 13,790</td>
</tr>
<tr>
<td>14</td>
<td>3,124</td>
<td>5,960</td>
<td>9,085</td>
<td>1,087</td>
<td>CHF 3,125</td>
<td>CHF 5,405</td>
<td>CHF 8,530</td>
</tr>
<tr>
<td>15</td>
<td>18,181</td>
<td>5,677</td>
<td>23,859</td>
<td>11,246</td>
<td>CHF 25,076</td>
<td>CHF 5,099</td>
<td>CHF 30,175</td>
</tr>
<tr>
<td>16</td>
<td>2,573</td>
<td>4,143</td>
<td>6,717</td>
<td>(369)</td>
<td>CHF 1,639</td>
<td>CHF 4,317</td>
<td>CHF 5,956</td>
</tr>
<tr>
<td>17</td>
<td>5,570</td>
<td>4,888</td>
<td>10,458</td>
<td>804</td>
<td>CHF 4,444</td>
<td>CHF 6,580</td>
<td>CHF 11,025</td>
</tr>
<tr>
<td>18</td>
<td>2,622</td>
<td>4,351</td>
<td>6,973</td>
<td>127</td>
<td>CHF 2,629</td>
<td>CHF 4,496</td>
<td>CHF 7,125</td>
</tr>
<tr>
<td>19</td>
<td>1,162</td>
<td>4,051</td>
<td>5,214</td>
<td>185</td>
<td>CHF 1,757</td>
<td>CHF 4,368</td>
<td>CHF 6,125</td>
</tr>
<tr>
<td>20</td>
<td>3,297</td>
<td>2,233</td>
<td>5,530</td>
<td>(510)</td>
<td>CHF 3,108</td>
<td>CHF 2,367</td>
<td>CHF 5,475</td>
</tr>
</tbody>
</table>

Table 4.2: Results of Stationary Model

4.5 Dynamic Segmentation

Though the overall business of the sponsor company had gone through many changes in 4 years, the safety stock remains constant across the time period of the simulation in a stationary model. For example, the following figure represents how the annual sales of few combinations have changed over time in 4 years. While the annual volume dropped by more than half in some combinations, it tripled in case of others. This is shown in Figure 4.8.

Such significant changes to business dynamics calls for changes in two keys aspects of the supply chain model – the segment the combination belongs to and the amount of safety stock. While the impact on safety stock is discussed in next section on Evolutionary model, changes in segmentation is discussed here. For example, the change in segment over time for combination 9 is illustrated in the Figure 4.9.
Figure 4-8: Changes in annual demand volume over time

The size of the bubble represents the annual volume and it is plotted over Contribution Margin (X-axis) and Mean Absolute Percentage Error (MAPE) (Y-axis). Hence the Cartesian plane is divided into 9 segments and we can see how the given combination jumps different categories in different years. These changes in the segment and the target service level are captured while running the simulation model for 4 years. For example, the constraints in the Opt-Quest module should be setup to meet a CSL of 90% (AX) in 2011, 75% (BX) in 2012 and 2013 as the volume increases.

Figure 4-9: Change in segmentation over time for one combination

In other words, the optimization model must be setup to meet the target service level every year rather than meeting the target service level for entire duration of the simulation (in this case 4 years). This holds true even for the case when a SKU doesn’t change the segment over years. For example,
consider a combination which belongs to AX category in all the 4 years. If the optimization is setup to meet the service level of 90% over 4 years, it could be the case that the solver finds the optimal safety stock (stationary model) resulting in a service level of 75% in 2012, 100% in 2013, 80% in 2014 and 100% in 2015. Though the overall service level for 4 years is 90% as desired, service levels attained in individual years do not meet the required criterion. Though this is the optimized safety stock with minimum costs for the company in the hindsight, such a model may or may not produce good results looking forward to meet the desired target level for next year.

4.6 Simulation Modeling – Evolutionary Model

An evolutionary model, which updates safety stock on a periodic basis as it learns more about the business trends, might lead to even lower costs when compared to Stationary or Normality based models, especially in such cases where we observed sporadic change in business trends. To test this, we’ve introduced an evolutionary model in two approaches – multi-variable and exponential smoothing. It is worth noting that the number of decision variables significantly increase in both of these evolutionary models when compared to a stationary model. This makes it not only computationally more challenging but also more time-consuming.

4.6.1 Multi-variable optimization

In this case, the key decision before running the optimization is the frequency to update the safety stock (SS) – monthly, quarterly, annually etc. Usually it is a management decision and the simulation can be modeled accordingly or the frequency of updating the safety stock itself can be a variable to be optimized. Unlike stationary model, a separate variable is created for every period when the safety stock needs to be updated. The more frequent SS is updated, the greater the number of variables and longer it takes for multi-variate optimization in ARENA-Opt Quest module. For example, if SS needs to be updated monthly, there would a 48 SS variables for a simulation for a period of 4 years. The results of optimized 48 SS variables can be regressed against respective Mean Standard Deviation (MSD) values to understand the underlying relation for a given distribution of demand, forecast or forecast error profiles. The below table captures the results of optimized SS values updated annually (4 decision variables) for the 20 combinations. The results indicate a further reduction of average inventory by 5% on an average of 20 combinations by annually updating the SS when compared to the optimized stationary model. The negative values observed in safety stock for some cases is attributed to positive forecast bias, which means that in such cases forecasts are higher than sales consistently for most of the review periods. Negative safety stock corrects for positive forecast bias.
4.6.2 Exponential Smoothing

Like discussed in the previous section, the key aspect of implementing this model is to decide the frequency of updating the safety stock. The only difference in this simulation model is that SS here is a derived variable which is calculated by the below equation, unlike stationary or multi-variable evolutionary model where SS is an output of optimization.

\[
SS = \alpha \cdot SS_B + (1 - \alpha) \cdot \varepsilon_{L+T}
\]

Where:

- \(SS\) = Safety stock for a given time period – a month in this case
- \(\alpha\) = Exponential smoothing constant, a value between 0 and 1
- \(SS_B\) = Base safety stock, a constant
- \(\varepsilon_{L+T}\) = Forecast error in the past (L+T) period, where L is lead time and T is the review period

<table>
<thead>
<tr>
<th>Combination</th>
<th>SS 2012</th>
<th>SS 2013</th>
<th>SS 2014</th>
<th>SS 2015</th>
<th>Average Total Inventory</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4,664</td>
<td>9,000</td>
<td>4,029</td>
<td>7,964</td>
<td>32,197</td>
<td>CHF 23,590</td>
</tr>
<tr>
<td>2</td>
<td>(1,109)</td>
<td>911</td>
<td>(1,405)</td>
<td>428</td>
<td>22,814</td>
<td>CHF 30,656</td>
</tr>
<tr>
<td>3</td>
<td>(534)</td>
<td>226</td>
<td>(645)</td>
<td>44</td>
<td>20,269</td>
<td>CHF 20,134</td>
</tr>
<tr>
<td>4</td>
<td>1,859</td>
<td>3,709</td>
<td>1,588</td>
<td>3,267</td>
<td>20,949</td>
<td>CHF 18,625</td>
</tr>
<tr>
<td>5</td>
<td>2,379</td>
<td>3,932</td>
<td>2,151</td>
<td>3,561</td>
<td>16,909</td>
<td>CHF 16,329</td>
</tr>
<tr>
<td>6</td>
<td>1,983</td>
<td>2,114</td>
<td>1,964</td>
<td>2,083</td>
<td>19,017</td>
<td>CHF 29,823</td>
</tr>
<tr>
<td>7</td>
<td>4,412</td>
<td>10,724</td>
<td>3,489</td>
<td>9,215</td>
<td>21,562</td>
<td>CHF 15,527</td>
</tr>
<tr>
<td>8</td>
<td>944</td>
<td>2,738</td>
<td>682</td>
<td>2,309</td>
<td>15,477</td>
<td>CHF 14,649</td>
</tr>
<tr>
<td>9</td>
<td>(965)</td>
<td>792</td>
<td>(1,222)</td>
<td>372</td>
<td>15,583</td>
<td>CHF 14,558</td>
</tr>
<tr>
<td>10</td>
<td>1,387</td>
<td>3,833</td>
<td>1,029</td>
<td>3,248</td>
<td>14,776</td>
<td>CHF 13,392</td>
</tr>
<tr>
<td>11</td>
<td>152</td>
<td>406</td>
<td>114</td>
<td>345</td>
<td>14,119</td>
<td>CHF 15,383</td>
</tr>
<tr>
<td>12</td>
<td>(1,786)</td>
<td>2,406</td>
<td>(2,399)</td>
<td>1,404</td>
<td>17,730</td>
<td>CHF 16,117</td>
</tr>
<tr>
<td>13</td>
<td>43</td>
<td>110</td>
<td>33</td>
<td>94</td>
<td>11,290</td>
<td>CHF 12,963</td>
</tr>
<tr>
<td>14</td>
<td>893</td>
<td>1,695</td>
<td>776</td>
<td>1,503</td>
<td>8,449</td>
<td>CHF 8,359</td>
</tr>
<tr>
<td>15</td>
<td>8,179</td>
<td>20,865</td>
<td>6,324</td>
<td>17,833</td>
<td>23,620</td>
<td>CHF 28,968</td>
</tr>
<tr>
<td>16</td>
<td>(950)</td>
<td>1,452</td>
<td>(1,301)</td>
<td>878</td>
<td>6,448</td>
<td>CHF 5,599</td>
</tr>
<tr>
<td>17</td>
<td>774</td>
<td>897</td>
<td>757</td>
<td>867</td>
<td>9,831</td>
<td>CHF 10,805</td>
</tr>
<tr>
<td>18</td>
<td>86</td>
<td>254</td>
<td>62</td>
<td>214</td>
<td>6,903</td>
<td>CHF 6,698</td>
</tr>
<tr>
<td>19</td>
<td>141</td>
<td>322</td>
<td>115</td>
<td>279</td>
<td>5,162</td>
<td>CHF 5,819</td>
</tr>
<tr>
<td>20</td>
<td>(1,045)</td>
<td>1,168</td>
<td>(1,368)</td>
<td>639</td>
<td>5,309</td>
<td>CHF 5,256</td>
</tr>
</tbody>
</table>

*Table 4-3 : Results of Evolutionary Model – Multivariate optimization*
As discussed earlier, Order up-to level (OUL) has two components – Forecast for next (L+T) period and a safety stock component to compensate for the forecast error. The two extremes of the proposed policy are when \( \alpha = 0 \) or 1. When \( \alpha = 1 \), \( SS = SS_B \), which is a constant. In other words, \( \alpha = 1 \) represents a passive stationary model where \( SS \) doesn’t change with time. On the other hand, when \( \alpha = 0 \), \( SS = \varepsilon_{L+T} \). This indicates an extremely reactive model that updates \( SS \) every month according to the forecast error of past (L+T) period. The proposed evolutionary model under exponential smoothing (where \( 0 < \alpha < 1 \)) is a middle ground between the two aforementioned passive-reactive extreme models. In this scenario, the Opt Quest module of ARENA is used to find optimum values of \( \alpha \) and \( SS_B \) while minimizing the total cost under the constraint of meeting the target service levels for the given time period. Due to time constraint, this simulation & optimization is run for only 5 combinations of top one SKU and their results are presented in the below table 4.4.

<table>
<thead>
<tr>
<th>Combination</th>
<th>Stationary Model Optimized SS</th>
<th>( SS_B )</th>
<th>( \alpha )</th>
<th>Average Total Inventory</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5712</td>
<td>6,414</td>
<td>0.77</td>
<td>31,512</td>
<td>CHF 22,637</td>
</tr>
<tr>
<td>3</td>
<td>(350)</td>
<td>(227)</td>
<td>0.51</td>
<td>19,235</td>
<td>CHF 19,715</td>
</tr>
<tr>
<td>5</td>
<td>2754</td>
<td>3,006</td>
<td>0.59</td>
<td>16,009</td>
<td>CHF 15,834</td>
</tr>
<tr>
<td>14</td>
<td>1087</td>
<td>1,217</td>
<td>0.62</td>
<td>8,177</td>
<td>CHF 8,189</td>
</tr>
<tr>
<td>19</td>
<td>185</td>
<td>214</td>
<td>0.66</td>
<td>4,693</td>
<td>CHF 5,696</td>
</tr>
</tbody>
</table>

*Table 4.4: Results of Evolutionary Model – Exponential Smoothing*

In these simulations \( SS \) is updated every month using the optimal values of \( \alpha \) and \( SS_B \) in above equation. These results indicate a further inventory reduction of about 8% on an average when compared to the results of stationary model. The choice of these 5 combinations are based on the fact that they belong to the same SKU but to different warehouses in Latin America and that their results/models can be used for further study on modifying network configuration.

### 4.7 Results Analysis

The results of the 20 combinations from all the models are compiled in the below Table 4.5.

- **AS-IS**: The current average annual inventory level held by the sponsor company
- **Normality**: Expected average annual inventory based on the normality assumption
- **Stationary Model**: The average annual inventory level based on the stationary model for the period 2012 to 2015
- **Evolutionary Model**: The average annual inventory level based on the Evolutionary model – multivariate method of updating \( SS \) annually during the period 2012 to 2015
- **Perfect Information**: This is the expected average annual inventory when we have perfect information of arriving demand, i.e. forecast = demand eliminating the need for safety stock
The objective is to get as close as possible towards average annual inventory of perfect information from the current AS-IS scenario. While implementing normality-based inventory system might give marginal benefits from current inventory levels in certain cases, stationary & evolutionary models present much more benefits by reduction in inventory by over 25% and 32% respectively from the current scenario.

The Figure 4.11 below graphically depicts the reduction in inventory levels for combination 1 through adoption of different models that are explained in this thesis.
We’ve noticed exceptions in case of combinations 15 & 18, where the AS-IS inventory levels are lower than that of any of the proposed supply chain models. The probable causes that were cited by company personnel when interviewed about these combinations are – Sponsor Company didn’t meet the target service levels resulting in heavy backorders in past years or it is data error in capturing the inventory levels accurately.

4.8 Supply Chain Network Configuration: Adding a DC

This section presents the scenario of adding a Distribution Center (DC) in Latin America to replenish the regional warehouses and LatAm DC will be replenished from Europe. Interviews with Latin American area experts of Sponsor Company indicated Mexico to be the best suitable location for placing a DC considering the volume, distance, governmental legislations, taxes and customs clearances.

Due to nature of the sponsor company’s business model, adding a DC is not going to eliminate the need of running regional warehouses because of two reasons. First, the regional warehouse serve all the Business Units of the sponsor company not just the one within the scope of this project. Secondly, serving end customers directly from DC is extremely difficult given the acceptable lead time to the customer is less than a week and it usually takes more than 10-30 days on an average for custom clearances in Latin America.
Simulations were run with the top SKU and stationary model is adopted to understand the impact of adding a DC on inventory levels and costs. The results are compiled in the below table 4.6. Though the amount of safety stock required at each facility has decreased by virtue of aggregation and reduction in lead times by adding a DC, we’ve observed an increase in total inventory levels and total costs after adding a DC when compared to before. This could be explained by two reasons. First, increase in inventory levels despite decrease in safety stock is attributed to increase in number of stocking locations. For example, inventory for catering to Argentinian demand is stored in both DC and then in the warehouse in Argentina. Secondly, increase in transportation costs is attributed to overall increase in ton-miles due to addition of another node in the supply chain network. Also, there would be additional costs of running a DC which are not captured in the simulation. From this analysis, we recommend against going for adding a DC in Latin America.

### Table 4-6: Comparison of results before and after adding DC

<table>
<thead>
<tr>
<th>FACILITY</th>
<th>Replenishment from</th>
<th>Inventory</th>
<th>Cost</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>On-Hand</td>
<td>Transit</td>
<td>Total</td>
<td>Holding Cost</td>
<td>Transpn Cost</td>
<td>Total Cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WITHOUT DC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td>Europe</td>
<td>11,226</td>
<td>23,026</td>
<td>34,252</td>
<td>CHF 7,467</td>
<td>CHF 16,361</td>
<td>CHF 23,828</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>Europe</td>
<td>5,079</td>
<td>15,602</td>
<td>20,682</td>
<td>CHF 6,825</td>
<td>CHF 14,160</td>
<td>CHF 20,985</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>Europe</td>
<td>5,442</td>
<td>12,546</td>
<td>17,988</td>
<td>CHF 4,820</td>
<td>CHF 11,673</td>
<td>CHF 16,494</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chile</td>
<td>Europe</td>
<td>1,342</td>
<td>3,408</td>
<td>4,750</td>
<td>CHF 1,249</td>
<td>CHF 3,071</td>
<td>CHF 4,321</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Colombia</td>
<td>Europe</td>
<td>1,105</td>
<td>2,224</td>
<td>3,329</td>
<td>CHF 755</td>
<td>CHF 2,406</td>
<td>CHF 3,162</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WITH DC IN MEXICO</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico DC</td>
<td>Europe</td>
<td>16,260</td>
<td>48,935</td>
<td>65,195</td>
<td>CHF 17,472</td>
<td>CHF 47,632</td>
<td>CHF 65,104</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td>Mexico DC</td>
<td>13,449</td>
<td>6,012</td>
<td>19,461</td>
<td>CHF 5,215</td>
<td>CHF 16,821</td>
<td>CHF 22,037</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>Mexico DC</td>
<td>5,478</td>
<td>2,732</td>
<td>8,211</td>
<td>CHF 2,200</td>
<td>CHF 14,547</td>
<td>CHF 16,748</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chile</td>
<td>Mexico DC</td>
<td>1,998</td>
<td>596</td>
<td>2,595</td>
<td>CHF 695</td>
<td>CHF 3,113</td>
<td>CHF 3,808</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colombia</td>
<td>Mexico DC</td>
<td>1,095</td>
<td>455</td>
<td>1,550</td>
<td>CHF 415</td>
<td>CHF 2,368</td>
<td>CHF 2,784</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>24,194</td>
<td>56,806</td>
<td>81,001</td>
<td>CHF 21,116</td>
<td>CHF 47,671</td>
<td>CHF 68,790</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 4.9 Further Analysis

With these models, further analysis can be done but for constraints in the time & resources. Here we present the scope for future analysis:

- The implementation of these models should also be examined from the technical capability and IT infrastructure within the sponsor company
- Optimizing Review period as a decision variable along with safety stock in all the simulations. Currently, review period is set as a constant of 30 days but running the similar analysis with review period as 15 days or 90 days would give different results and there is a scope to optimize the inventory levels further. While shorter review periods help in managing inventory better, frequent orders might not capitalize the benefits of aggregation in transportation costs. On the other hand, longer review periods means more uncertainty in the demand scenarios and may require higher safety stocks to compensate the uncertainty
- Pallet-size constraint: All replenishment orders are currently modeled to be rounded off to the nearest integer multiple of pallets due to current manufacturing & distribution practices
of the sponsor company. Relaxing this constraint would have some impact on availability of stock and transportation costs which might be worthwhile to study

- Segmentation strategy is currently based on Contribution Margin (ABC) and Forecasting Error (XYZ). While profitability is required for bottom-line financial savings, inventory costs are dependent on the unit cost and forecast error. So it could be interesting to study segmentation based on Unit cost of a combination.

5 Conclusion

This thesis project is a great remark of how multi-step approaches are able to breakdown larger problems and handle large amounts of data, whilst keeping the results accurate. In addition, it is a proof that scientific methods and tools such as discrete event simulation can not only be used to support or validate companies’ decision but also to optimize them.

Throughout the thesis, many different tool and techniques such as Probability distributions, Demand aggregation, Stock Policies, discrete event simulation and non-linear optimization were used in order to handle the data and enable us to build models and draw recommendations. This clearly poses the multi-disciplinary aspect not only of our project, but also of many supply chain related challenges that companies need to overcome on a daily basis.

Latin American market is relatively small but more challenging from supply chain standpoint due to complexity driven by non-stationary demand distributions. Descriptive statistics showed that the demand doesn’t follow a normal behavior irrespective of aggregating on daily, weekly or monthly basis. The evolutionary inventory models and dynamic segmentation discussed in the thesis would help the sponsor company to plan better with these non-stationary non-normal demand distributions. Consequently, the output of the non-linear optimization the DES Models presents the optimal safety stock for Sponsor Company’s current network. Three different models were discussed for inventory policy – Normality, Stationary & Evolutionary optimization each having not only increasing benefits of inventory levels and costs but also increasing difficulty in consistent implementation in large organizations. Our proposal to the company in the short term and long term will optimize their costs, however, preliminary results recommends against opening a centralized distribution center in Latin America due to increase in both inventory levels and costs.

At last, after deploying a lot of efforts on researching, handling data, building models, the most important take away of this project apart from simulation, optimization and recommendations, is the alignment between business assessments and a scientific approach that works as a robust fundament to support short, middle and long term companies’ decisions.
6 Bibliography


