MASTER

Inventory policies for the consumer after sales walk-in-centre strategy

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Inventory Policies for the Consumer After Sales Walk-In-Centre Strategy

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Abstract

This study investigates how a consumer electronics manufacturer can determine the service parts re-order levels at the various warehouses present in their after sales supply chain. This supply chain consists of a multiple of echelons and locations covering numerous regions. The performance is evaluated on multiple service criteria being Fillrate and Average Waiting Time.

We develop a mathematical model that can be used in alternative situations to determine the spare parts re-order levels for the warehouses at the various echelons. We turn this mathematical model into a software tool that is able to determine the required inventory necessary to determine the spare parts re-order levels at all echelons. In our tool we distinguish a number of alternative models and two approaches, being a single-item and multi-item approach. A case study is performed to evaluate the different models and determine possible improvements to the current situation.

Executive Summary

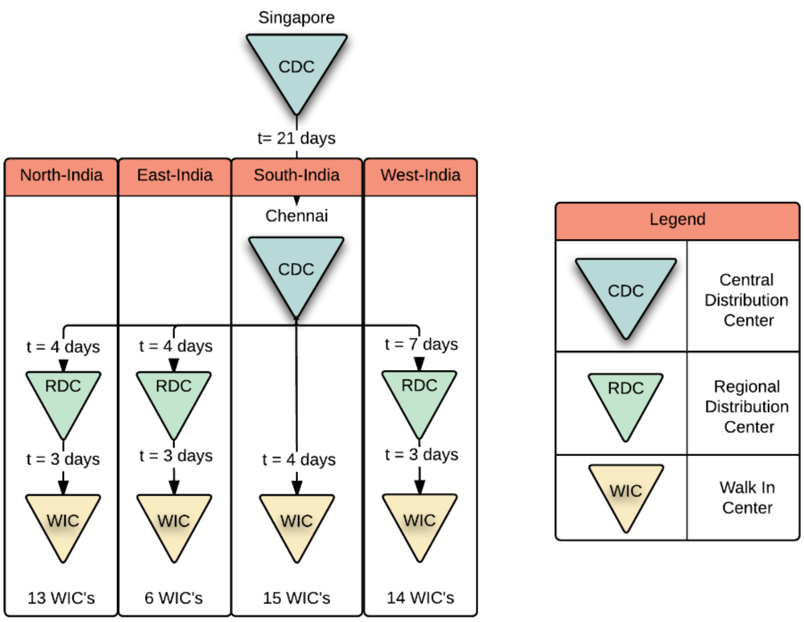
Logitech is expanding their presence in India. In order to have this possible the retailers in India request from Logitech that there should be some kind of warranty service process for the consumers. Most western based companies have decades of experience in the mature markets. But the question arises, how to set up an after-sales service for markets that are in no way comparable to the traditional markets that a company has been serving successfully for years. None of the standard models can be applied in this situation due to the large number of tiers between distributor and consumer. This length of the supply chain makes it harder to provide warranty services for a number of reasons; lack of visibility on supply chain; absence of trust and no presence in the country.

Logitech introduced a ‘new’ warranty service model called the ‘Walk-In-Centre’ (WIC) model. A WIC is basically a shop where consumers can be referred to if they want to claim their right to warranty. In this WIC there is clerk that will check whether the warranty claim is valid and if so hand out a new product. Logitech sets KPI’s on the performance of these WIC’s. In order to reach this performance stock should be kept at the WIC’s and their suppliers. This leads to the following research question:

> *How much stock should be present in order to meet the service measures? And where should this stock be kept, given the various echelons present?*

Logitech Supply Chain Characteristics

Logitech has a three echelon supply present in India, they distinguish four different regions and three types of warehouses. Due to the long lead-times and high service requirements regional warehouses are needed in some regions.



There are a number of important characteristics present in the supply chain.

- Logitech distinguishes three different kind of classes, with each their own service requirements.
- There are two types of service requirements, Fillrate and Waiting Time.
- Periodic review is used at all warehouses.
- Two types of emergency shipment can be requested, either a CDC or a RDC emergency shipment

In order to solve this problem, we need to find a scientific model that has all these features. However, a scientific model that fits well to the Logitech situation does not exist. This means that we have to combine different scientific papers in order to solve this problem. We use a paper written by Kranenburg (2006) and Axsäter (1993), and use our own ideas how to fill up the remaining parts of the problem. We create a mathemtaical model based on these papers and program it in Excel VBA.

Main conclusions

We start by studying the fillrate objectives at the CDC and RDC, as they are not stated explicitly by Logitech. We show that for both locations the 70% fillrate objectives minimizes the total system costs.

In Chapter 7 we perform a sensitivity analysis and find the following relationships:

- For the demand rate we show that for every 5% change in demand the costs change with 3%.
- For the supplier lead-time we found that if Logitech was able to reduce the lead-time with 10%, approximately 2.1 days, the total costs would decrease with 4% on a monthly basis.
- Overstocking tends to occur due to low item value. In most cases the WIC was stocked approximately at the 90% level, whereas only 70% was necessary (Section 7.4.2 and 7.4.3). This leads us to believe that the current KPI levels do not match with reality. We show that the fillrate levels could be set considerably higher and the total costs would not be effected significantly.
- Introducing Lateral transshipment as a possibility for emergency shipment. Instituting Lateral transshipment reduces the total costs and waiting time significantly. This decline of average waiting time is especially visible for the items that are not requested that often. Additionally, we discovered that these changes in average waiting time were most noticeable in the region without a RDC, being the South region. These reductions in waiting time could be as high as 40%.

Overall we can conclude that we developed a model that provides insight into the working and the savings potential in the WIC strategy. Our analysis show that the service requirements could be increased significantly, while having insignificant effects on the total costs.

Recommendations

Based on our conclusions, the following recommendations are given to Logitech.

Implement the tool as a support for decision making: Currently Logitech's responsibility ends at the Chennai warehouse and they appointed a third party that would take of the remaining processes. We suggest that Logitech should implement the tool in steps. Currently Logitech has not directly the power to change how demand is fulfilled inside India. However, this will become a possibility during the next contract negations. In this case Logitech will have more knowledge of the working inside India. However, as a first step we advise that Logitech focus on the CDC, as Logitech is responsible of stock provisioning to this stocking point. This action can be taken immediately, whereas the actions related to the lower echelons require the involvement of the ASP.

Evaluate the current Service Requirements: From our analysis in Chapter 6 and 7 we found that our tool would overstock in some cases. This entails that the tool would stock more than required to meet a service measure. The overstocking occurs due to the low item value, which makes it favourable to stock an item instead of requesting an emergency shipment. We show that a 90% fillrate objective is best suited in these conditions.

Evaluate the Number of WIC's: Due to the low demand arriving at a number of C-class WIC's, we suggest that these should be closed. Demand arriving at these WIC's could easily be forwarded to other WIC's.

Investigate the real costs: The usability of our tool and results depend on the quality of the input. Due to a third party being involved, reduces our availability to the real costs. We suggest that Logitech should research these costs as the usefulness of the tool is influenced by it.

Use the tool in other regions: We purposefully used a modular approach to Problem P. This modelling approach makes it uncomplicated to apply the tool in other regions than India. As the Walk-In-Centre warranty service model is used in other countries in the AP region.

Preface

This report is the result of my Master thesis study conducted at Logitech Nijmegen in partial fulfilment for the degree of Master in Operations Management and Logistics at Eindhoven University of Technology in the Netherlands. This challenging study at Logitech gave me the opportunity to experience the ins and outs of a large and interesting organisation. The real life experience of the working of the After Sales department is a big contribution to theoretical side of the study and provided me with valuable experiences. This thesis would not have been possible without the help from several people, who I would like to thank.

From Logitech, I would like to thank Frank Jacobs for providing me with the opportunity to write my thesis within his department. I enjoyed our thesis and non-thesis related talks. Many thanks also for your patience regarding the time frame of this project, as it eventually ended up longer than anticipated. Furthermore, I would like to thank the other members of the ASO-department, especially Paul Riemslag for providing me with the necessary information regarding this project. Also, thanks to the members of the other departments which were seated next to us, for our conversations about everything but the thesis.

From the University, I thank Arun Chockalingam, my mentor and first supervisor. His guidance and involvement has been a great help for me. Many thanks for your patience and guidance throughout this study. The several discussion sessions we had were enjoyable, but were moreover very useful for the progress of my project. Furthermore, I would like to thank my second supervisor Tarkan Tan for stepping in for Mr. Flapper so late in the process. I appreciated your constructive and challenging feedback.

This study concludes my years as a student which I enjoyed immensely. However, it is time to move on to other challenges and experiences. Finally, I would like to thank my family and friends, who supported me during my study and graduation project.

The end of an era.

Arslan Malik

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Chapter 1. Introduction

1.1 Problem Introduction

In today's business environment, the importance of after sales service should not be underestimated. Providing a fast, high-quality after-sales service to your consumers contributes to a better consumer experience. After-sales service is valuable as a competitive advantage for manufacturers as well as direct revenues resulting from carrying out after-sales related actions.

This study is devoted to designing a model that would decide where to position stock, needed to facilitate after sales services for consumers. As a result of high after sales requirements service providers design special supply chains focused on reducing the downtime of machines at their customers. These supply chains often consist of various echelons where stock is kept, all in order to reduce the waiting time at the consumer, at the same time lowering downtime costs. Service providers and their customers can set up a various number of service level requirements that can be used, typically they specify constraint on the expected system availability. Given these constraints, the service provider intents to minimize total costs. Service requirements are measured on an aggregate level as a result this provides opportunities for smart inventory management and supply chain design. The goal of the service provider is to reach requirements on average, meaning that there will be differences among item performance. All these factors, contribute to a complex inventory problem which forms the basis for this assignment.

In this study we approach this inventory problem as a spare parts problem. The justification to this approach is explained later on in this study. The spare parts business is in the literature recognized as a special research area. Spare parts inventory models differ substantially from regular inventory models. Huiskonen (2001) observed three major differences between regular inventory and spare parts inventory. Firstly, service requirements for spare parts inventory is higher due to the enormous financial effects of stockouts. Secondly, the demand for spare parts can vary extremely and is difficult to forecast. Finally, the prices of individual parts can be very high. The key reason for this difference between regular and spare parts is that spare parts provisioning is not an aim in itself but a mean to guarantee meeting the service requirements.
The main question under study is, which parts to put on stock in which location in which quantity. Considering stocks of spare parts, located at the appropriate locations can prevent long downtimes of technical systems that are used in the primary processes of their users

1.2 Logitech Problem

This study is performed at Logitech, Logitech is a Swiss company that offers products that span multiple markets such as computing, communication and entertainment platforms. Logitech has two operating segments: Computer peripherals and video conferencing. Logitech is best known as a producer of mice, the company shipped more than 500 million of essential peripherals devices in numerous models. Logitech has divided their operating activities in three different regions, namely Europe Middle East and Africa (EMEA), America's (AMR) & Asia Pacific (AP).

The traditional markets, being North-America and Europe have been in a mature state for a long time, especially regarding the PC market which has changed dramatically in the past years. The sales of PC's in the mature regions has been declining in the past years (Sherr & Ovide, 2014). So, a majority of the Western Based companies are expanding their operations to the so called BRIC countries.

The BRIC countries are considered to have to possibility to initiate a shift in global economic power. These countries have been showing double-digit growth for the past years. As one of the largest growth markets in the world, it attracts companies that want to establish a present and be part of this growth. In pursuance of increasing sales, distributors require companies to set up a proper service channel for consumers. Otherwise, the distributors are reluctant in including the companies' products in their assortment. The responsibility of setting up a warranty service process lies with the After Sales department. Most western based companies have decades of experience in the mature markets. But the question arises, how to set up an after-sales service for markets that are in no way comparable to the traditional markets that a company has been serving successfully for years. They have to ask themselves what the best warranty service model is for that particular market. The After Sales department is unable to implement one of the 'standard models', we elaborate this claim in Section 2.1. The Logitech After Sales department choose to implement a WIC warranty service model as an alternative model in these environments. The WIC warranty service model is a relatively new model to Logitech and this leads to valid questions such as; where should stock be placed in order to meet the KPI's? What quantity is needed of each SKU, and in what is the best combination of SKU's? What are the expected costs in this situation? etc. These questions are just a small example of the questions that the Afters Sales department is concerned with. Answering these questions form the basis for this study.

1.3 The Walk-In-Centre Model

Companies are obliged to handle warranty claims within a specific amount of time. There are dozens of different possible warranty service models that could provide warranty to consumers. However, not each model is suitable for every region. Because, each market has its own characteristic that might enable some type of warranty service models while hinder others. In this study we focus on a special case of the warranty service models, called 'Service Centres', hereafter referred to as Walk-In-Centres (WIC). A WIC is a physical store located strategically across a country and its cities. In a WIC a consumer can enter with a 'defective' product and the clerk will check whether the claim made by the consumer is valid or not. If the claim is valid a new product will be handed out, or in the case that the product is not on stock an emergency order will requested. In the case that the claim is unjustified the consumer is told that the he/she is not eligible for a refund, and will be asked to leave. One of the main advantages of the WIC's, besides the higher number of consumers having the possibility to make a claim, is that WIC clerk workers can check whether a claim is valid or not. Consumer return rates generally range from five to nine percent of sales; it can be up to 35% in the case of the fashion industry. A percentage of these returns can occur due to product failure, however in most cases a majority of the returns have no verifiable functional defect

(Kumar, V. D. R. Guide, & Van Wassenhove, 2002).The possibility to check a claim would reduce the number of returns considerably, as it is assumed that a majority of the returned products are still in working condition. As the estimates are that this figure can be as high as 65%. These defects are classified as no failure found (NFF).

The WIC warranty service model is a relatively new system, and forms the subject of this study. Due to the lack of knowledge regarding this new warranty service model, question arise on how to set up such a model. This study focuses on the stock related questions that arise implementing this model. We provide a more in depth discussion concerning WIC's in Chapter 2.

1.3 Methodology

We approach this study as a case study, where we try to have a generalized focus while addressing the problem and designing the model. We chose for this kind of approach as it makes this thesis more useful for companies besides Logitech. The problem that we are facing is not unique to Logitech. Throughout the first five chapters we try to be as general as possible. However, after our model build we will explicitly mention the changes we make to the model to fit the Logitech situation, if any.

The research is conducted in accordance with the methodology proposed by (Sagasti & Mitroff, 1973). They consider Operations Research from a general systems theory, assuming that the OR process should be considered as a system with several component subsystems. (figure 1) These subsystems are of a conceptual nature and correspond to some phase of the operations research process. The researcher should be concerned with both the subsystem and the relationship between them. The component subsystem exists only in relation with each other, they do not have any meaning if examined on their own.

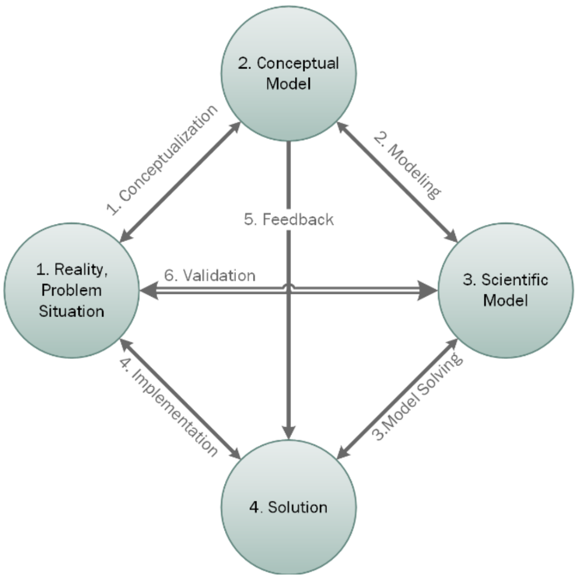

Figure 1: A system view of problem solving (adopted from Sagasti & Mitroff (1973))

All the subsystems are critical and cannot be ranked in priority or importance. This section briefly describes the systems view of problem solving as proposed by Sagasti and Mitroff (1973).

The first subsystem is called reality, and it consists of all the aspects of the real world that concern the problem situation. All of the unorganized perceptions of the OR analyst regarding the problem situation belong in this subsystem. When facing a problem, the operations researcher needs to construct a "mental image" that corresponds with reality. This "mental image" is defined as the *conceptual model* of the problem situation. The mental image should act as a framework that has the ability to translate reality to concepts that allow the reality to be modelled. The focus should lie on those characteristics that are relevant to the problem under investigation. The conceptual model specifies what variables are used in order to describe the problem, as well as how those variables are included in the model (e.g. the degree of aggregation, the time horizon and so on, (Sagasti & Mitroff, 1973). Furthermore the researcher identifies the structure of the problem and decides which aspects are relevant and which are irrelevant.

The *scientific model* is a formalized representation of both reality and the conceptual model. A scientific model can be developed at a high level of abstractness, it should still relate to the real world in order for it to be useful. The researcher is able to test the model for its internal consistency, validity and degree of correspondence with regard of reality by manipulating the model.

Solving the scientific model should lead to a feasible solution. The solution can be considered as the output of the OR process, and should lead to recommendations and advice to the decision maker. In some cases, a feedback link is placed between the solution phase and the conceptual model. This link is called feedback in the narrow sense, and it provides the researcher to test the relevance and coherence of the solution by contrasting it with the original model of the problem situation.

1.4 Report Structure

The report is structured in line with the research methodology. First, Chapter two describes the reality by performing an in depth analysis of the relevant supply chain characteristics. It aims to accurately describe and validate the problem under consideration. Second, Chapter 3 is used for the conceptualization of the current problem, by focusing the research assignment. In Chapter 4 we perform a literature review, in order to obtain more knowledge about the problem at hand. In Chapter 5 we explain how the model is formalized into a scientific or mathematical model. This chapter is concluded by explaining how we evaluate the problem. Subsequently, Chapter 6 is used for performing a case study hereby comparing several different approaches to the problem. Additionally, we explain the choices for the configuration and clarify the reason for the selected software. Furthermore, this chapter validates the model and elaborates on the chosen input for the model. Hereafter, a sensitivity analysis is performed in Chapter 7. Finally, in Chapter 8, the conclusions are presented together with the recommendations that follow from them. This final chapter is concluded with possible model extensions and directions for future research.

Chapter 2. The Walk-In-Centre Model

In this Chapter we first discuss the reasoning behind the use of Walk-In-Centres in certain markets. In Section 2.2, we focus on the supply chain that describes the replenishment strategy of all the warehouses in our network. We conclude this Chapter by clarifying the important parameters in the WIC replenishment supply chain.

2.1 Why Walk-In-Centre's?

In Section 1.2 we provided a small introduction to the WIC warranty service model, hereby focusing on the working of this particular model. In order to get a better understanding why this warranty service model is preferred or sometimes the only option we discuss the reasons behind applying this WIC model in practice.

Before we can explain the reasoning why the so called 'standard' models occasionally are not applicable, we should explain what models we consider 'standard'. We consider the warranty service models that run through the distributor as 'standard'. These are models where the seller of the product is the responsible party that is addressed when a consumer has a faulty product. This seller, often a distributor or a small retailer, will contact the product manufacturer and sort everything out. This procedure is quite easy in these regions because of the short forward supply chain. This is not the case in a majority of the countries in the Asia Pacific (AP) region. In these counties the forward supply chain is quite long, which makes it difficult to apply one of the standard warranty service models. In figure 2, we show an example of a possible forward supply chain that one could encounter in the AP region.

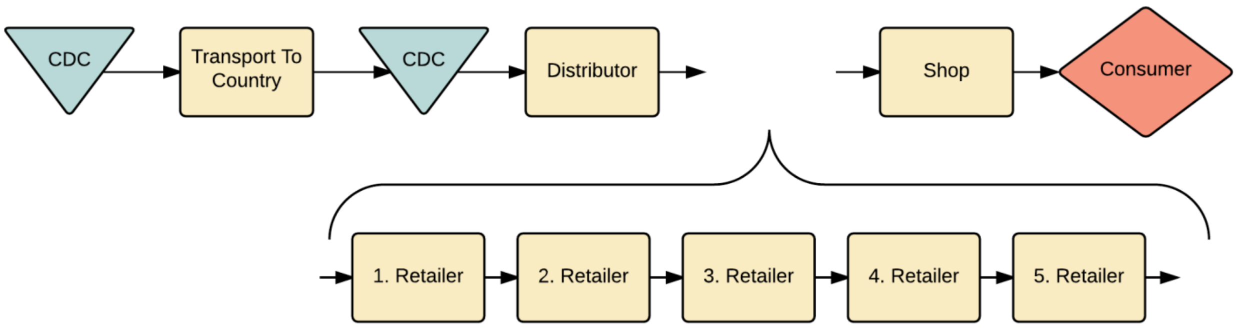

Figure 2: Typical Forward Supply Chain in the AP Region

The forward supply chain can contain as much as seven tiers between an OEM DC and a consumer. In the mature regions the number of tiers between an OEM DC and a consumer regularly does not exceed three tiers. The length of this supply chain makes it harder to provide warranty services for a number of reasons:

- **Lack of visibility**
  Due to the length of the forward supply chain the visibility on the supply chain is limited. As the OEM has no clear vision on the actors in the supply chain they are restricted in their possibilities.

- **Absence of trust in supply chain**
  The parties in the forward supply chain are not willing to take the responsibility of setting up a warranty service model, due to the lack of visibility on the whole supply chain. Shop owners are not willing to take the risk of losing money by providing the consumer with the necessary warranty. As they do not know whether they will receive any kind of reimbursement if they do so.

- **No presence in Country**
  Not every OEM has or wants a presence in each country they serve. This means that the OEM is restricted in their possibilities to provide warranty services. In this case a third party is hired that will take up the task of providing warranty to the consumers.

In conclusion these 'new' markets have vastly different characteristics than the traditional markets that most Western based companies have been serving for years. The question arises how to set up a warranty service model in these kind of environments. These characteristics require companies to find new ways to provide warranty to consumers. In order to overcome the consequences of the length of the supply chain OEM introduced a 'new' warranty service model, the WIC solution.

The use of Walk-In-Centre specifically in the AP region is not that uncommon. High tech companies such as Apple, Samsung etc. provide warranties to their consumers in the same manner. However, in most cases a third party, an Authorized Service Partner (ASP), is given the responsibility to provide the warranty to the consumers. The ASP is responsible for the location, the staffing, meeting the KPI, the capacity needed in order to help the consumer in time etc. Whereas, the OEM responsibility lies in in supplying enough products to the ASP, so that they can distribute the stock over the different region hubs and WIC. The ASP in turn is reimbursed in fees that are coupled to the number of returns.

In this section we discussed the reasons for an OEM to apply a WIC warranty service model in a certain market. The question that rise from applying this model form the basis of this study. These questions are addressed in Chapter 3.

2.2 The Walk-In-Centre supply Chain

In this study we focus on a supply chain that distinguish three types of warehouses; Central distribution centres (CDC), regional distribution centres (RDC) and Walk-In-Centre's (WIC's). In figure 3, the WIC replenishment supply chain network has been depicted. We chose to depict four regions, where regions one, two and four have a RDC and region three is without a RDC. For the sake of consistency, we keep using the same colours for the different warehouses throughout the remainder of this study. Each warehouse has its own function in this supply chain, which we depicted in table 1.

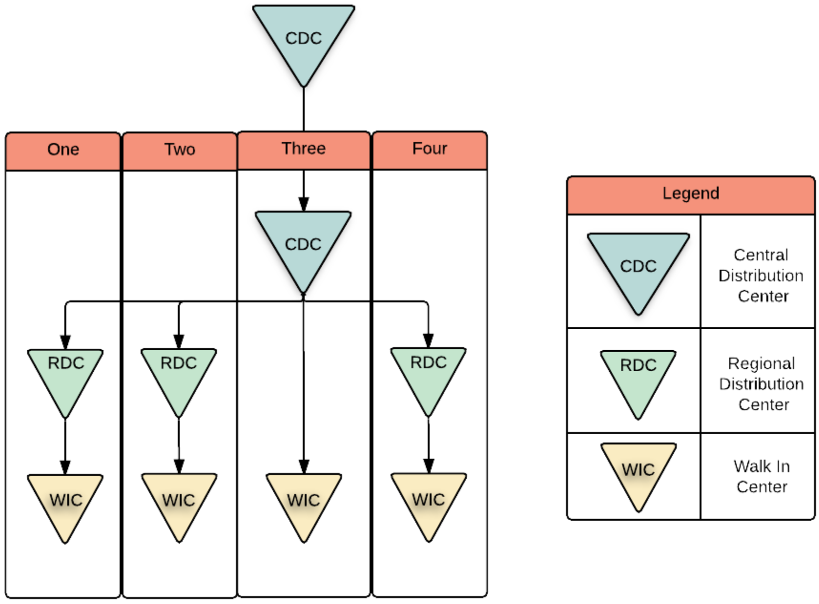

Figure 3: Walk-In-Centre Replenishment Supply Chain

Warehouse Type	Main Function	Remarks
Central DC	The CDC stores the largest amount of stock and is used as a distribution centre. All demand eventually arrives at this centre which will place a replenishment order once a period.	Can be used to provide an emergency shipment to all WIC's.
Regional DC	The RDC 's function is to shorten the lead-time to the WIC's in a certain area.	Can be used to provide an emergency shipment to all WIC's in the RDC's respective region.
Walk-In-Centre	The WIC's main function is to provide warranty to the consumers that enter these stores.	Can request for either a Regional or a Central emergency shipment, in the case that the WIC is unable to fill demand.

Table 1: Function of Warehouses present in Supply Chain

Replenishment Process

The CDC places an order at the CDC abroad. After the arrival of an order the units are distributed over the various regions to the RDC's and WIC's. It should be noted that the third Region does not have a RDC, as a result of the CDC which lies in the third region and consequently the lead-times' are already of an 'acceptable' nature. The RDC's are placed with the reasoning that it would reduce the lead-times to the WIC's, otherwise reaching the service objectives could become problematic. The function of the WIC is to check whether the claim of the consumer is valid or not, if found valid the clerk will hand out a new item. In order to reach the service levels, which are measured at the WIC's, stock will be needed at each warehouse.

We show the working of the demand fulfilment process with a small example: a consumer enters a WIC with the claim that a previously purchased product is not functioning anymore. A WIC clerk will validate this claim that the product is not functional anymore and that it is returned within the warranty period. When the consumer is proven right in his claim by the clerk at the WIC, the clerk will investigate and see whether the product can be replaced immediately. In the case that the WIC is unable to fulfil this consumers demand, the clerk will request for an emergency shipment. Either the RDC or the CDC will eventually satisfy this demand for an emergency shipment. The warehouse that ultimately fills the order will re-order a new product immediately, hereby restoring their basestock level.

2.3 WIC Supply Chain Parameters

In order to get a better view of the replenishment process we focus on the important parameters in the WIC replenishment supply chain. These parameters become an essential part of the model that is built in Chapter 5.

Demand distribution: In this study we assume that demand arrives according to a Poisson process at each warehouse. A Poisson process is widely accepted in literature to describe the demand process for failure of products. The Poisson distribution is used for phenomena where events occur independently from each other.

Different Service Levels: We distinguish three different kind of WIC's, namely Class A, Class B and Class C cities. Both the number of sales and the number of returns determine in which class a city is classified. Each city has it own service objectives that should be met. Hereby the service objective for the A class cities are the highest, and for C class cities are the lowest.

Periodic Review: In the supply chain we assume that periodic review is used at each warehouse. This means that the at a fixed point, R, in time stock is replenished in the system. The value for R can differ between echelons, however at the same echelon level we assume that this value is fixed.

Emergency shipment: In the case that a WIC is unable to fulfil demand, it will ask for an emergency shipment. This emergency request can be fulfilled by either the RDC or the CDC, depending on the stock levels on these locations. We assume that the request is first send to the RDC, if this warehouse is not able to match the demand the request is forwarded to the CDC.

Lead-time: In our study we assume that the regular lead-times between the various warehouse is deterministic. Which entails that the lead-time is fixed between warehouses. Nevertheless, we take in account the different lead-times for each region as often is the case in reality.

Chapter 3. Research Assignment

In Section 3.1 we discuss the goal of the study. Then we address the service measures relevant to this this study in Section 3.2. Subsequently we address the research questions in Section 3.3. We conclude this chapter by defining the scope in Section 3.4.

3.1 Project Goal

"Develop a planning tool which determines the base stock levels of service parts at the various stocking locations, while minimizing total system costs, subject to predefined service measures."

This tool should be universally applicable for calculating the optimal stock levels in the case of a WIC warranty service model. The optimal solution is defined as the solution with the lowest costs considering that all service measures are met.

3.2 Service Objectives

We judge the performance of our warehouses on two front, being Fill rate and Waiting time. However, not each warehouse has to comply to both service objectives. The CDC and the RDC are only judged on the Fillrate objective. The WIC's performance is judged on both fronts, Fillrate and Waiting time. The decision not to include the waiting time performance at the CDC and RDC level is made because of the type of demand arriving at these levels. As only internal demand arrives at these warehouses and only demand that can be immediately filled is measured in this case. Whereas the WIC's only face external demand from consumers, which judge the performance on both criteria.

The fill rate is defined as the performance of consumers that have a turnaround time (TAT) equal to zero. In the literature known as the probability that an arbitrarily arriving consumer order will be completely served from stock on hand. The second service measure, average waiting time, refers to the time needed to complete all demand that arrives at a warehouse. In Section 2.3 we mentioned that we have different classes in our system, the target objective of these service measures depend on the type of class a city belongs to.

3.3 Research Questions

The main research question that summarizes the aims of this research is formulates as:

How much stock should be present in order to meet the service measures? And where should this stock be kept, given the various echelons present and the WIC warranty service model?

Sub Questions

1. **Which costs could be expected given a Walk-In-Centre type of warranty service model, and keeping the KPI setting as they are?**

As we are studying a relatively new warranty solution, we are interested in the total costs that one could expect applying this warranty service model given the current settings. Since our main research question focuses on finding the best combination of SKU's that would meet the service objectives. This combination of SKU's eventually also leads to the lowest total costs.

2. **What are the effects of changing the current settings of the Key Performance Index?**

In order to get a better view of the connection between the various parameters, we are interested in seeing the results of changing the KPI's by either increasing and decreasing. Hereby focusing on the effects that these changes have on the total system costs.

3. **What are the effects of including lateral transhipments into the model?**

A possible extension to the current system would be incorporating lateral transhipments in the model. Incorporating lateral transhipment entails that an extra emergency option becomes available in the system. In the case that a WIC is unable to meet demand, instead of requesting a Central or Regional emergency shipment another WIC could be approached. With the assumption that a lateral transhipment is cheaper and has a shorter lead-time this could lead to an interesting savings potential.

4. **What are the effects of having a RDC present in a region?**

In our WIC replenishment supply chain, we have four regions, the main difference between these regions are that the region either contains a RDC or not. The function of the RDC is to reduce the average waiting time at the WIC's. We want to examine whether this occurs and if so with how much?

5. **How large are the costs benefit if chosen for a system approach over an item approach?**

In a system approach a warehouse is optimized by taking in account all the items and their costs, hereby looking for the items that contributes the most towards the service objective while not increasing the total costs significantly. Whereas, in an item approach the service objective is met for each item separately. In a system approach the potential savings could be as high as 50% compared to the standard single-item approach where the target is met for each individual item.

The main question under study is which parts to put on stock in which location in which quantity. This is a complicated problem because it is a combination of several factors: multi-echelon, multi-item, multi-service constraint and the presence of multiple transportation modes. There is no go to model in the current literature that addresses the combination of all these factors, due to the complicatedness of this environment.

3.4 Research Scope

This section defines the scope of the study. We ignore the presence of the ASP in this network. Including the ASP in the network would complicate the problem too much and limit the generality of the proposed models. We want to propose our solution, this provides Logitech with some insight in how the ASP (probably) works and might provide them ideas how to do better. The remainder of the scope Section is subdivided in several aspects, which are each described in a separate sub Section.

3.5.1 Level of Management

The level of management divides the decision process in three categories, namely strategic level, tactical level and operational level. The strategic level is not within scope, hence questions related to the locations of WIC, the number of WIC etc. are not within scope for this assignment. However, the tactical and operational levels are in scope. These levels deal with processes that are either executed every quarter to daily.

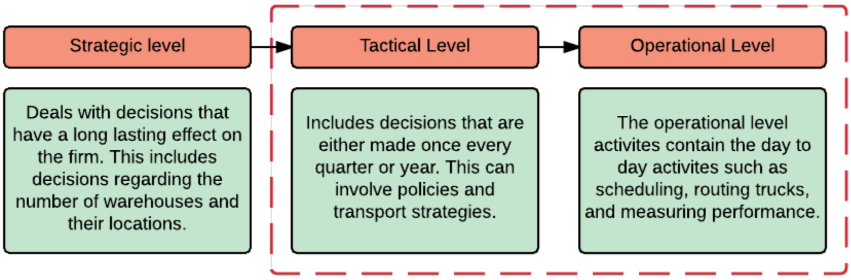

Figure 4: Level of Management within scope

3.5.2 Processes

Several processes like order fulfilment, repairing, checking consumer claims and disposal of faulty products etc. can be identified within the supply chain network. The setting of the research question, marks the boundaries of the scope, every process beyond the setting of the stock levels over the various echelons is beyond the scope of this assignment.

3.5.3 Return Options

This assignment focusses on products that are marked defective. Only the WIC warranty service model is taken in account, the other ('standard') models are not part of this project.

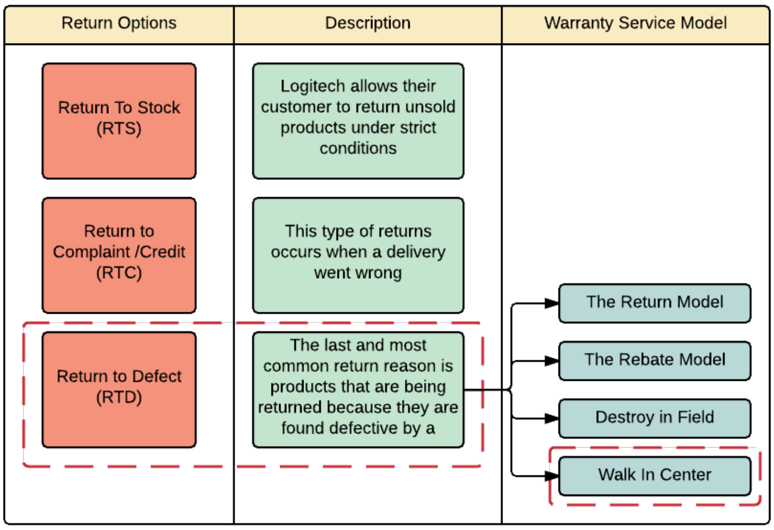

Figure 5: Overview of all possible return options and warranty service models

Chapter 4. Literature Study

In this chapter we recall the important topics, discussed in the literature review performed before starting this research. We look at the differences between spare parts and 'regular' inventory in Section 4.1. In Section 4.2, we look at literature regarding spare parts inventory control and make a distinction in papers assuming a continuous review models and periodic review models. In Section 4.3, we discuss literature regarding lateral transhipments. We conclude this chapter by addressing the issue of products becoming obsolete, in Section 4.4.

4.1 Characterization of spare parts Environment

Spare parts are treated differently than other manufacturing inventories. Firstly, the requirements for planning the logistics of spare parts differ in several ways (Huiskonen, 2001):

- Service requirements hare higher as the effects of stock outs may be financially remarkable
- The demand for parts may can vary extremely, and is difficult to forecast
- The prices of individual parts can be very high.

Secondly, spare parts inventories have a different function then other manufacturing inventories (Kennedy, Patterson, & Frendendall, 2002):

- Finished product inventories exist as a source of products for delivery to customers and are designed to protect against irregularities in demand, differences in quality levels, differences in machine production rates, labour troubles etc.
- The policies that govern final product inventories are different then the policies applied to spare parts inventories. Final product inventories can be increased or decreased by changing the production rates and schedules, improving quality, reducing lead times etc. However spare parts inventories are largely in function of how equipment is used and maintained. The choice of maintenance action can impact the spare parts inventory immediately. Another policy that would affect spare parts inventory is the policy of pre-emptively replacing spare parts.

There are a number of relevant areas of research regarding spare parts logistics, such as maintenance and reliability, production and inventory control, supply chain management, and strategic management. However, most of these areas are beyond the scope of this research.

4.1.1 Characterization of Spare Parts

Determining the inventory levels is complicated in a spare parts environment. This is caused by the characteristics of spare parts. In practice, spare part inventories are often managed by applying general inventory management principles, and not enough attention is paid to control characteristics specific to spare parts only. The need for specific categorization of items originates in their varied control requirements (Huiskonen, 2001). Item categorization can be performed in several ways, but the common aspects of all the categorization methods is that they are all based on certain item control characteristics. In this paragraph an article by Huiskonen (2001) is discussed in relation to the assignment provided by Logitech. This article provides insight in the most relevant control characteristics that can be used to classify spare parts. Huiskonen (2001) reflects these characteristics in four identified control characteristics of spare parts: criticality, specificity, demand pattern and value of part.

The criticality of a spare part is related to the consequences if a failed part cannot be replaced immediately. The specificity of a spare part relates to whether the (replacement) part is a standard part or a user-specific part. The demand pattern contains two important aspects: volume and predictability. The basic nature of the spare parts environment is that the demand for parts is very low. When this characteristic is combined with the other challenging characteristics, such as high criticality, an increase in the safety stock is a logical step to cover for the unpredictable situations. Predictability of demand is related to the failure process of the part and can be divided into parts with random failure and parts with a predictable failure pattern. The final control characteristic of spare parts according to Huiskonen (2001), is the value of the spare part. High value parts are undesirable to keep on stock, and in many cases they demand for more complex inventory holding control principles.

4.2 Spare parts inventory control

A large body of research has focused on the multi-echelon spare parts inventory problem. Each of these papers has their own assumptions and system settings. In order to capture a broad picture of the current literature concerning multi-echelon spare parts systems, several papers were analysed. Each paper can be classified with respect to the following characteristics (Topan E. , 2010).

- Item approach vs. System approach
- Number of Items
- Demand Distribution
- Inventory Policy
- Service Motivator
- Repairable vs. Consumable items

These characteristics are mentioned most often in literature regarding spare parts. Another characteristic that isn't mentioned explicitly by Topan (2010) but is assumed by a majority of the papers is the assumption of a continuous review model. Most papers regarding spare parts control assume a continuous review model over a periodic review model. In a continuous review system, the stock status is always known. Having a continuous review system has the advantage of having the possibility to make a replenishment decision any moment in time. The reason for implementing a continuous review system in a spare parts setting lies in the high service contracts that are set up between companies and their customers. With high downtime costs in the case of a failure of a part in a machine, which would make the machine unusable until the failed part is replaced. Therefore, in this paragraph the distinction is made between continuous review models (Section 4.2.1) and periodic review models (Section 4.2.2)

4.2.1 Continuous review models

Research concerning Multi-Echelon systems dates as far back as the sixties. Clark & Scarf (1960) developed a method to determine optimal base-stock levels in a serial system, and state that this method could be used as an approximation method for distriubtion systems. Sherbrooke (1968)developed METRIC which is an abbreviation of Multi-Echelon Technique For Recoverable Item Control. This was an easy-to-use method for determening base stock levels in a multi-echelon system with repaireable items. The repairable items inventory was controlled via a base stock model. The base stock model is often used for expensive, slow moving items, and in the situation where holding and backordering costs dominate. in literature regarding spare parts problems often a (S-1, S) (basestock) policy is assumed, i.e. once an item from the stock is used to satisfy a customer's request, immediately a new item is ordered to replenish the stock in the warehouse. Although other types of policies are possible, it is widely recognized that this type of policies are well-suited for spare parts inventory control (Kranenburg, 2006).

Axsäter (1990) considers a inventory system with one warehouse and N retailers, in a system setting with constant leadtimes and retailers facing Poisson demand. This sytem is solved by introducing recursive procedures for determening the holding and shortage costs of different control policies. Deuermeyer & Schwarz (1981) designed a analytical model for estimating the performance of the following system setting: One warehouse, *m* identical retailers,single-item and consumble spare parts. All of the retailers face Poisson demand and are operating uner an (Q,R) replenishment policy. Deuermeyer & Schwarz (1981) approximate the demand process at the warehouse by a renewal process and they derived expressions that would approximate the mean and variance of the warehouse lead time.
Hopp, Zhang, & Spearman, (1999) considered a mulit-item, two-echelon spare parts distribution system; with the objectibe of minimizing the total average inventory investment in the entire system subject to constraints on average annual order frequency and total average delay at each facility.

Wong et al. (2007)present several solution methods for a two-ecehlon distriubtion system based on the system approach. They recommend the use of the Greedy-alogrithm with the use of approximation evaluation method of (Graves S. , 1985). Topan et al. (2010) consider a multi-item two-echelon inventory system in which the central warehouse operates under a (Q.R) policy, and the local warehouses implement basestock policy.They develop a procedure that proposes an exact solution while minimizing the system-wide inventory holding and fixed ordering cost subject to an aggregate mean response time constraint at each facility. Topan et al. (2010) propose a branch-and-price algorithm in order to find the exact solution.
Basten & van Houtum (2014) perform a survey on the literature on models for spare parts inventory control. Their focus lies on models with a system-oriented service measures. Furhtermore they take both single-location and multie-echelon are treated, including various extensions such as lateral and emergency shipments.

4.2.2 Periodic review models

In the previous subsection we addressed continuous review spare part models, and concluded that there has been great progress since Sherbrook's METRIC. However, this is not the case with research regarding periodic review, the research to periodic review models is very limited. This seems to be due to the difficulty of these kind of problems, and scientific progress on these kind problems has been much slower (Graves S. , 1996). Graves (1989) presents a model for multi-echelon inventory systems. This model rests on two key assumptions: a fixed schedule for replenishments for all sites in the system, and a simplistic allocation rule in which stock at an upper echelon is virtually committed as demand occurs at a lower echelon. Jackson (1988) focused on a model where there are N retailers where the only shipments allowed during the cycle are from the warehouse to the retailers. Jackson developed both an exact cost model and an approximate model for the order-up-to-S policy.

Axsäter (1993) considers an inventory system with one warehouse and N retailers. Transportation times are constant and each retailer faces independent Poisson demand. Each facility applies a periodic review order-up-to-S policy; demand is filled according to a virtual allocation policy. Axsäter shows that the assumption of virtual allocation means that the system can be analysed in essentially the same way as a continuous review $(S-1, S)$- system where orders are filled on a first-come-first-served basis. Using this approach Axsäter made it possible to derive simple recursive procedures for the exact costs of different policies. The only change that Axsäter makes is that he addas an extra variable to the leadtime. This variable represents the random delay that is caused by the periodic ordering policy.

4.3 Lateral Transhipments

Lateral transhipments within an inventory system are stock movements between locations of the same echelon. Members of the same echelon pool their inventories together, which allows them to lower inventories and costs while achieving the required service levels (Paterson et al., 2011). Two main aspects of literature on lateral transhipments can be identified that differ in the timing of transhipments. Lateral transhipments can either take place at a predetermined time, or they can take place at any moment that another warehouse (at the same echelon) is out of stock. In proactive transhipments models, lateral transhipments are used to redistribute stock amongst all stocking points in an echelon at a prearranged time.

Besides the classification of proactive transhipments and reactive transhipments, there is another important distinction made in literature, namely whether a model applies full or partial pooling. The former is a term that is used to identify policies where the transhipping location is willing to share all of its stock, the latter is used when part of the stock is held back for own use. Kranenburg & van Houtum (2009) propose an alternative approach to partial pooling. Instead of allowing all locations to ship when it is beneficial, they restrict the locations which are allowed to make shipments. They make a distinction between 'main' and 'regular' locations. Main locations are allowed to both send and receive transhipments, whereas regular locations are only allowed to receive transhipments. Wong et al. (2006) use METRIC as a basis for their multi-item model where uptime of machines is considered more important rather than availabilities of individual parts. The use of lateral transhipments is especially beneficial for spare parts because short product life cycles and part obsolescence make holding stock expensive and risky.

4.4 Spare parts obsolescence

Spare parts obsolescence is a large factor in the electronics and computer industries, due to the constantly changing environment. New innovating products are released every year, which make some of the older product generations obsolete. Logitech is a consumer electronic provider, they are active in a market where changes occur constantly. Therfore it is necessary to address this issue, as it is an essential characteristic of the market. In the case of Logitech and the India market, the risk of obsolescence is especially high. All products are Logitech owned until the spare(service) part has been handed out to an consumer. If Logitech overestimates the expected demand for service parts, the excess stock that is kept at the Walk In Centers becomes obsolete if a product is discontinued.

One of the fastest way a product can become obsolete, is when sales for a new product are below expectations than the decision is made to discontinue the product (Cobbaert et al. (1996) address this risk of unexpecte immediate obsolescence of spare parts inventory. The analyze several effects of obsolescence on costs using an extention of the Economic Order Quanity model. Kim & Park (2008) study a firm's strategy to determine its product price and warranty period, and plan the spare parts manufacturing in order to maximize its profit and at the same time to fulfil its commitment to customers. They explicitly take in account the End of Live service. By depicting key dynamics in this problem, Kim et al. (2008) show how to make decisions for optimal pricing and warranty when the product life cycle is finite and the company is obliged to provide after-sales service to customers for an extended period of time.

Koppes (2008) adapts her model by incorporating the cost of obsolescence in the inventory costs. Hereby, assuming that costs of capital and obsolescence cover the opportunity costs of the money invested. Theses parameters are a fixed interest percentage of an SKU. By including the costs of obsolesence factor into the inventory costs the problem is simplified and still taken into account. This approach basically is a good substitution in cases that the obsolesence costs are not the main costs factor, but are still important enough to take into account.

Chapter 5. Stock Control Model

The model described in this chapter is a formal representation of Logitech's WIC provisioning structure aiming at the evaluation of given stocking and service policies. In Section 5.1 we explain our approach to this problem. In Section 5.2 we describe all the different models that we design for each region. In Section 5.3 we discuss the relevant costs are included in the system. In Section 5.4 we discuss the inventory order policy for Block A. We start building the model for block A in Section 5.5. while in Section 5.6 we build the model for block B. In Section 5.7 we introduce an addition to the current model, in the form of Lateral transhipment. In Section 5.8 we summarize the assumption we made throughout the model building. We end this chapter by explaining how we evaluate the models that were created.

5.1 Model Building Blocks

We are dealing with the supply chain depicted in figure 6. Our network consists of three echelons. The CDC is where all stock arrives and eventually is distributed over the various regions. Furthermore, we distinguish two types of regions; regions that have a RDC and regions that do not. Due to the size of the problem the total integration and control of all stock locations leads to enormous complexity, both from a theoretical and a practical point of view. From a theoretical angle, this supply chain is in its current state to complex of a model to gasp in one single model, and optimization would require unacceptable computing times. From a practical angle, the required changes to the organization, the (information) system and the processes are too complex to implement at once. Therefore, problems of this size are disjoined in smaller blocks, which are solved separately and eventually added up to one model.

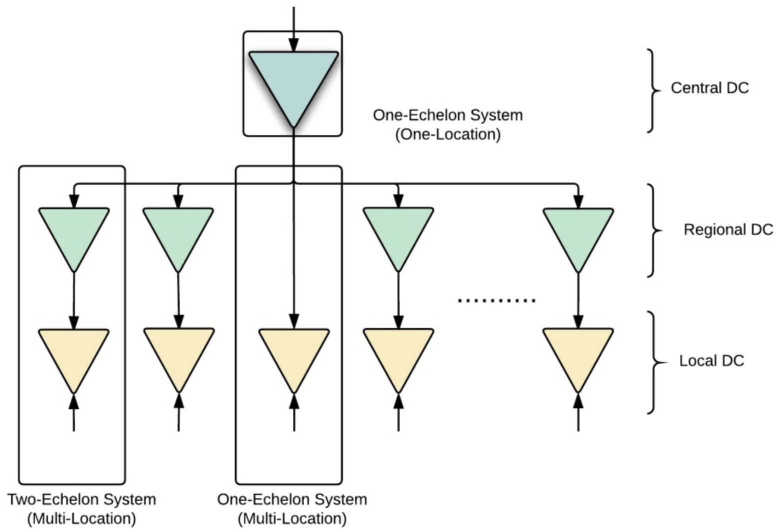

Figure 6: Stock Replenishment Supply Chain WIC's

We apply the same procedure to the multi-location, multi echelon problem of disjoining the problem is smaller solvable blocks. Our system consists of four regions, where region 1, 2 and 4 have a RDC this is not the case in region 3. This problem, hereafter referred to as **Problem P**, is disjoined in two smaller blocks, with each their own focus and objective function (figure 7)

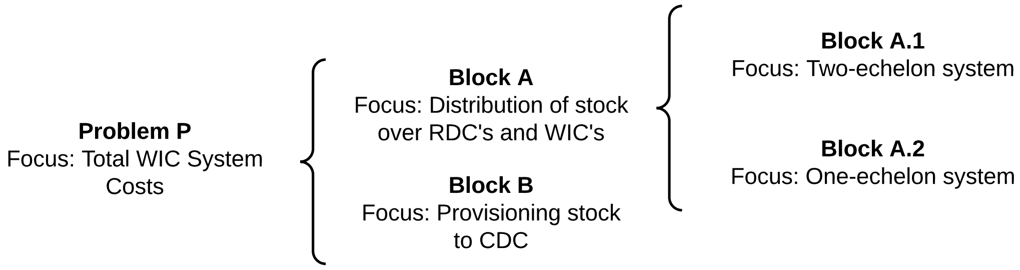

Figure 7: Problem P disjunction in the two smaller blocks A and B

Firstly, block A addresses the multi-location, multi-echelon problem, the scope of block A has been depicted in figure 8. Block A sets the re-order levels for the RDC and WIC locations, with the assumption that there is ample stock in the CDC. Block A is split into two smaller problems, A.1 and A.2, the distinction is made because of the differences between the two sub blocks. For example, block A.2 determines the re-order levels at both the WIC and the RDC, the WIC can receive two kind of emergency shipments while this is not the case with the one-echelon system. Furthermore, in the case of a two-echelon system the expected waiting time relies on the basestock levels on both the RDC and the WIC location, whereas in the case of a one-echelon system it depends on the emergency lead-time from the CDC. Secondly block B uses the demand pattern created by block A and use it to set the base stock levels at the central warehouse with the assumption that there is ample stock in CDC outside the country.

First we focus on describing and designing the non-linear optimization problem for block A in paragraphs 5.4 till 5.6. Hereby we explicitly describe the differences between block A.1 and A.2, if any. Block B and its objective function is discussed in paragraphs 5.6 and on. Afterwards, we explain how we are going to integrate the different sections into one model. Hereby, letting go of the assumption that the CDC can always deliver and taking in account the 'real' lead-time.

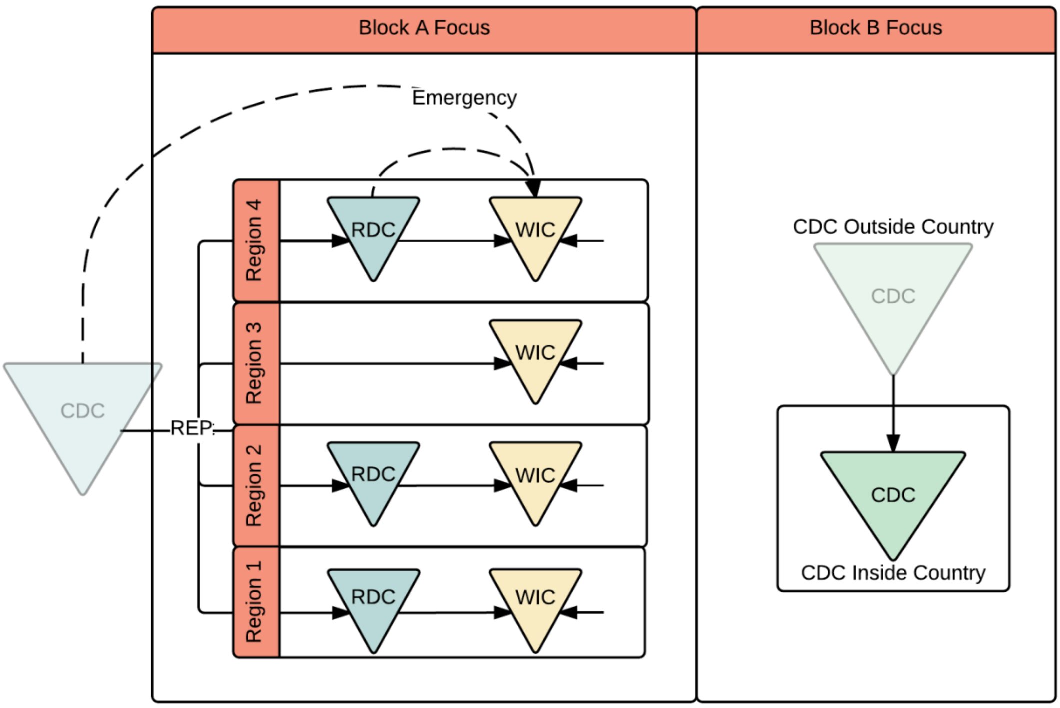

Figure 8: Focus of Block A and B

5.2 Alternatives Models

We are designing several different models, each with their own objective function and approach. Hereby distinguishing three types of approaches to address the problem, see table 2. In the first approach, we optimize each item separately. Whereas in the second approach we look for the combination of items that reaches a service objective with the lowest costs. In the third approach, we test the effects of adding lateral transhipments to the current settings. Besides the division of the models in the approach taken, we also split the service objective in three ways. This split provides us to do interesting analysis of the underlying process and discover where the real costs are located.

Item Approach
Fill Rate objective
Waiting Time objective
Fill Rate + Waiting Time objective
Multi-Item Approach (System)
Fill Rate objective
Waiting Time objective
Fill Rate + Waiting Time objective
Multi-Item + Lateral Approach
Fill Rate objective
Waiting Time objective
Fill Rate + Waiting Time objective

Table 2: The Alternative models that are programmed in the tool

In this study we only mention the 'Multi-item-Fillrate + Waiting Time objective' and the 'Multi-item-Fillrate + Waiting Time objective + lateral' mathematical models explicitly. The other alternatives are simplifications of the two main models and are therefore not interesting to mention explicitly.

5.3 Costs

In the case of a WIC warranty solution several different costs components can be distinguished, transportation costs and warehouse related costs. The selection of these costs is based on both literature and practical experiences of Logitech employees. The different subsections elaborate further on the different network costs.

5.3.1 Transportation Costs

The total costs related to transportation of the goods can be divided in three groups, regular shipments costs and costs raised by emergency shipments.
The regular shipments can be distinguished in two parts; one part is the shipping of the products from CDC (outside country) to CDC (inside country) and the second part is the shipping of the products from the central warehouse in CDC (inside country) to the various stocking locations. The emergency shipment costs occur when there is no stock

at a WIC for a requested item. The emergency costs differ whether an emergency shipment is requested from an RDC or a CDC.

5.3.2 Warehouse Costs

The total warehouse costs consist of the inventory holding costs and the costs of obsolescence. The inventory costs are calculated by multiplying the basestock levels with the holding costs percentage. One of the largest risk that spare parts face is that they become obsolete, in that case the products become worthless as they can't be used anymore. If we would treat the risk of obsolescence separately it would be another decision variable and it would make the problem too complex. To simplify our problem and still incorporate the risk of a product becoming obsolete, we add a risk percentage to the holding costs. Items that are closer to their EOL would have a higher costs of risk and therefore less desirable to stock.

5.4 Inventory Order Policy Block A

As shown in Chapter 4, in literature regarding spare parts problems often a (S-1, S) (basestock) policy is assumed, i.e. once an item from the stock is used to satisfy a consumer's request, immediately a new item is ordered to replenish the stock in the warehouse. Although other types of policies are possible, it is widely recognized that this type of policies are well-suited for spare parts inventory control (Kranenburg, 2006). A well-known paper in this field is one by Sherbrook (1968). Sherbrook introduced METRIC, which is an acronym for Multi Echelon Technique for Recoverable Item Control. We have discussed the elements of METRIC in Chapter 4, but we will shortly recall the important elements and highlight the differences between METRIC and our situation.

Due to the large number of contributions to Sherbrook's work (over 900) and the fact that it is widely recognized as a good paper in situation with multi echelon spare parts control, makes it a good basis for our model. METRIC uses a basestock policy as their inventory order policy. The insight of using a basestock policy, is based upon the well-known formula for the economic order quantity.

$$Q^* = \sqrt{\frac{2DK}{h}}$$

Often, spare parts are expensive items with low demand, hence h is a high number while the value of D is low, resulting in an optimal Q^* equal to one. Another important element of METRIC is the fact that Sherbrook assumes a continuous review system. In a continuous review system, the stock status is always known. Having a continuous review system has the advantage of having the possibility to make a replenishment decision at any moment in time. The reason for implementing a continuous review system in a spare parts setting lies in the high service contracts that are set up between companies and their customers. With high downtime costs in the case of a failure of a part in a machine, which would make the machine unusable until the failed part is replaced.

In conclusion a basestock policy is most appropriate for expensive, slow moving items and used in a continuous review setting. In table 3 METRIC vs our system is compared based on the important characteristics.

	METRIC	Logitech
Items	Expensive items	"Cheap" items
Demand	Low	Large differences
Review Type	Continuous Review	Periodic Review
Cost vs Service constrained Model	Costs (s. t. minimize backorders)	Costs (s. t. fill rate and max delay)

Table 3: Comparison between METRIC and Logitech characterization

From the above table it becomes clear that there are evident differences between the METRIC model and the Logitech situation. However, with some small changes the METRIC model can still be applicable for our situation. In the case of Logitech using a basestock policy initially does not make sense, for a number of reasons. First, the fact that we are dealing with products that have an average value of $15 and high variability in demand, would make the basestock policy not the best choice. Using a basestock policy in this situation would inflate the ordering costs immensely. Furthermore, the fact that the METRIC model uses a continuous review system, whereas Logitech uses a periodic review system for all their locations. All these problems can be solved by implementing one 'simple' solution, assuming a so called virtual allocation policy (Axsäter, 1993). The virtual allocation policy was first introduced by Graves (1989).

The assumption of virtual allocation means that the warehouse observes real time the demand processes at the retailers. Each demand will eventually trigger a replenishment request. In the occurrence of demand, the (regional) warehouse will commit a unit of its inventory to replenish the retailer, but the actual shipment does not take place until the next order from the retailer. Basically, a site will take a unit from its uncommitted inventory and place it in a truck headed for a WIC. However, this truck will not leave until the next order occasion when the actual shipment occurs, depicted in figure 9.

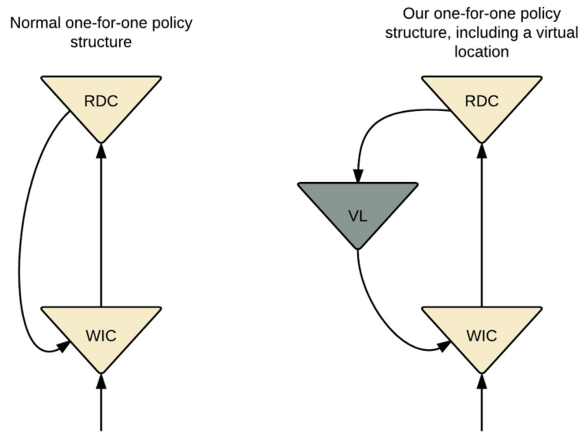

Figure 9: The Working of the Virtual Allocation Policy Visualised

The additions to the lead time are the only differences compared to a system with continuous review and basestock policies (Axsäter 1993). Implementing this virtual allocation policy would turn the a basestock policy into an order-up-to-S policy with periodic review. This leaves us with two possible inventory possibilities the (R, s, S) or an (R, S) policy. The distinction between these two policies lies in the fact that the (R, S) policy orders every R periods, whereas the (R, s, S) policy will only place an order when the stock levels are below a threshold referred to as 's'. We believe that the (R. S) policy is the policy that should be implemented in our situation. We have several motivations for this choice; First, as we are ordering overseas once a month, this means that the necessity exists to fill a shipping container in order to keep shipping costs under control. Second, due to the large demand fluctuations we believe it that the (R, s, S) policy would underperform due to its working. This policy will not place an order if the current inventory level would equal 's', but due to the large demand fluctuations the next period demand could be large enough to completely deplete the stock. Third, as this is a master thesis we are limited in our time, if we would involve the (R, s, S) policy it would require us to solve for another variable. These reasons let us believe that applying a (R, S) policy at all warehouses is the best choice.

5.5 Model and Infrastructure Block A

First building block A is addressed, with the necessary assumptions and service measures, later we look at block B and its network structure.

5.5.1 Network

The multi-location model optimizes the inventory within a WIC-region. A WIC-region is defined as a geographical region in which a possible RDC and several WIC's are located. In our system we define four regions are defined, respectively, Region 1, Region 2, Region 3 and Region 4. Each WIC is allocated to one RDC, however in the case of region 3 there is no RDC hence these are directly replenished by the CDC. In the case that a WIC is unable to meet exogenous demand, an emergency shipment can be requested from either the RDC or the CDC. Figure 10 shows a visual presentation of this concept.

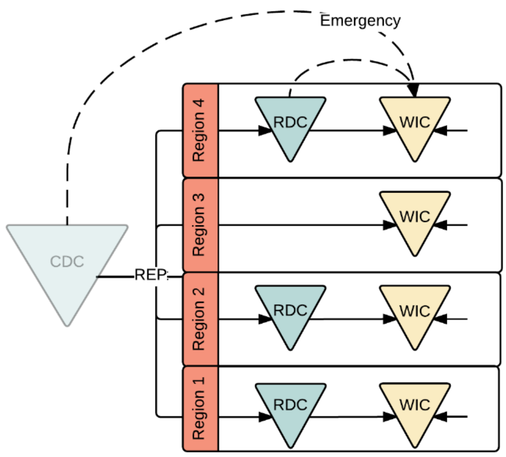

Figure 10: Visual Representation of Block A with its two types of Emergency Shipments

SKUs are denoted by set I, and are numbered $1,2 \dots, |I|$. Three types of warehouses can be distinguished each of them has their own function in the network. The CDC which is denoted as $N_C = \{0\}$, the RDC denoted as $n_r \in N_R$ with $n_r = 1, \dots, |N_R|$and the WIC's which are represented by $n_w \in N_W$ and numbered as $|N_R| + 1, \dots, |N_W|$. For the total set of warehouses the following relations hold $N = N_w \cup N_R \cup N_C$ and $N_w \cap N_R \cap N_C = \emptyset$. Each WIC is part of a city class $n_w \in J$, denoted by the set $J = \{A, B, C\}$.

Each WIC faces consumer demand, it is assumed that this occurs according to a Poisson process with constant rate m_{i,n_w}($i \in I$, $n_w \in N_W$). The total demand rate for WIC $n_w \in N_W$ is denoted as $M_{n_w} = \sum_{i \in I} m_{i,n_w}$. Each WIC $n_w \in N_W$ is assigned to only one regional warehouse $n_r \in N_R$, denoted as $N_{w,r}(\subseteq N)$. The total demand for SKU $i \in I$ at regional warehouse $n_r \in N_R$ is denoted as $M_{n_r} = \sum_{n_w \in N_{W,R}} m_{i,n_w}$.

At the central warehouse several demand flows come together. The total demand for SKU i at the central warehouse is the sum of the demand arriving from a regional warehouse and demand arriving from the WIC's located in a region without a regional warehouse, denoted as $M_{n_c} = \sum_{n_r \in N_R} M_{n_r} + \sum_{n_w \in N_W} m_{i,n}$. In total 3 different demand sources that can be recognized, an overview of them is provided in table 4. The right side of the table sums all demand over i.

	Demand rate for SKU i in demand source n	Total demand rate for demand source n
WIC	m_{i,n_w}	$M_{n_w} = \sum_{i \in I} m_{i,n_w}$
RDC	$m_{i,n_r} = \sum_{n_w \in N_{W,R}} m_{i,n_w}$	$M_{n_r} = \sum_{i \in I} \sum_{n_w \in N_{W,R}} m_{i,n_w}$
CDC	$m_{i,n_c} = \sum_{n_r \in N_R} m_{i,n_r} + \sum_{n_w \in N_W} m_{i,n_w}$	$M_{n_c} = \sum_{i \in I} \sum_{n_r \in N_R} m_{i,n_r} + \sum_{i \in I} \sum_{n_w \in N_W} m_{i,n_w}$

Table 4: The demand streams arriving at the various echelons

5.5.2 Performance Measures

Every individual WIC has two target service measure, the fill rate and the average waiting time. The target objective of these service measures depend on the type of class that this city belongs to. We distinguish between cities by having different values for their respective parameters. This entails that in our model we don't differentiate demand streams arriving at a regional or a central warehouse. In short, we assume a first come first served (FCFS) policy is used at the regional and central warehouses. We chose for this structure due to the time limit as adding this feature would require that we estimate another variable.

Block A.1
Each WIC is part of a city class $N_W \in J$, denoted by the set $J = \{A, B, C\}$. In the case of Block A.1, there are three alternative options to satisfy a demand for SKU $i \in I$ at WIC $n_w \in N_W$. Whenever demand arrives at a WIC $n_w \in N_W$ it is immediately satisfied from stock if there is an available part, otherwise an emergency shipment is requested. The service strategy is shown in figure 11. The time needed to fulfil demand depends on these strategies. More background on the lead-times regarding service fulfilment is provided in paragraph 5.6.3. The use of the above options depends on the basestock levels at the WIC $n_w \in N_W$ level and the basestock level at the RDC $n_r \in N_R$. As we made the assumption that the CDC has ample supply. In this case the use of the above strategy depends on the basestock levels at the three locations namely, WIC, RDC & CDC. Therefore we define the following vectors $\hat{S}_i := (S_{i,n_r}, S_{i,n_w})$ and $\hat{S} := (S_1, \dots, S_{|I|})$.

The first service measure, is referred to as, fill rate, and it can be measured on an item or a system approach. With respect to the fulfilment of demand for SKU $i \in I$ at WIC $n_w \in N_W$, the following notation is introduced.

1. $\beta_{i,n_w}(\hat{S}_i)$: Fraction of the demand for part i at WIC location n_w that is delivered immediately upon request. This performance indicator is called the (item) fill rate for this location.
2. $\theta_{i,n_w}(\hat{S}_i)$: Fraction of the demand for part i at WIC n_w that is delivered from the RDC as an emergency shipment.
3. $\gamma_{i,n_w}(\hat{S}_i)$: Fraction of the demand for part i at WIC n_w that is delivered from the CDC as an emergency shipment.

It holds that:

$$\beta_{i,n_w}(\hat{S}_i) + \theta_{i,n_w}(\hat{S}_i) + \gamma_{i,n_w}(\hat{S}_i) = 1,$$

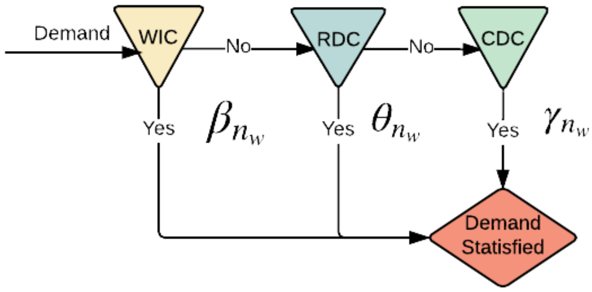

Figure 11: Demand fulfilment process, in the case of two echelons

As we assume that all demand is fulfilled the sum of the different three alternative options equals 1, i.e. all demand is fulfilled. We are interested in a system approach hence we should create a parameter that calculates the total fill rate for WIC $n_w \in N_W$. With $\beta_{i,n_w}(\hat{S}_i)$ we denote the fill rate for SKU i at location $n_w \in N_W$, this means that the aggregate fill rate can be denoted by:

$$\beta_{n_w}(\hat{S}) = \sum_{i \in I} \frac{m_{i,n_w}}{M_{n_w}} \beta_{i,w}(\hat{S}_i)$$

The target fill rate at WIC $n_w \in N_W$ is denotes as $\hat{\beta}_{n_w}^{obj}$. The second service measure is the aggregate mean response time, which measures the time needed to fulfil an arbitrary request from group $n_w \in N_W$. We follow the same procedure as in the first service measure, where we first lay our focus on the response time for SKU $i \in I$ at WIC $n_w \in N_W$, thereafter sum over $i \in I$ in the interest of gaining the aggregate mean response time at WIC $n_w \in N_W$. When a consumer arrives at WIC $n_w \in N_W$ he only has to wait if the WIC is unable to meet his demand, i.e. when an emergency shipment is requested. The mean waiting time for an emergency order for SKU i to arrive at WIC n_w depends on the warehouse that is sending the part, resulting in the following notation for the mean waiting time for demand of SKU i at WIC n:

$$W_{i,n_w}(\hat{S}_i) = \theta_{i,n_w}(\hat{S}_i) t_{i,n_w}^{c.em} + \theta_{i,n_w}(\hat{S}_i) t_{i,n_w}^{r.em}$$

The aggregated mean waiting time for an arbitrary request from WIC n_w, is the weighted sum of the average waiting times of that group for the individual SKU's $i \in I$:

$$W_{n_w}(\hat{S}) = \sum_{i \in I} \frac{m_{i,n_W}}{M_{n_w}} W_{i,n_w}(\hat{S}_i)$$

The target aggregate mean waiting time for an arbitrary demand at WIC n_w is denoted as $\widehat{W}_{n_w}^{obj}(> 0)$.

Block A.2

The big difference between blocks A.1 and A.2 lies in the 'extra' emergency options that the WIC's in the first block have available. Due to this difference we have to adjust the design parameter regarding the fill rate and waiting time in the 1-echelon system, currently present in the South of India. As a result of only one emergency shipment possibility and the assumption that the CDC has ample supply, we can let the vectors we defined previously forgo. As the use of an emergency options solely depends on the basestock level at the WIC $n_w \in N_W$. With respect to the fulfillment of demand for SKU $i \in I$ at WIC $n_w \in N_W$, the following notation is introduced.

1. $\beta_{i,n_w}(S_i)$: Fraction of the demand for part i at WIC location n_w that is delivered immediately upon request. This performance indicator is called the (item) fill rate for this location.
2. $\theta_{i,n_w}(S_i)$: Fraction of the demand for part i at WIC n_w that is delivered from the CDC as an emergency shipment.

In total this results in $\beta_{i,n_w}(S_i) + \theta_{i,n_w}(S_i) = 1$. With $\beta_{i,n_w}(S_i)$ we denote the fill rate for SKU i at location $n_w \in N_W$, this means that the aggregate fill rate can be denoted by:

$$\beta_{n_w}(S_i) = \sum_{i \in I} \frac{m_{i,n_w}}{M_{n_w}} \beta_{i,n_w}(S_i)$$

The target fill rate is at WIC $n_w \in N_W$ is denotes as $\hat{\beta}_{n_w}^{obj}$. The second service measure is the aggregate mean response time. The mean waiting time for an emergency order for SKU i to arrive at WIC n_w equals $t_{i,n_w}^{c.em}$, resulting in the following notation for the mean waiting time for demand of SKU i at WIC n_w:

$$W_{i,n_w}(S_i) = \theta_{i,n_w}(S_i) t_{i,n_w}^{c.em}$$

The aggregated mean waiting time for an arbitrary request from WIC n_w, is the weighted sum of the average waiting times of that group for the individual SKU's $i \in I$:

$$W_{n_w}(S_i) = \sum_{i \in I} \frac{m_{i,n_w}}{M_{n_w}} W_{i,n_w}(S_i)$$

The target aggregate mean waiting time for an arbitrary demand at WIC n_w is denoted as $\widehat{W}_{n_w}^{obj}(> 0)$.

5.5.3 Transportation Mode

In the transportation process several different transportation modes can be used. These transportation modes can be distinguished in two groups, regular shipments and emergency shipments. Both groups differ in terms of time and costs. The regular shipments are shipments between the central warehouse and the regional warehouse and the shipments between the regional warehouse and the WIC's. These shipments are performed every R periods, with R depending on the replenishing strategy at that echelon level. The costs associated with these shipments are denotes as $C^{reg}_{N_C,N_R}$ and $C^{reg}_{N_R,N_W}$. The lead-time is denoted as $t^{reg}_{N_C,N_R}$ and $t^{reg}_{N_R,N_W}$. These terms assume that there is a regional warehouse between the central warehouse and the WIC's, however this is not always the case. This means that we need 2 additional terms to describe the regular shipments to the third region, these shipments and costs are denoted as $C^{reg}_{N_C,N_W}$ and $t^{reg}_{N_C,N_W}$.

The fastest (and most expensive) transportation mode is referred to as the emergency shipment mode. This type of service is only used when SKU i requested at WIC $n_w \in N_W$ is not available at this location. Overall emergency shipments should result in faster delivery against higher costs. The costs associated with emergency shipping a SKU i from CDC are denoted as $C^{c.em}_{n_w}$ and the time needed for this shipment is represented by $t^{c.em}_{n_w}$, and in the case of an emergency shipment from the RDC $C^{r.em}_{n_w}$ and $t^{r.em}_{n_w}$. The value for the parameters for both transportation modes depend on the shipping and the receiving warehouses. The different shipping modes are part of a set $Y = \{1,2\}$. Where 1 refers to the fastest shipping mode, used for emergency shipments between CDC and WIC. Whereas shipping mode 2 refers normal replenishment shipments, slow shipments.

5.5.4 Replenishment Process

After demand has been served from a WIC, the stock should be replenished. In a normal continuous system, after demand at a local warehouse stock is immediately replenished. However, in our case due to the low price of the items and the varying demand we opted for a periodic review model. Implementing a periodic review system, means that for each type of warehouse replenishment orders are issued at a predetermined frequency. This frequency is denoted by R_W for the WIC's. R_R denotes the review time at the RDC's and R_C is used to denote the review period at the CDC. All warehouses issue orders at the same moment, all R's are multipliers of each other.
We change the continuous review system to a periodic review system based on the research performed by Axsäter (1993). Axsäter addressed this problem by adding a variable that captures the delay caused by periodic ordering. In figure 12 we show the working of this delay.

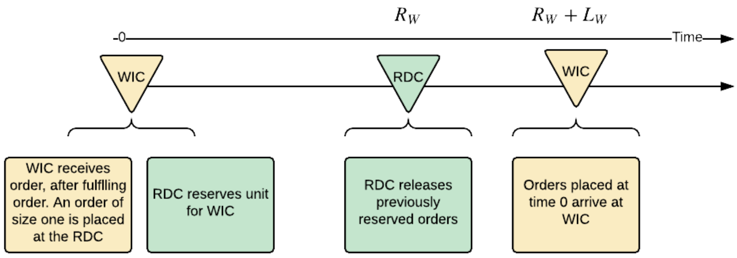

Figure 12: Lead-time delay, due to the use of Periodic Review

The additions to the lead-time are the only differences compared to a system with continuous review and a basestock ordering policies. We define the length of the adjusted lead-time by adding the mean of the review period to the current lead-time. In formal form:

$$L_{C.adj} = L_C + (0.5 * R_C)$$
$$L_{R.adj} = L_R + (0.5 * R_R)$$
$$L_{W.adj} = L_W + (0.5 * R_W)$$

In figure 13 we show an example of the working of the delay caused by periodic review. We have three demand request arriving at the WIC at time t=0, t=2 and t=4. Demand is met at each of these occasions, after fulfilling demand a replenishment part is requested from the RDC. However, this part is not released until time equals the review period of the WIC. At this point all demand arrived between two periods will be released and will arrive at the WIC with a delay of R+L.

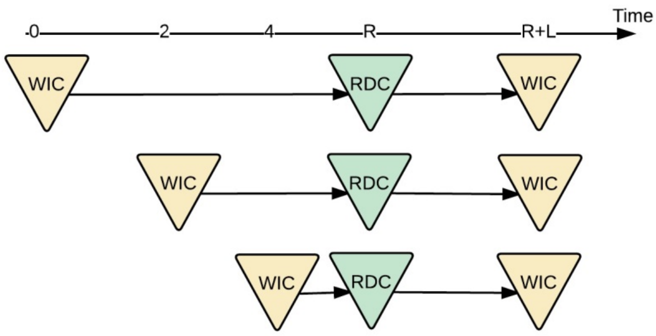

Figure 13: Working of the Delay caused by Periodic Review

5.5.5 System Costs

This section describes the expected total system cost per time unit for the provisioning of service parts. The system cost composes of the transportation costs and the holding costs.

Transportation costs

$$\sum_{n_w \in N_w} M_{i,n_w}\left(C_{n_w}^{r.em}\theta_{i,n_w}(\hat{S}_i) + C_{n_w}^{c.em}\gamma_{i,n_w}(\hat{S}_i)\right)$$

Holding costs (at WIC and at RDC)

$$c_i^h \sum_{n_w \in N_W} S_{i,n_w} + c_i^h \sum_{n_r \in N_R} S_{i,n_r}$$

Totalling in:

$$C_i(\hat{S}_i) = c_i^h \sum_{n_w \in N_W} S_{i,n_w} + c_i^h \sum_{n_r \in N_R} S_{i,n_r} + \sum_{n_w \in N_W} M_{i,n_w}\left(C_{n_w}^{r.em}\theta_{i,n_w}(\hat{S}_i) + C_{n_w}^{c.em}\gamma_{i,n_w}(\hat{S}_i)\right)$$

Sum over all i's

$$C(\hat{S}) = \sum_{i \in I} C_i(\hat{S}_i)$$

$$(A.1) \quad \begin{array}{ll} Min & C(\hat{S}) \\ Subject\ to & \beta_{n_w}(\hat{S}) \geq \hat{\beta}_{n_w}^{obj} \\ & W_{n_w}(\hat{S}) \leq \widehat{W}_{n_w}^{obj} \\ & S_{i,n} \in \mathbb{N}, i \in I, n_w \in N_W, n_r \in N_R \end{array}$$

The objective function for block A.2 is quite similar however the build-up of the costs is different.
Transportation costs:

$$\sum_{n_w \in N_W} M_{i,n_w} C_{n_w}^{r.em}\theta_{i,n_w}(\hat{S}_i)$$

Holding costs (at WIC):

$$c_i^h \sum_{n_w \in N_W} S_{i,n_w}$$

Totalling in:

$$C_i(\hat{S}_i) = c_i^h \sum_{n_w \in N_W} S_{i,n_w} + \sum_{n_w \in N_W} M_{i,n_w} C_{n_w}^{r.em}\theta_{i,n_w}(\hat{S}_i)$$

Sum over all i's

$$C(\hat{S}) = \sum_{i \in I} C_i(\hat{S}_i)$$

$$(A.2) \quad \begin{array}{ll} Min & C(\hat{S}) \\ Subject\ to & \beta_{n_w}(\hat{S}) \geq \hat{\beta}_{n_w}^{obj} \\ & W_{n_w}(\hat{S}) \leq \widehat{W}_{n_w}^{obj} \\ & S_{i,n} \in \mathbb{N}, i \in I, n_w \in N_W, n_r \in N_R \end{array}$$

5.6 Model and Infrastructure Block B

The central warehouse serves demand from several different demand sources. We assume that all arrival of demand at the central warehouse follows a Poisson process. This assumption was already made in Block A, where an adjusted basestock policy is implemented. We are dealing with a single echelon location facing Poisson demand, as shown in figure 14.

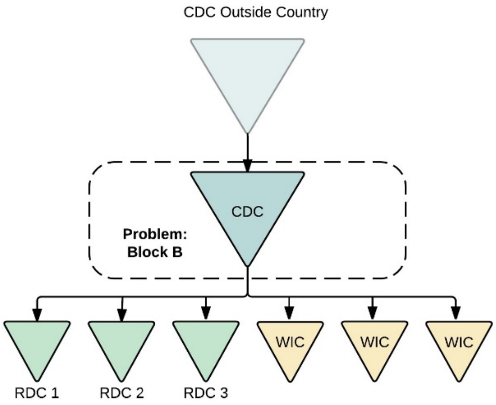

Figure 14: Focus of Block B

The set of SKU's is denoted as i, and are numbered as $i = 1, \dots, |I|$. The rate m_i denotes the demand rate for all machines together. The total demand for all SKU's is denoted by $M = \sum_{i \in I} m_i$.

Service Measure:

1. $\beta_{i,n_c}(S_i)$: Fraction of the demand for part i at WIC location n_w that is delivered immediately upon request. This performance indicator is called the (item) fill rate for this location.

With $\beta_{i,n_c}(S_i)$ we denote the fill rate for SKU i at location $n_c \in N_C$, this means that the aggregate fill rate can be denoted by:

$$\beta_{n_c}(\hat{S}_i) = \sum_{i \in I} \frac{m_{i,n_c}}{M_{n_c}} \beta_{i,n_c}(S_i)$$

The costs are denoted by:

Transportation costs:

$$\sum_{n_c \in N_C} M_{i,n_c} \left(C_{N_C}^{reg} \beta_{n_c}(\hat{S}_i) \right)$$

Holding costs:

$$c_i^h \sum_{n_c \in N_C} S_{i,n_c}$$

Totalling in:

$$C_i(\hat{S}_i) = c_i^h \sum_{n_c \in N_C} S_{i,n_c} + \sum_{n_c \in N_C} M_{i,n_c} \left(C_{N_C}^{reg} \beta_{n_c}(\hat{S}_i) \right)$$

Sum over all i's:

$$C(\hat{S}) = \sum_{i \in I} C_i(\hat{S}_i)$$

$$\begin{array}{lll} (B) & Min & C(\hat{S}) \\ & Subject\ to & \beta_{n_c}(\hat{S}) \geq \hat{\beta}_{n_c}^{obj} \\ & & S_{i,n} \in \mathbb{N}, i \in I, n_c \in N_C \end{array}$$

5.7 Extensions to current Model: Lateral Transhipments

One possible extension to the current model could be including an extra emergency option named: lateral transhipments. Lateral transhipment is defined as a *WIC which provides stocked items to another WIC which is out of stock or to prevent out-of-stock occurrences. In other words, these local warehouses exchange inventory on the same echelon level.* In our application of lateral transhipment, we only take in account lateral transhipments that occur when a WIC is out of stock. In the case that a WIC n_w is unable to fulfill demand normally it will request lateral transshipment from another WIC, that is located in the same region, and if the WIC's in the region are unable to meet the request, only in that case an emergency shipment is requested from either the RDC or the CDC. Figure 15 shows the extra transportation line, that is added to the current situation with two emergency options currently present. One important assumption is that the lead-time for a lateral transhipment is shorter than any of the emergency lead-times.

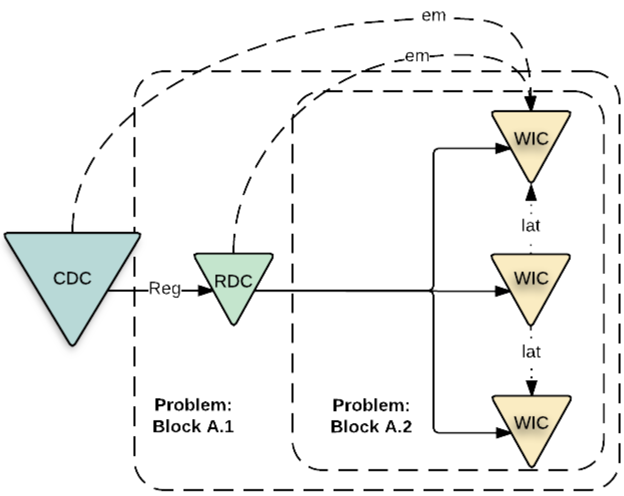

Figure 15: Visualization of the additional Lateral demand streams

We distinguish two types of WIC's, main and regular WIC's. In our setting main WIC's have the ability to be a supplier of lateral transhipments, whereas the regular WIC's are only allowed to receive lateral transhipments. The motivation for this structure is that there are differences between WIC's. Some WIC's (A class cities) face demand that is a factor 10^2-10^3 larger than WIC' located in smaller demand cities (B/C Class Cities). This automatically means that the stock levels at these high demand cities are higher, and theoretically chances are high that this WIC will be able to provide a service part quickly.

This type of lateral transhipment is called partial pooling. Normally models that include this kind of pooling assume that the main warehouse can both send and receive lateral transhipments. In our case this is not preferable as the number of WIC's that are eligible of becoming a main WIC are really low. Furthermore, there is already a RDC present in that region, that shortens the lead-time for an emergency shipment. So, in the case that a main WIC is unable to meet demand, demand is forwarded to either a RDC or CDC.

Network Addition

Let N_W denote the (non-empty) set of WIC's, numbered $n_w = N_R + 1, \dots, N_W$. In our network we distinguish two types of WIC's, main and regular WIC's. Let K ($\subseteq N_W$) denote the subset of **main** WIC's. All other WIC's $n_w \in N_W \backslash K$ are **regular** WIC's. In principle K can be empty, which would mean that no lateral transshipment takes place. However, in this part of the analysis we will assume that $|K| > 0$.

In the case that WIC n_w is unable to fulfil demand from a consumer, then it will try to obtain the part by means of lateral transhipments from the main WIC. The transportation time for this lateral transhipment from main $k \in K, k \neq n_w$, to WIC $n_w \in N_W$ equals $t_{n_w,k}^{lat}$ and corresponding costs of $C_{n_w,k}^{lat}$. It should be noted that n_w can be both a main or a regular WIC.

Each regular WIC is assigned to one main WIC which is checked first for availability of a service part. Each regular WIC is assigned to one main, a main can have multiple regular WIC's assigned to it. Let k_{n_w} denote the main WIC $k \in K$ to which a regular WIC $n_w \in N_W \backslash K$ is assigned. In our model this has the following effect, we introduce a new option in case of stock out at the WIC. The vectors $\hat{S}_i := (S_{i,n_r}, S_{i,n_w}, \dots, S_{i,n_w})$ and $\hat{S} := (S_1, \dots, S_{|I|})$, should include the basestock level at all WIC location present in one region.

1. $\beta_{i,n_w}(\hat{S}_i)$: Fraction of the demand for part i at WIC location n_w that is delivered immediately upon request. This performance indicator is called the (item) fill rate for this location.
2. $\alpha_{i,n_w,k}(\hat{S}_i)$: Fraction of the demand for part i at WIC n_w that is delivered from main WIC k, $k \neq n_w$
3. $\theta_{i,n_w}(\hat{S}_i)$: Fraction of the demand for part i at WIC n_w that is delivered from the RDC as an emergency shipment.
4. $\gamma_{i,n_w}(\hat{S}_i)$: Fraction of the demand for part i at WIC n_w that is delivered from the CDC as an emergency shipment.

Which results in:

$$\beta_{i,n_w}(\hat{S}_i) + \alpha_{i,n_w}(\hat{S}_i) + \theta_{i,n_w}(\hat{S}_i) + \gamma_{i,n_w}(\hat{S}_i) = 1$$

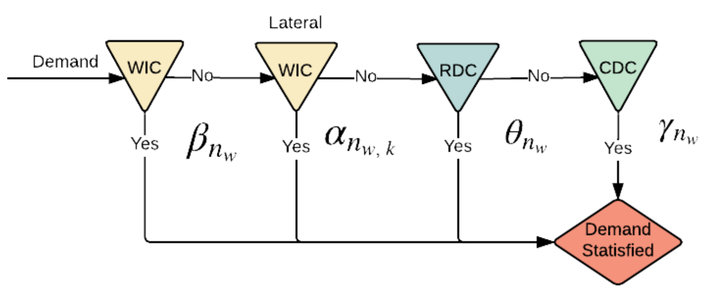

Figure 16: Demand fulfilment with three emergency options

Performance Measures

The equation for the fill rate stays the same, whereas the mean waiting time equation is changed.

$$\beta_{n_w}(\hat{S}) = \sum_{i \in I} \frac{m_{i,n_w}}{M_{n_w}} \beta_{i,n_w}(\hat{S}_i)$$

The mean waiting time for an emergency order for SKU i to arrive at WIC n_w equals the following notation:

$$W_{i,n_w}(\hat{S}_i) = A_{i,n_w}(\hat{S}_i) t_{n_w,k}^{lat} + \theta_{i,n_w}(\hat{S}_i) t_{i,n_w}^{c.em} + \theta_{i,n_w}(\hat{S}_i) t_{i,n_w}^{r.em}$$

The aggregated mean waiting time for an arbitrary request from WIC n_w, is the weighted sum of the average waiting times of that group for the individual SKU's $i \in I$:

$$W_{n_w}(\hat{S}) = \sum_{i \in I} \frac{m_{i,n_w}}{M_{n_w}} W_{i,n_w}(\hat{S}_i)$$

The target aggregate mean waiting time for an arbitrary demand at WIC n_w is denoted as $\widehat{W}_{n_w}^{obj}(> 0)$. The objective function does not change for both sub blocks A.1 and A.2.

5.8 Assumptions

For the model that we are proposing, several assumptions have been made. In this section we summarize them. Some of these assumptions are subject of the sensitivity analysis performed in Chapter 7.

- All items are equally important (multi-item models)
- Demand at location n is described by a stationary Poisson distribution
  A Poisson process is widely accepted in literature to describe the demand process for spare parts, because their demand is low and irregular. However, to test whether this is the case, we conducted a Chi-Square goodness-of-fit test (See Appendix C). Due to the large differences between item demand rates we explicitly check these products and their fit to the Poisson distribution. However, a majority of the items have demand rates below the 10 units a year.
- The outside supplier has ample stock and a deterministic lead-time.
- An adjusted one-for-one replenishment policy is applied for all SKU-s at all warehouses
- There are no capacity constraints on storage or transport
- No fixed costs at any location
- Holding costs at all locations are linear
- Ordering and handling costs are neglected
- ASP related costs are neglected
- The replenishment lead time for every warehouse and SKU is fixed
- Emergency costs are independent of distance
- Items are traded in for new products, no repairs are taken place.

5.9 Evaluation

5.9.1 Greedy Algorithm

Optimization concerns the process of finding the optimal values for the decision variables. For the type of problems that we are dealing with, it is proven that no other optimization procedure exists besides enumerative methods. However, enumerative methods become hard to trace for real life problem instances, with thousands of SKU's and large number of different locations. Therefore, for multi-item spare parts inventory problems approximation algorithms are used, also known as heuristics.
We use the greedy method, to evaluate problem that we are looking at. The greedy method is a method that proceeds iteratively. The greedy method iteratively chooses the alternative that provides the 'biggest bang for a buck' until a certain stopping criterion is reached. Applied to our type of problem, greedy method could be used to stepwise increase the basestock levels until a service level is reached. In each iteration, the base stock level is increased for that item and location that has the highest ratio of improvement in service level over cost increase. This method shows good results with real-life situations that contain data sets with large number of SKU's (kranenburg,2006) (Reijnen et al. 2008).

5.9.2 Evaluation Separate Blocks

In this section, we first look at block A.2 as it is the block that only consists of one echelon and multiple locations. Afterwards we continue to Block A.1 and B.

Block A.2
Kranenburg (2006) proposes an evaluation method that uses the greedy method in order to solve a 1-echelon system with (lateral) emergency shipments. In the approximate evaluation method, the goal is to reduce the state space of the Markov process that we have to analyse. This reduction is performed in two steps. The first reduction step involves decoupling the regulars from the mains, leaving us separate regulars and a system of mains to analyse. The second step analyses the main warehouse individually. We describe the approximate evaluation method algorithmically, in algorithm 1 and 2. Both steps are explained in detail in Appendix D.

Algorithm 1

- **Step 1** For all regulars $n_w \in N_W \backslash K, \beta_{i,n_w}(S_i) := 1 - L(S_{i,n_w}, M_{i,n_w} t^{reg})$.
- **Step 2** For all mains $k \in K, \widetilde{M}_{i,n_w} := M_{i,k} + \sum_{n_w \in N_W | k_{n_w} = k} \left(1 - \beta_{i,n_w}(S_i)\right) M_{i,n_w}$.
- **Step 3** For all mains $k \in K$, determine $\beta_{i,k}(S_i), \alpha_{i,k}(S_i), k \in K$, and $\theta_{i,k}(S_i)$, using *algorithm 2.*
- **Step 4** For all regulars $n_w \in N_W \backslash K$, if $K = \emptyset$, then $\theta_{i,n_w}(S_i) := \left(1 - \beta_{i,n_w}(S_i)\right)$. Otherwise, $\alpha_{i,n_w,k}(S_i)$ is determined using $\left(1 - \beta_{i,n_w}(S_i)\right) \beta_{i,k_{n_w}}(S_i)$ and $\theta_{i,n_w}(S_i) := \left(1 - \beta_{i,n_w}(S_i)\right) \theta_{i,k_{n_w}}(S_i)$.

Algorithm 2

- **Step 1** For all mains $k \in K, \theta_{i,k}(S_i) := L(\sum_{k \in K} S_{i,k}, \sum_{k \in K} \widetilde{M}_{i,k} t^{reg})$.

- **Step 2** For all mains $k \in K, \beta_{i,k}(S_i) := 1 - L\left(S_{i,k}, \widetilde{M}_{i,k} t^{reg}\right)$, and $\alpha_{i,k}(S_i) := 1 - \left(\beta_{i,k}(S_i) + \theta_{i,k}(S_i)\right)$.

Optimization
This section discusses the optimization of the system by finding a feasible policy for Problem A.2 while the system costs are minimized. This procedure is based on the work of Kranenburg (2006). The greedy heuristic provided by Kranenburg uses the approximate evaluation method discussed in the previous Section to determine the base stock levels. The greedy method determines the inventory for each SKU $i \in I$ in all WIC's $n_w \in N_W$ $l$ocated in a region, the working of the greedy algorithm can be explained in five steps.
In the first (initialization) step, all base stock levels equal to zero, $S_{i,n_w} = 0, i \in I, n_w \in N_W$.

The second step, increases the base stock levels if and as long as it does not increase total system cost. In the case that for SKU i an increase in base stock level S_{i,n_w} leads to a cost decrease, we increase the basestock level that gives us the largest decrease in system costs by one. We execute these steps for each SKU $i \in I$ seperatly. In the third step, we iteratively increase $S_{i,n_w}, i \in I, n_w \in N_W$, that provides us with the largest increase in aggregate fill rate $\beta_{n_w}(S)$ per unit cost increase, until $\beta_{n_w}^{obj}$ is met.

In our algorithmic description we denote e_{n_w} as a row vector of size $|N_W|$ with the n_w-th elements equal to 1 and all other elements equal to 0. We define

$$\Delta C(i, n_w) := C_i\left(S_i + e_{n_w}\right) - C_i(S_i) \quad i \in I, n_w \in N_W$$

as the difference in cost if the base stock level for SKU i at local warehouse n_w would be increased by one, at a given vector S_i. The decrease in distance to the set of feasible policies if for SKU $i' \in I$ and local warehouse $n'_w \in N_W$, the basestock level S_{i',n'_w} will be increased by one, is defined as $\Delta\beta(i', n'_w)$.

$$\Delta\beta(i', n'_w) := \sum_{n_w \in N_W} \sum_{n \in N_{n_w}} \left[\beta_{n_w}^{obj} - \sum_{i \in I} \frac{m_{i,n_w}}{M_{n_w}} \beta_{i,n_w}(S_i)\right]^+ -$$

$$\sum_{n_w \in N_W} \sum_{n \in N_{n_w}} \left[\beta_{n_w}^{obj} - \sum_{i \in I \setminus \{i'\}} \frac{m_{i,n_w}}{M_{n_w}} \beta_{i,n_w}(S_i) - \frac{m_{i',n_w}}{M_{n_w}} \beta_{i',n'_w}(S_{i'} + e_{n'_w})\right]^+$$

For the waiting time service measure we follow the same procedure as with the fillrate service measure.

$$\Delta W(i', n'_w) := \sum_{n_w \in N_W} \sum_{n \in N_{n_w}} \left[\beta_{n_w}^{obj} - \sum_{i \in I} \frac{m_{i,n_w}}{M_{n_w}} \beta_{i,n_w}(S_i)\right]^+ -$$

$$\sum_{n_w \in N_W} \sum_{n \in N_{n_w}} \left[\beta_{n_w}^{obj} - \sum_{i \in I \setminus \{i'\}} \frac{m_{i,n_w}}{M_{n_w}} \beta_{i,n_w}(S_i) - \frac{m_{i',n_w}}{M_{n_w}} \beta_{i',n'_w}(S_{i'} + e_{n'_w}) \right]^+$$

$$R(i,n_w) := \frac{\Delta\beta(i,n_w)}{\Delta C(i,n_w)} \qquad i \in I, n_w \in N_W$$

$$R(i,n_w) := \frac{\Delta W(i,n_w)}{\Delta C(i,n_w)} \qquad i \in I, n_w \in N_W$$

In algorithm three we describe the heuristic formally.

Algorithm 3:

Step 1 Set $S_{i,n_w} := 0, i \in I, n_w \in N_W$.

Step 2 For each SKU $i \in I$:

- **a.** Calculate $\Delta C(i,n_w), n_w \in N_W$.
- **b.** While min $\{\Delta C(i,n_w) \leq 0$:
  1. Determine $\hat{n}_w$ such that $\Delta C(i,\hat{n}_w), n_w \in N_W$
  2. Set $S_{i,\hat{n}_w} := S_{i,\hat{n}_w} + 1$
  3. Calculate $\Delta C(i,n_w), n_w \in N_W$

Step 3 3-a. Calculate $R(i,n_w), i \in I, \ n_w \in N_W$.

3-b. While max $\{R(i,n_w) > 0$:

1. Determine $\hat{\imath}$ and $\hat{n}_w$ such that $R(\hat{\imath},\hat{n}_w) \geq R(i,j), i \in I, n_w \in N_W$
2. Set $S_{\hat{\imath},\hat{n}_w} := S_{\hat{\imath},\hat{n}_w} + 1$
3. Calculate $R(i,n_w), i \in I, \ n_w \in N_W$.

Block A.2

The difference between block A.2 and A.1 lies in the presence of a RDC in the A.2 region. This changes our situation to 2-echelon multi–location model. Having a RDC in a region lowers the lead-time to the WIC's considerably. There is no clear method that could be used to solve this kind of problem (Basten & van Houtum, 2014). Basten & van Houtum (2014) suggest several different ways that this problem could be approached, however none of them are proven. We use a 3 step procedure that is visualized in figure 17.

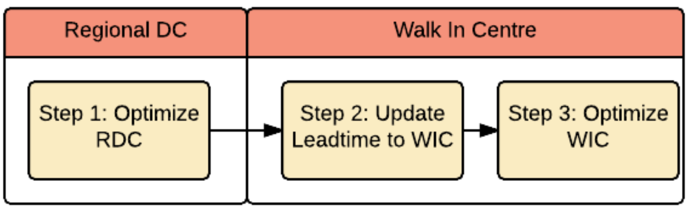

Figure 17: The three step process in order to optimise Block A

First, we optimize the RDC given a fillrate objective. Second, we update the lead-time for each item separately using the following formulas:

$$L_W = L_W * \beta_{i,n} + \left(1 - \beta_{i,n}\right) * (L_W + L_R)$$

Hence, the lead-time is updated from a single value for the whole WIC, to a lead-time per item per WIC. By adjusting the lead-time per item we can include the fillrate per item at the RDC in our model. In the last step we update the WIC as shown in Block A.1.

Block B
In Block B we are dealing with a single-echelon single location model. We use the same procedure as in Block A.1, the difference lies in the fact that we have a single location and only one service measure.

5.9.3 Evaluation Total System

For the total system evaluation, we constructed a five-step plan that we show in figure 18. We use the same steps as explained in the previous evaluation sections. In step one we start by optimizing the CDC. The user of the tool can input the required fillrate at this location. After the CDC optimization, we update the lead-time for each SKU separately. We repeat the same two-steps in the case of the presence of a RDC in a region. We conclude by optimizing the WIC's for each region.

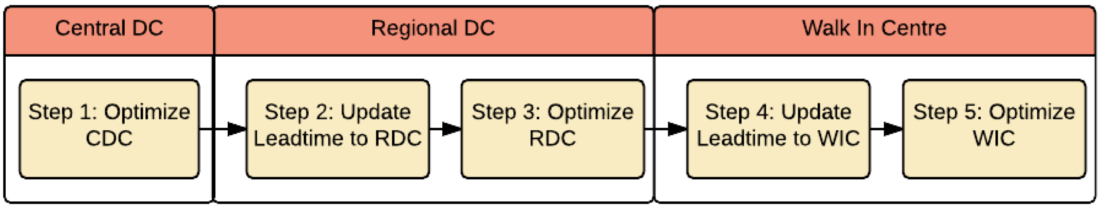

Figure 18: The five step procedure used to evaluate the total system

5.9.4 Design Approaches

We have discussed a number of approaches to **Problem P.** In the previous sections we developed a model for the System approach both with and without lateral transshipment. In Section 5.2 we distinguished several different models; all of these models focus on the service objective. They do not address the underlying issues of how to connect the various warehouses.

The reason for addressing Problem P from a number of viewpoints lies in the fact that there is no uniform accepted solution to solve this kind of problem. Basten and van Houtum (2014) address the issue of problem P and suggest several options to solve this problem. In this study we address two of those approaches. The first approach suggests that we de-compose the system in smaller blocks and solve them separately and connect them afterwards (decoupled design approach). The second approach proposes that we follow the steps outlined in Section 5.9.3(integrated design approach). Furthermore, we introduce two approaches that compare the presents of having lateral transshipment present or not. In approach 5 and 6 we look at two extreme cases, where for an item approach all items have to match the service requirements, whereas in the system approach we have an aggregate service objective. As the item approach is quite extreme in it settings, we introduce an approach which we call the XYZ technique. In the XYZ technique we use the Pareto principle, which states that 80% of the overall consumption value is based on 20% of the returns. We create three groups, all with their own service objectives. Items are allocated over the different groups by use of the following formula:

$$consumption\ value = \frac{Demand}{Price}$$

Group X, are items with the highest consumption value. Group Y consist of items with medium consumption value and group Z consist of items with the lowest consumption value. The number of items per class depends on the cut off points that are chosen. When we apply this approach we explicitly mention the cutoff points chosen. Introducing the XYZ approach provides us with a number of advantages; First, it helps to identify inefficient products; Second, it allocates more resources on profitable products; Third, the XYZ approach is easier to implement than the system approach. It provides the user more freedom to assign service objectives, which can be based on numerous aspects. We apply the XYZ approach in the following way, we create three product groups X, Y and Z. We allocate items in these groups with the use of the following formula:

We have introduced a number of design approaches, each of them are included in the tool. We test the differences among them in the next Chapters.

I. Decoupled Design approach
II. Integrated Design approach
III. Integrated Design approach without lateral transhipments
IV. Integrated Design approach with lateral transhipments
V. Item Approach
VI. System(Multi-item) Approach
VII. XYZ Approach

Chapter 6. Practical Case Study: Logitech

This chapter starts by focusing on the supply chain in India and the service requirements in this region. In Section 6.2 we explain our motivation for choosing the parameter values, necessary to execute the model. Subsequently in Section 6.3, we research whether we implemented the model correctly by using different verification and validation techniques. Then in Section 6.4 we discuss the modelling and execution issues that we faced and how we dealt with them. In Section 6.5 we introduce the scenario analysis we perform. WE conclude this chapter by providing an overall impression of the results found in the previous section.

6.1 Practical Case Settings

6.1.1 Choice of Software

The algorithms described in Chapter 5 are programmed in Excel VBA. Excel might not be the most advanced programming tool available as it has its limitations. However, there are decent arguments that support the use of this programming language. The main reason for using Excel lies in the fact that Logitech is already in the possession of a Microsoft office license. Whereas, more sophisticated and elaborate programs such as Matlab, Arena etc. are not licensed, hence the use of these programs is not possible. Another reason for using Excel lies in the fact that the VBA language is quite easy to learn. There are hundreds of websites and books dedicated to this software package. Furthermore, Excel is used for the preparation of the data and makes it easy to link to the tool that will be created. These reasons form enough support for us to choose for programming our code in Excel VBA.

6.2.1 Supply Chain India

Logitech has been active in India for several years. During these years the distributors had to take it upon themselves to take care of consumer returns and charge Logitech with the monetary value of the number of returned products. However, not all consumers were eligible for this service and this situation made it necessary for Logitech to react. Logitech opened 48 Walk-In-Centres (WIC) as of January 2015 in India, a WIC is basically a synonym for a service centre which we discussed in Chapter 2. These 48 WIC's are distributed over four regions (table 5). The Walk-In-Centre model has been created to deal with markets in the AP region. The use of Walk-In-Centre's specifically in the AP region is not that uncommon, other high tech companies such as Apple, Samsung etc. provide warranty to their consumers in the same way.

Indian Region	Number of WIC
North	13
East	6
South	15
West	14
Total	**48**

Table 5: The distribution of WIC's over India

In India three types of warehouses can be distinguished Central distribution centres (CDC), regional distribution centres (RDC) and Walk-In-Centre's (WIC's). In figure 19, the supply chain network currently present in India has been depicted. The number of WIC's per region differ notably. East India has the lowest number of 6 WIC's and South India the highest number with 15 WIC's. Besides the number of WIC's per region, there is another WIC characteristic that should be mentioned, as it will become an important service measure later on. Logitech distinguished three different kind of WIC's, namely Class A , Class B and Class C cities. Both the number of sales and the number of returns determine in which class a city is classified, see Table 6.

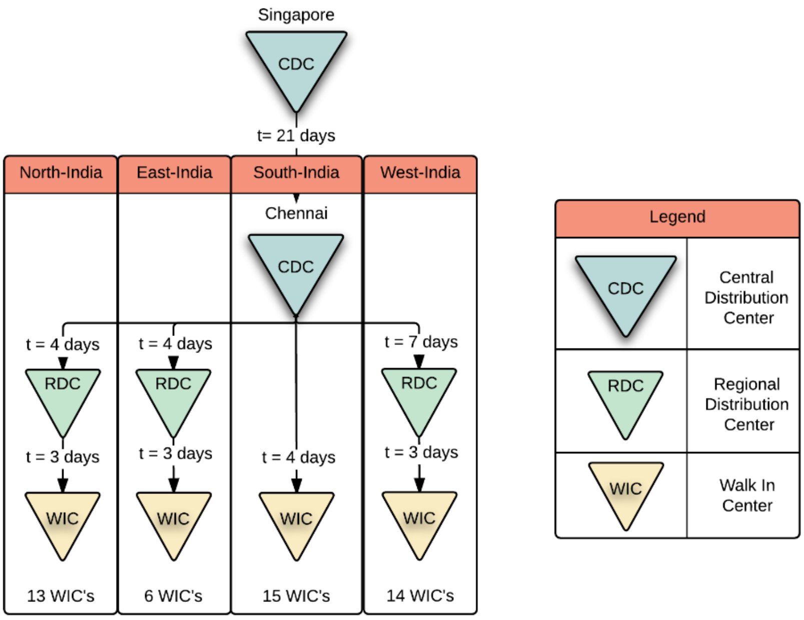

Figure 19: Lead-time to the different stocking locations

City Class	Sales Volume in Units/Month	Return Volume in Units/Month
Class A	>10.000	>200
Class B	>1.000	>50
Class C	>200	<50

Table 6: Differentiation of WIC's over the classes based on sales and return volume

Just looking at the return volume, we can already establish that for example, the amount of products to stock at an A location is going to differ significantly from a C location. In table 7, we show the distribution of the different city classes over the regions. Each city class has its own service measures objectives; these will be discussed in Section 6.1.3.

City Class/Region	North	East	South	West	Total
A	1	1	3	2	**7**
B	7	4	6	10	**27**
C	5	1	6	2	**14**
Total	**13**	**6**	**15**	**14**	**48**

Table 7: The distribution of WIC's over India and their respective classes

In figure 20 we show all WIC locations currently present in India. The figure shows that in some cases, 'middle' India, the WIC's lie unaccompanied by other WIC's. Which automatically leads to long lead-times. In appendix A, we display each region separately with the WIC present in that region. Another important factor of this particular supply chain that should be explicitly mention in which way demand is filled. At all locations a periodic review system is used; at the WIC level an order is placed at the end of every week, whereas order placement occurs every 2 weeks at the RDC level. The CDC located in Chennai places an order every month. The above process does not mention how demand is filled on a day-to-day basis. We will focus on that process: when demand arrives at a WIC, two things could occur, either the item is on stock or it is not. When the item is on stock, it will be handed out to the consumer and included in the next order. However, if it is not on stock an emergency shipment will be requested from the RDC. Again, there are two possibilities on what could happen, either the RDC has the product on stock or it has not. In the case that it has the product it will ship it to the WIC, if not the demand is forwarded to the CDC. The CDC often has large enough stock to meet demand due to the long review period that is present at that location.

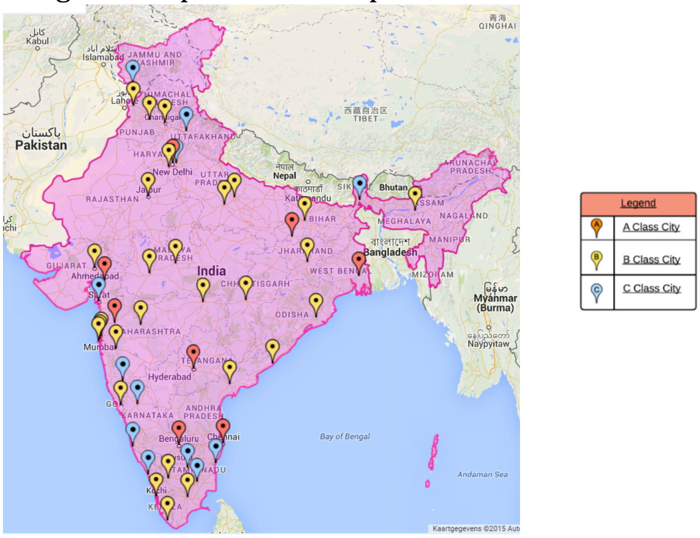

Figure 20: Geographical locations of the WIC's

6.1.2 Service Levels

In India the performance is measured WIC's on two fronts, being Fill rate and Waiting time. The fill rate is defined as the performance of consumers that have a turnaround time (TAT) equal to zero. The second service measure, average waiting time, refers to the time needed to complete all demand that arrives at a WIC. Logitech has set the maximum TAT time at 5BD, i.e. within 5BD all demand arriving at a WIC should be filled. The values of these service measures depend on the type of class a city is subdivided. Table 8 shows the service levels, in this table the same day percentage refer to the fill rate and the remaining percentages define the value of the waiting times.

City Class	Same Day	2BD	3BD	5BD
A	**70%**	**10%**	**10%**	**10%**
A (Cumulative)	70%	80%	90%	100%
B	**60%**	**20%**	**10%**	**10%**
B (Cumulative)	60%	80%	90%	100%
C	**50%**	**20%**	**20%**	**10%**
C (Cumulative)	50%	70%	90%	100%

Table 8: Service Measures per Class

Class A cities are typically markets with higher sales volume; hence it is expected that a higher number of products will be returned. Class A cities are metro cities and are the prime focus for Logitech's Indian market sales team. The number of Class A cities is limited. In class A cities Logitech requires that the ASP will provide a new product to the consumer the same day 70% of the time, 80% of the consumers should have a new product within 2 business days(BD); 90% within 3 business days; and 100% should be served within 5 business days. Class B cities are cities with lower sales and return volume. The majority of the cities are classified as a class B city. Class C cities are small with respects to number of sales and returns, therefore the required service levels are set to a lower level.

6.1.3 Return Characteristics

In order to get a view of the current situation we analyse the consumer returns that occurred during the period February '14 till April '15, hereby once again should be noted that the WIC warranty service model started in India in January 2015. In this section our focus lies on analysing the total returns in the past year. We analyse the consumer returns on two aspects: return volume and SKU costs. In the main body of text, we only mention the total returns and costs and how they are related. In Appendix B we show a more detailed view, mentioning different statistics.

Return Volume

We have data regarding the returns during the period February '14 until April '15, during these 14 months 69.160 units were returned, distributed over 269 SKU's. There are 12 SKU's with a return volume over a 1000 units, which coincides with 4.5% of the total number of SKU's. The highest return volume, 11.318 units, occurs for the 'M100R'. Only a small number of SKU's are returned this often, the largest percentage of the SKU's have a return volume lower than a 100. In total 213 SKU's (80%) have a return volume lower than 100 units. A majority of these SKU's has a return volume lower than 10 units. Approximately 148 SKU's have a return rate lower than 10, this fraction equals 53% of the total number of SKU's.

SKU Costs

The total provisioning costs are $418,463.81 during the period February '14 until April '15. We use the product price to compare the costs between SKU's, the product price refers to the item costs, i.e. the costs for Logitech to make the item.
In total there are 9 SKU's with a price higher than $80, the most expensive products is priced at $155.95. But for the most part Logitech products have an item costs lower than $80, meaning that we are dealing with relatively 'cheap' items. The average item costs come down to $40.28.

6.1.4 Logitech Scope

The scope is fixated on one region, namely India. The reason for choosing this particular country is twofold: Firstly, the focus on India is mainly because Logitech is very new to the market and it is one of the hardest cases that Logitech has to deal with, regarding warranty services. Secondly, the data that will be needed for the calculations are easier to receive from the different sources. The solution that should be provided needs to be designed on a high abstraction level, which means that the details defined as coordination decision by Silver, Pyke, & Peterson, (1998) such as vehicle routing, choice of transportation and warehouse design are not taken in account. However, it should be noted that the use of the models that we created in Chapter 5 is not limited to India. In our model we explicitly distinguish two kinds of regions, regions with and without RDC's. This distinction increases the usability of the tool, which is discussed in Chapter 8.

6.2 Stock control model settings

In our model we used numbers to represent different regions, as it would make it easier to extend the model if the number of regions would grow. However, currently this is not the case Logitech distinguishes 4 different regions being North (1), East (2), South (3) and West (4). Furthermore, another important decision should be made, we need to decide how many SKU's are we going to involve in our analysis. This is a hard decision as there could be hundreds of different SKU's that are returned, however only a small fraction is currently actively being sold. This makes it harder for Logitech to determine how many products are needed for products that are marked EOL, but still require service. Figure 21 shows this difficulty with an example.

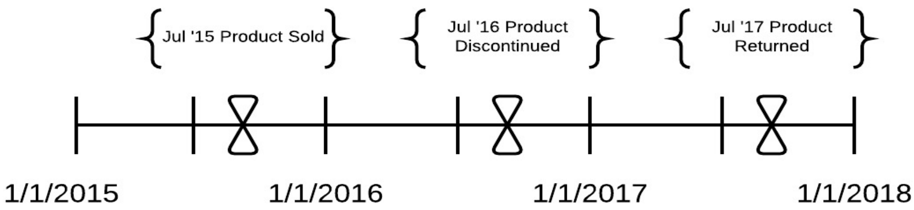

Figure 21: Difficulty of determining the items that will be returned

In the figure above there are three events that explain how difficult it is for Logitech to decide which SKU's should be provisioned to the ASP in India. The first event is the sale of a product, this occurs in July '15, this means that the user has a warranty of until July'17. A year later Logitech decides that the product will be discontinued, hence the product will not be produced anymore. At this moment the After Sales department has to decide how much will be produced to cover the warranty demand for the upcoming months/years. We decide that we include 152 SKU's in the remainder of this study. We include those items that contribute the most to the total number of returns. Hereby setting the limit at 99%, when the SKUs included represent 99% of the returns during the past year we stop. By performing the aforementioned steps, we end up with 152 SKU's

6.2.1 Demand

For the determination of the demand rates we requested demand data per item per WIC. We received demand data from the periods February '15 till July'15. The data of the month February is not used, as it was the first full month that the WIC's were running. The demand data during that month is not a good representation of reality, because more and more consumers are getting knowledgeable about the existence of these WIC's. In order to prepare the data for use in our tool we perform the following steps. We have demand data per item per WIC per day, furthermore we know the number of days that the WIC were open. With these number we can calculate the average demand per item per day.

6.2.2 Lead-times

In the transportation process several different transportation modes can be used. These transportation modes can be distinguished in two groups, regular shipments and emergency shipments. In all instances we assume deterministic lead times, as this assumption makes the model less complicated.

Regular Shipments Lead-time
All items arrive by shipment in Chennai from Singapore. The lead-time for this shipment is variable, however our model is not capable of including stochastic lead-times. We did not involve this kind of variation as the data regarding the lead-time between the two CDC is very limited. As only once a month this shipment is made, and the WIC warranty solution has only be present for eight months. After discussion with the India WIC manager, it was decided that we take one number that would represent this lead-time. We set the lead-time between the two CDC's on 21 days. In Section 6.1.1 we showed the various regular lead-times in the India WIC supply chain.

Emergency Shipments Lead-time
The ASP is responsible for stock distribution and how emergency shipments should be handled. Hence, this means that we do not have a clear view of the time that each type of shipment takes. However, we can make valid assumption in collaboration with the India WIC manager. We state that an emergency shipment from a RDC to a WIC takes two days, where an emergency shipment from a CDC takes three days. For the lateral shipment method, we set the lead-time equal to 1.5 days.

6.2.4 Item Price

Item prices fluctuate during the years; these fluctuations can occur due to several reasons. First, during the lifetime of an item it often becomes cheaper to produce due to new techniques or more efficiency. Second, the exchange rates have an effect on the costs of items. We take the last noted item price and use that in our model, as this is the price of the item that Logitech will use to charge the costs.

6.2.5 Holding Costs

For the inventory cost calculation, we need to assign a value to the holding costs. The holding costs percentage consist of three costs factors, the interest rate, the cost of handling the items and to costs to cover the risk of obsolescence. We set the sum of the first two costs factors equal to 15% per year, as they are all the same for each item. Whereas, the risk of obsolescence can vary among items. However, due to the limited time for this study we choose to set the risk of EOL equal to a yearly percentage of 5%. This totals the yearly holding costs to 20%. We believe that this rate translates properly to reality. In Chapter 7 we will test the sensitivity of this parameter.

6.2.6 Review Period

One of the main characteristics of our model is the use of periodic review in spare parts settings. In reality, Logitech uses periodic review at all stock locations. The reason for using a periodic review model lies in the fact that Logitech's item prices are low in comparison to the order costs. This combination of low item price and order costs, logically leads to a periodic review system instead of a continuous system. Furthermore, due to the fact that the items are inexpensive the tread off of having an item on stock or requesting an emergency shipment favours the fact that items are stocked. For the CDC Logitech orders once a month, hence $R_C = 4$ weeks, the RDC is replenished twice a month $R_R = 2$ weeks, and the WIC's are replenished at the end of every week $R_W = 1$ week.

6.2.7 Lateral Transhipment

Before we can run code containing lateral transhipment we have to make choices which WIC's are the main WIC's and which are regular WIC's. In order to make an appropriate choice for our main WIC 's we look at what we expect from a main WIC. We have two criteria that we use to find our main WIC's. The first criterion is that the WIC should be at least located in a B-class city. We use this criterion in order to distinguish between cities that carry a lot off stock and cities that hardly carry any. This means that C-class cities are not fit for being a main WIC. The second criteria is related to the geographical location of a WIC. WIC's that are located in a location surrounded by other WIC's are more fitting to be a main WIC, as they have a shorter lead-time. This is often the case with A-Class cities, which are located in the largest cities in India.

We explained our criteria for choosing main WIC's, we start applying them in order to find our mains. First, we sort the WIC's based on total demand they received in the first half year of 2015, high to low. In table 9, we show the WIC's that have the most demand for their region. This table shows us the candidates for begin the mains in each region. It is apparent that the A-Class cities carry significantly more stock than the smaller B and C-Class cities.

The next step is to look at the geographical location of each of these WIC's and see whether they would be a good choice for a main WIC. In appendix A, all WIC locations are mapped per region. We start with the North region, we see that that one location lies central in comparison to the other WIC, this is the New Delhi WIC. The remaining candidates all lie close to New-Delhi, but due to the large demand differences we make the choice to only have one main WIC in this region being New-Delhi.

In the East region we only have six WIC's in total, with Kolkata as the only A-class city. For this region we also only choose to go for only one main, the other WIC's have lower demand in comparison to the Kolkata WIC. For the South region we need multiple main WIC's as they are all spread across the region and due to the large number of WIC's present in that region. The Chennai WIC is located at the East coast, whereas Bangalore lies in the middle of the South region. Both these locations seem good choices for being a main WIC's. In the West region we have a large concentration of WIC's. Of course, Mumbai is a logical choice for being a Main WIC. For the second main WIC, we choose

Ahmedabad which is located North to Mumbai and is surrounded by three WIC's that it will be able to serve.

City	City Class	Region	Totals
NEW DELHI	A	North	5334
GURGAON	B	North	860
LUDHIANA	B	North	485
JAIPUR	B	North	411
KOLKATA	A	East	1393
BHUBANESHWAR	B	East	375
PATNA	B	East	315
CHENNAI	A	South	1959
BANGALORE	A	South	771
COCHIN	B	South	741
HYDERABAD	A	South	594
MUMBAI	A	West	2860
AHMEDABAD	B	West	2149
SURAT	B	West	1979
ANDHERI	A	West	1274

Table 9: Largest WIC's, based on the number of returns

6.3 Model Verification and Validation

Model verification and validation are essential parts of model development process if models are to be accepted and used to support decision-making. We have to make sure that we present a good model to Logitech. Of course, what constitutes a good model is subjective. However, there are ways to judge the goodness of models and how accurate the model represents reality.

6.3.1 Model Verification

With model verification is meant the process of determining that a model implementation accurately represents the developer's conceptual description and specifications. Verification is able to catch errors that validation cannot catch, it is a lower level exercise. In order to verify our model, we use several different techniques. First of all, the computer program is written in smaller parts that are programmed in modules. Each module consists of smaller parts called subs. Breaking down the codes is smaller parts makes it easier for us to find errors, when present. We ran every part of code separately to check whether the code would execute fully without any errors.
For the second technique, we execute the different models and look at what is printed. We have two type of output sheets, one that records extensive results while the other looks at the whole region. By having these two sheets we are able to see how the total costs are distributed over the various debit entries. By printing these results we can spot errors more easily, as we have both the extensive and compact view.

The last technique that is used is manual calculation. We execute the code in steps and for each step we print the results and compare them with the manual calculation. This technique is quite time consuming especially when the demand is high. Using this verification technique, we can also find other faults, if present. We check whether the code stops adding items to a WIC location when the service objective is reached.
By applying all of these verification techniques, we assume that the tool has been verified and continue to the next step.

6.3.2 Model Validation

Validation is the task of demonstrating that the model is a reasonable representation of the actual system. That the model reproduces the systems behaviour with enough confidence to satisfy analysis objectives. We use multiple approaches to validate our model. We start by executing the code given various settings and look at the results with an individual that is knowledgeable about the expected behaviour and results. For the second technique, we execute the model in various settings and check whether the output is as expected. In this Section we only discuss one of the settings that were checked namely, the presence of lateral transhipments. The remainder of the analysis can be found in Appendix E.

Including the option for Lateral Transhipment to the model has the following expected results:

- Holding costs at the Main WIC's will increase, as they stock more due to extra demand arriving from the RDC.
- Waiting Time's at the Regular WIC's will decrease, due to the possibility of a lateral transhipment from a main WIC.
- Total costs decrease at regular WIC, as an extra emergency option is included which is cheaper.

We test whether these three results occur by running two models with exactly the same settings, however for model one there is no lateral transhipment option and for model two we have lateral transhipments enabled. Table 10 and 11 show the results of executing the code with and without lateral transhipments. In this analysis the first two WIC are main WIC's whereas WIC three, four and five are regular WIC's.

	No Lateral Transhipment				
	1	2	3	4	5
Regular Shipping Costs ($)	$ 88.2	$ 20.3	$ 29.1	$ 21.3	$ 8.0
Waiting Time (days)	0.5	1.0	0.6	0.9	1.2
% of demand supplied by Lateral Transhipment					
Lateral Shipping Costs ($)					
% of demand supplied by emergency shipment	$ 0.3	$ 0.5	$ 0.3	$ 0.5	$ 0.6
Emergency Shipping Costs ($)	$ 48.9	$ 31.6	$ 21.1	$ 28.1	$ 17.5
Holding Costs ($)	$ 52.6	$ 15.2	$ 19.2	$ 13.5	$ 6.1
Total WIC Costs ($)	$ 189.6	$ 67.1	$ 69.4	$ 62.9	$ 31.6

Table 10: Costs Distribution in a system without lateral emergency shipment

	Lateral Transhipment				
	1	2	3	4	5
Regular Shipping Costs ($)	$ 143.4	$ 27.1	$ 29.1	$ 21.3	$ 8.0
Waiting Time (days)	0.6	0.9	0.5	0.8	0.9
% of demand supplied by Lateral Transhipment	0%	0%	19%	20%	34%
Lateral Shipping Costs ($)	$ -	$ -	$ 9.9	$ 9.5	$ 7.8
% of demand supplied by emergency shipment	$ 0.3	$ 0.4	$ 0.1	$ 0.2	$ 0.2
Emergency Shipping Costs ($)	$ 90.6	$ 34.1	$ 8.0	$ 15.4	$ 7.0
Holding Costs ($)	$ 94.4	$ 21.2	$ 19.2	$ 13.5	$ 6.1
Total WIC Costs ($)	$ 328.4	$ 82.4	$ 66.1	$ 59.8	$ 29.0

Table 11: Costs Distribution in a system with lateral emergency shipment

We check whether we see the expected results:

- At main 1 the holding costs rise from $52.6 to $94.4 for main 2 the costs rise from $ 15.2 to $ 21.2.
- The waiting time at location three reduces from 0.6 days to 0.5 days, at location four from 0.9 days to 0.8 days and at the fifth location the waiting time decreases from 1.2 days to 0.9 days.

- The total costs at location three reduces from $ 69.4 to $ 66.1, at location four from $ 62.9 to $ 59.8 and at the fifth location, the total costs decrease from $ 31.6 to $ 29.0.

We can conclude that the we find the expected results on all three points; we see an increase of holding costs at the Main WIC's and a decrease of Waiting time at the regular WIC's and a decrease of total costs at the regular WIC. The last technique that we use to validate the model is by performing a sensitivity analysis. In order to keep the size of this chapter to an acceptable level we spend the whole of chapter seven on the sensitive analysis.

6.4 Modelling and Execution issues

In this section, we discuss modelling and execution issues we ran into while translating the reality to the model. We discuss the problems that we faced was and how we dealt with them.

6.4.1 Waiting Time service measure

First, Logitech uses two different service levels filtrate and waiting time. For the fillrate one requirement is set, however for the waiting time there are multiple requirements per WIC. In table 12 we show this distribution of the waiting time requirements.

City Class	Same Day	2BD	3BD	5BD
A	**70%**	**10%**	**10%**	**10%**
B	**60%**	**20%**	**10%**	**10%**
C	**50%**	**20%**	**20%**	**10%**

Table 12: Service Requirements per Class

If we would incorporate a service requirement for each requirement separately it would make the model more complex. In order to deal with this issue, we take the average of the waiting time, which leads to one waiting time objective per city class. We use the following equations to determine the new waiting time requirements:

$$Waiting\ Time\ requirement\ A\ Class = \frac{1}{3} * 2 + \frac{1}{3} * 3 + \frac{1}{3} * 5$$
$$Waiting\ Time\ requirement\ B\ Class = \frac{1}{2} * 2 + \frac{1}{4} * 3 + \frac{1}{4} * 5$$
$$Waiting\ Time\ requirement\ C\ Class = \frac{2}{5} * 2 + \frac{2}{5} * 3 + \frac{1}{5} * 5$$

This leads to the following results:

$$Waiting\ Time\ requirement\ A\ Class = 3.3\ days$$

$$Waiting\ Time\ requirement\ B\ Class = 3\ days$$

$$Waiting\ Time\ requirement\ C\ Class = 3\ days$$

in the remainder of our analysis we use these numbers to represent the waiting time constraints. The second modelling issue we faced concerned the interaction between different regions. In reality if an item is not on stock in a region, WIC and RDC, we request an emergency shipment from the CDC. In the case that the CDC does not have the item on stock, it might occur that the item is available in another region. In reality, it would be possible to send this item across regions. However, we choose to not include this issue, as it would complicate the model too much. We already have 3 emergency options in case of a stockout, incorporating another emergency option would make the model too complex. Furthermore, this kind of transhipment does not occur very often therefore we feel confident that it is the right choice to leave this out of our model.

6.4.2 Service requirements at RDC and CDC

Logitech does not have any service objectives for the CDC or the RDC. As the service provider is responsible of locating sufficient items in these locations, as backup for the WIC's. However, in our system we have to provide some kind of service objective that our tool should aim to achieve. In case, that a region contains a RDC a choice menu presented in figure 22 will be shown. The tool user in this case has two possibilities either he will fill out a fillrate and waiting time objective that the RDC should aim for or one can choose for the aggregate measure. If chosen for the aggregate measure, we take the service objectives that are set for the WIC's in that region and take in account the demand per WIC, in order to determine the service objectives at the RDC. The same process occurs for the CDC's where we take the service levels of all the WIC, as a way to determine the objectives at the CDC level. We test the sensitivity of the service objectives at the CDC and RDC in Chapter 7.

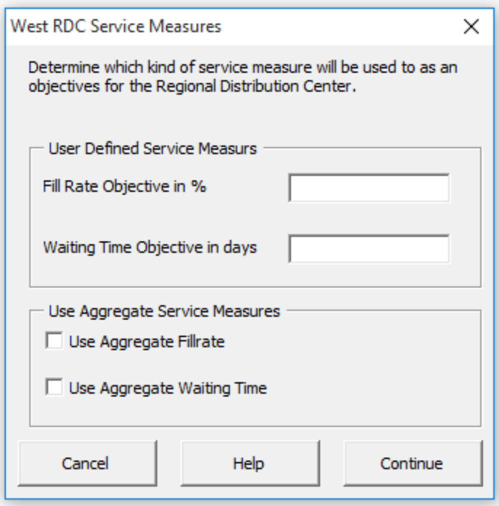

Figure 22: Userform shown to tool user, in order to decide fillrate level at RDC

6.4.3 System Costs

Due to the division of responsibilities between Logitech and the service provider, the real internal costs are unknown. As we are dealing with low item costs and relatively low service objectives, the costs of emergency shipments are a crucial part of the total costs. When we set the costs for emergency shipments too high, the model will overstock as a result of low item costs. Due to the fact that it is cheaper to have an item on stock for a period than requesting an emergency shipment. We address this issue in

Section 6.5.4. In order to deal with the fact that we have no clear data regarding the costs of shipping in India, we use uplift factors to represent these shipping costs. Herby making the assumption that a regular shipment is the cheapest possible form of shipment. For the remaining emergency options, we assume that the factors are as follows (High to Low) CDC > RDC > Lateral. In table 13 we show possible values for the uplift factors. In Chapter 7 we perform a sensitivity analysis and look at the values of these uplift factors.

Shipment	Costs	Possible values
Regular Shipment	Cheapest	1
Lateral Emergency Shipment	Inexpensive	1.5
RDC Emergency Shipment	Expensive	1.75
CDC Emergency Shipment	Most Expensive	2

Table 13: Possible Values for the costs parameters

6.4.4 Overstocking at WIC

While executing the model we encountered that the model tends to overstock. This entails that more stock is located at a WIC than needed to reach the service objectives. In table 14, we show an example of the West-Region and the top five WIC's based on the number of returns. We see that the RDC and the WIC located in Indore both stop adding items after the fillrate objective is achieved. While, in the other cases more than necessary is stocked. Looking at Ahmedabad, we see an expected fillrate of 76.49% although only 60% is required.

WIC	Name	Fill Rate (%)	Fill Rate objective (%)
1	RDC	61,41%	61,41%
2	Mumbai	79,17%	70,00%
3	Ahmedabad	76,49%	60,00%
4	Andheri	65,11%	60,00%
5	Indore	61,43%	60,00%

Table 14: Overstocking at WIC, due to low item value

After analysing this behaviour, we found that this occurs due to the low item value and the working of our evaluation algorithm. The first step in our algorithm consists of increasing the number of item stocked as long as the costs do not rise. Due to the low value of the items, the costs of holding an item on stock is quite low, whereas requesting an emergency shipment is significantly higher. So after performing the first step in the algorithm for each item, we continue to the second step. The second step is immediately skipped as the WIC fillrate objective is already reached just by going through step one.

In conclusion, due to the low item value our algorithm would decide to stock more than might be necessary in some cases. Because if it is cheaper to have a SKU on stock for a whole year and hereby reducing the necessity of an expensive emergency shipment, it might be an interesting point to set the service measures higher. We see this more clearly in Chapter 7, where we perform a sensitivity analysis on the fillrate for each of the echelon. Hereby focusing on the effects that this has on the total costs and service expectations.

Another problem that occurs while executing the model besides the general overstocking is the overstocking of extremely inexpensive items. This often leads to expensive items not being stocked and having low expected service measures. We solve this issue by introducing a variable called F_i^{max} , this variable sets a maximum limit on the fillrate for each item. In our analysis in the next section we set this value at 99%.

6.5 Scenario Analysis

In Section 5.9.4 we introduced seven different design approaches. This section will compare the results of the different approaches on a various number of levels. Each of these approaches are included in the tool.

I. Decoupled Design approach
II. Integrated Design approach
III. Integrated Design approach without lateral transhipments
IV. Integrated Design approach with lateral transhipments
V. Item Approach
VI. System(Multi-item) Approach
VII. XYZ-Approach

6.5.1 Decoupled vs Integrated Design Approach

We approached this problem by disjoining the problem, **Problem P**, into smaller blocks. We connect these blocks to the CDC by following the five-step procedure explained in section 5.9.3. However, the problem can also be solved by solving each block separately and adding them together afterwards. We want to compare both methods and see the effects of including the fillrates at the CDC. We start by creating the table 15 and 16 and compare them on the important characteristics.

Aproach I	CDC	North	East	South	West	Total
Number of Units	4.238	1.116	464	370	1.605	7.793
Aggregate Fillrate (%)	92,27%	86,92%	85,65%	83,09%	87,30%	89,65%
Aggregate Waiting Time(days)		0,33	0,24	0,34	0,48	0,39
Total Costs ($)	$ 21.475	$ 3.907	$ 1.293	$ 1.046	$ 5.291	$ 33.013

Table 15: Decoupled Approach, not including CDC Lead-time

Aproach II	CDC	North	East	South	West	Total
Number of Units	4.238	1.722	709	620	2.329	9.618
Aggregate Fillrate (%)	92,3%	84,1%	83,0%	80,4%	85,0%	87,6%
Aggregate Waiting Time(days)		0,41	0,29	0,39	0,56	0,46
Total Costs ($)	$ 21.475	$ 7.027	$ 2.347	$ 2.105	$ 9.295	$ 42.252

Table 16: Integrated Approach, including CDC Lead-time

We see clear differences between the two tables:

- Stock Levels: Because we are taking in account the item fillrate at the CDC level, the lead-time for items that have a lower fillrate is longer. Due to the longer lead-times, the tool stocks more items to overcome the longer lead-time.
- Aggregate Fillrate: Due to a longer lead-time, more stock is necessary to achieve the same fillrate.
- Aggregate Waiting Time: The average waiting time increases, due to the fact of taking in account the 'real' lead-time of the replenishments.
- Total Costs: The result of stocking extra items is clearly visible in the rise of the total costs, for each region. We compared both approaches on the high level. In order to get a clear view of the effects of including the CDC in the system on the number of items stocked we create figure 23.

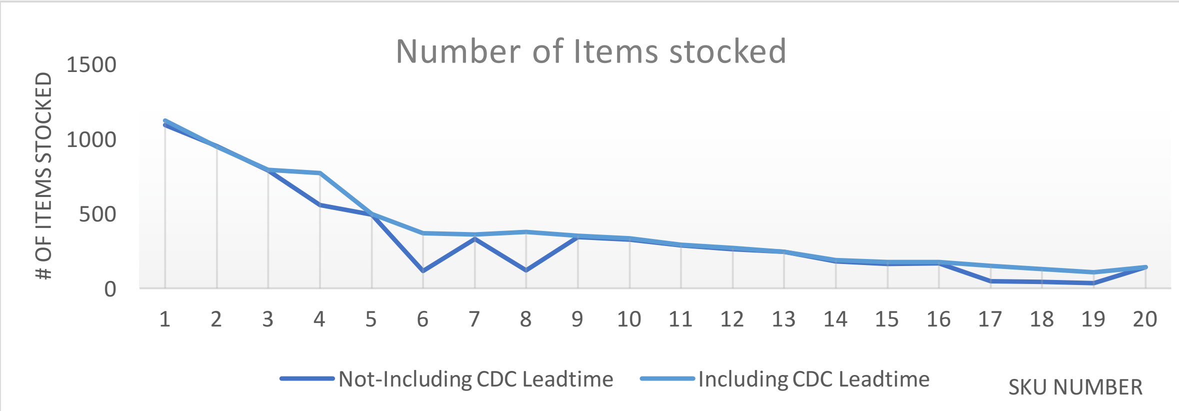

Figure 23: Numbers of units stocked in Approach I and II

In this figure we set out the top 20 items that were returned during the first half year of '15. We chose for the top 20 items as they are returned significantly more often than the other SKU's. For the first three items, we see no change in the amount of items stocked. This can be explained due to the fact that demand for these SKU's is extremely large. This would result in the tool favouring these items as they contribute significantly to the service objective, resulting in a high expected fillrate. Furthermore, for SKU 4 we clearly see the effect of including the CDC fillrate in the lead-time, there are 200 units more required, in the regions, to reach the same service objective. Additionally, the effects of expensive SKU's are deductible from the figure as well, as SKU 6 and 8 are both less desirable to have on stock. We do not see any significant difference for the remaining SKU's depicted in the graph. In order to have better understanding of the effect of approach II, we involve a larger number of SKU's in figure 49 found in Appendix F.
For the SKU's numbered 20 till 100, we see a lot of variability of the effects of Approach II. This is the result of the CDC having a fillrate close to zero for some SKU's, which lengthens the lead-time for the lower echelons considerably for these SKU's. This results in higher demand and consequently higher 'bang for a buck' for SKU's which were less interesting to stock previously. The result of including the CDC are more clear for items that have low demand as they are stocked less at the CDC, resulting in higher lead-time. For these SKU's, SKU numbered 100 and up, the number of items stocked is doubled in most cases.

In conclusion

This analysis has shown that there is a significant difference between the two approaches. The question rises which approach is the best reflection of reality? In reality the fillrate at the CDC matters for the item lead-time to the lower echelons. As shown in the analysis, if an item has a high fillrate it has little effects on the lead-time, whereas a low fillrate would increase the lead-time considerably. The fact that in approach I we solve each region separately makes the results less robust. As the chances of stock out are considerably higher, due to the fact that approach I has the assumption that the CDC is always able to deliver. Approach II shows that this is not always the case, which results in considerably longer lead-times for certain items. These arguments provide us with enough confidence to believe that the Integrated Approach (approach II) is the correct way of connecting the regions with the CDC and the outcomes of this approach reflect reality the best. In the remainder of this study we will keep using the integrated approach to connect the various echelons.

6.5.2 Integrated with lateral transhipments vs Integrated without lateral transhipment

This section describes the findings from the results of comparing the different design approaches III and IV. We will use the following three features to judge the performance of each approach: Inventory, Service Measures and Total Costs.

Inventory

In Section 6.3.2 we validated the working of including lateral transhipment into our system. We tested whether the expected inventory increase was indeed occurring. However, we did not explicitly discuss the reason why we expected this increase. The increase of inventory is only expected at the main WIC's, due to the working of our model. The model first optimizes the regular WIC's, subsequently we know the expected item fillrate and the percentage of emergency shipment requested. From this information we can deduce the extra demand arriving at the main WIC's Hereafter, we optimize the main WIC's. This explains the fact that only at the main WIC's the amount of inventory rises, whereas no difference can be found at the regular WIC's.
In figure 24 we plot the increase of inventory increase at the main WIC's both on an absolute and relative scale.

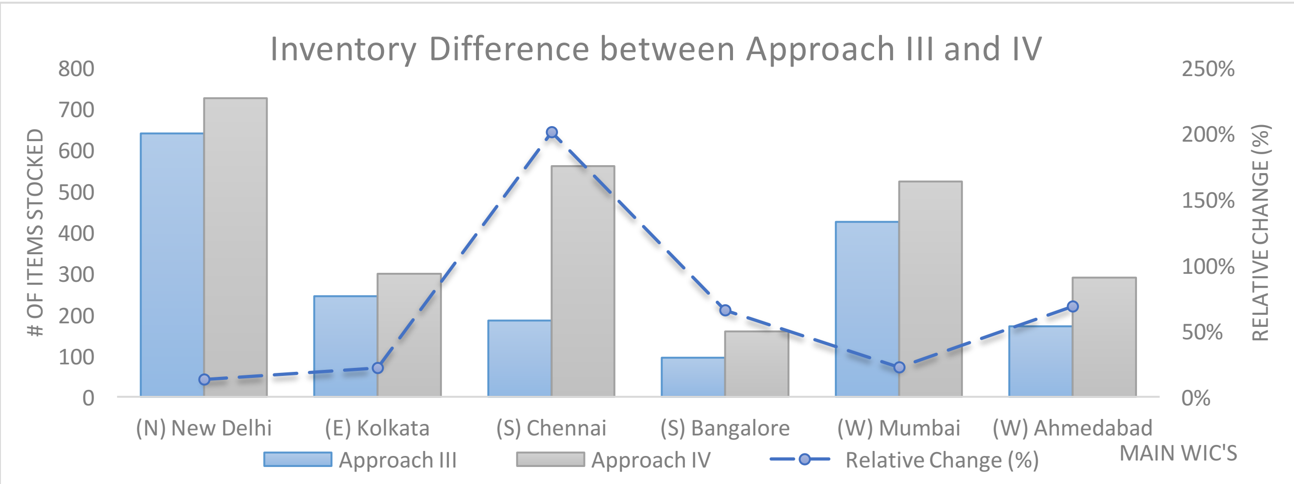

Figure 24: Change in Inventory between Approach III and IV

We see a small increase of the inventory kept on stock in the North region. The biggest inventory increase occurs in the South Region at the Main WIC located in Chennai. There are two causes for this increase; First, the South region has the highest number of C-class cities which have lower service objectives. The low service objectives result in a high percentage of the demand being requested by means of emergency shipment. Second, we have three A-class cities in the South region and decided that only two of them should be classified as main, in Section 6.4.2. the third A-class city that is classified as a regular city is connected to the main WIC located in Chennai. This results in the 'extreme' increase of inventory necessary at the Chennai WIC. In the West region, the main WIC located in Ahmedabad also has a large increase of inventory at one specific location. We reason that this increase depends on the fact that over 70% of the cities in the West region are B-Class cities. This are cities with high demand, with a fillrate objective of 60%. Which indicates that approximately 40% of the demand is forwarded to the main WIC Ahmedabad.

We can conclude that the involvement of lateral transhipment has a positive effect on the amount of stock kept in a region. The effects of this stock increase is the focus off the next paragraph.

Service Measures

In this paragraph we explore the results of including lateral transhipments in our system (Approach IV). Hereby particularly focusing on the consequences for the average waiting time. Since, the extension of the current model with lateral transhipment has no significant effect on the fillrate. Each WIC still has a fillrate objective, which equals a zero day turn-around-time, the inclusion of lateral transhipment does not affect the parameters that effect this objective. Whereas, the real effects of approach IV are expected to be seen for the average waiting time. Since, an additional emergency option that has a considerably shorter lead-time is included. In figure 25 we both show the absolute and relative change in average waiting time for the top 20 SKU's, an overview involving more SKU's can be found in Appendix F.

What we learn from the figure is that in 13 out of the 20 cases a reduction of the average waiting time can be seen. The relative reduction lies between 5 to 45%, it is clearly visible that the average waiting time for SKU 5 reduced by 40%. This is the largest decrease among the top 20 items, as a majority of the SKU's have a reduction between 10 to 20%.

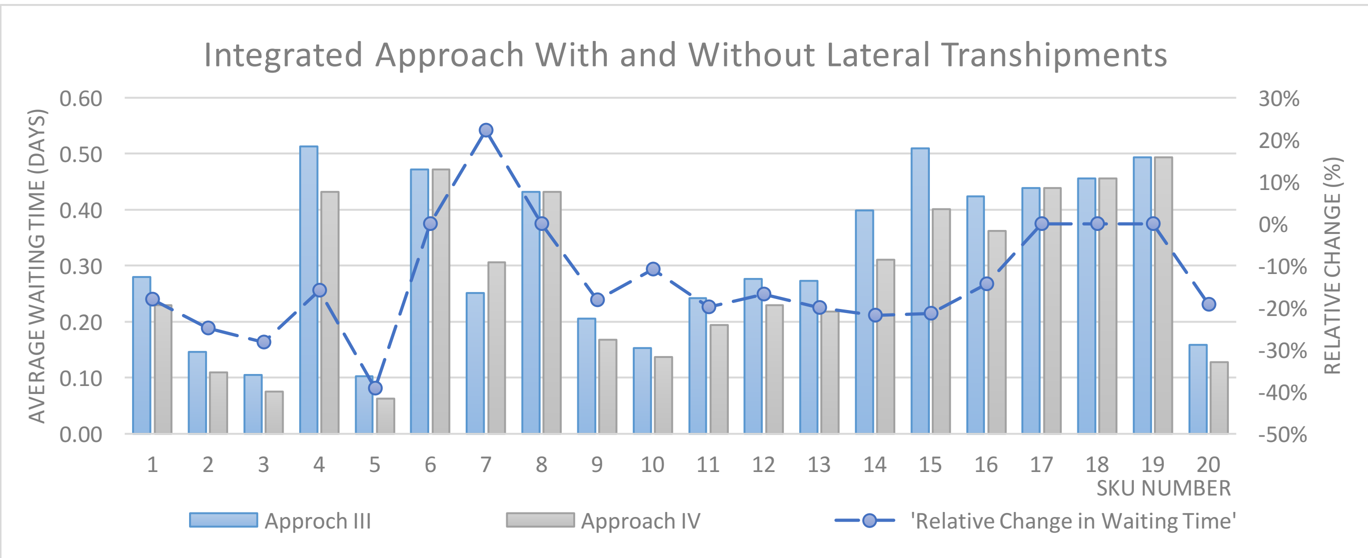

Figure 25: Relative Change in Waiting Time between Approach III and IV

If we look at the top 50 SKU, depicted in Appendix F, we see that for items that have lower demand the relative waiting time reduction is quite large, often in the fortieth percentile. This can be explained by the fact that the waiting time for these item's is already quite large, due to the low demand and consequently lower desirability to be stocked. However, in the case of lateral transhipment, the main WIC receives the extra demand for these items, which results in higher stock levels for these items at the main WIC. Furthermore, the shorter lead-time between main and regular WIC in comparison to the other emergency options leads to the lower average waiting time. In order to get a better understanding of the average waiting time reduction, we graph the relative reduction per region, see figure 26. We want to check what the effects are of having a RDC in a region vs not having a RDC in the region.

From the figure it becomes clear that the biggest gains are to be found in the South region. This waiting time reduction is due to the absence of a RDC. The lead-time to the WIC's in the South region is large, in comparison to the other regions that have a RDC which reduces the lead-time noticeably. Besides the results that can be measured directly, such as the effects of including lateral transhipment on the average waiting time. We are interested in the way demand is fulfilled, in the case of approach IV. In figure 27, we compare both approach III and IV and how emergency demand is fulfilled. We have one main in this region, New Delhi, In the North region we only have one A-class city, most of the cities are B-class cities which explains the large percentage of demand that is fulfilled by means of emergency shipment. As the fillrate objective for the B-class cities equals 60%, we know that around 40% of the demand is met by emergency shipment.

In case that a WIC is not able to fulfil demand an emergency demand will be requested. In approach IV the location that is checked for an emergency shipment is the main WIC located in New Delhi. Due to the working of our model, New Delhi is already prepared for the extra demand arriving and consequently the stock has been raised. As shown in the previous paragraph. This results in the fact that the main WIC can fulfil a large portion of this demand, on average around 25%. The remaining 15 % is fulfilled by either the RDC or the CDC. If we compare it with approach IV, which includes lateral transhipment, the percentage of demand fulfilled by means of RDC emergency shipment drops significantly. For all the regular WIC's the fraction of demand fulfilled by RDC emergency shipment is close to 1%. The remaining demand is fulfilled by means of a CDC emergency shipment.

The demand fulfilment distribution for the remaining regions can be found in Appendix F. In the interest of seeing the effects of these changes how demand is fulfilled and the increase of stock at the main WIC we will focus on the effects of lateral transhipment on the total costs. In this paragraph we focused on the effects of including lateral transhipments on the service measures. We concluded that the addition of lateral transhipment for most SKU's reduced the average waiting time. This reduction was especially significant in regions without a RDC. Moreover, we looked at the different ways demand is fulfilled with and without lateral emergency shipment. Besides the positive results on the waiting time service measure we also expect an emergency costs decrease. As, lateral transhipments are cheaper than any other form of emergency shipment. This hypothesis will be the focus of our next paragraph.

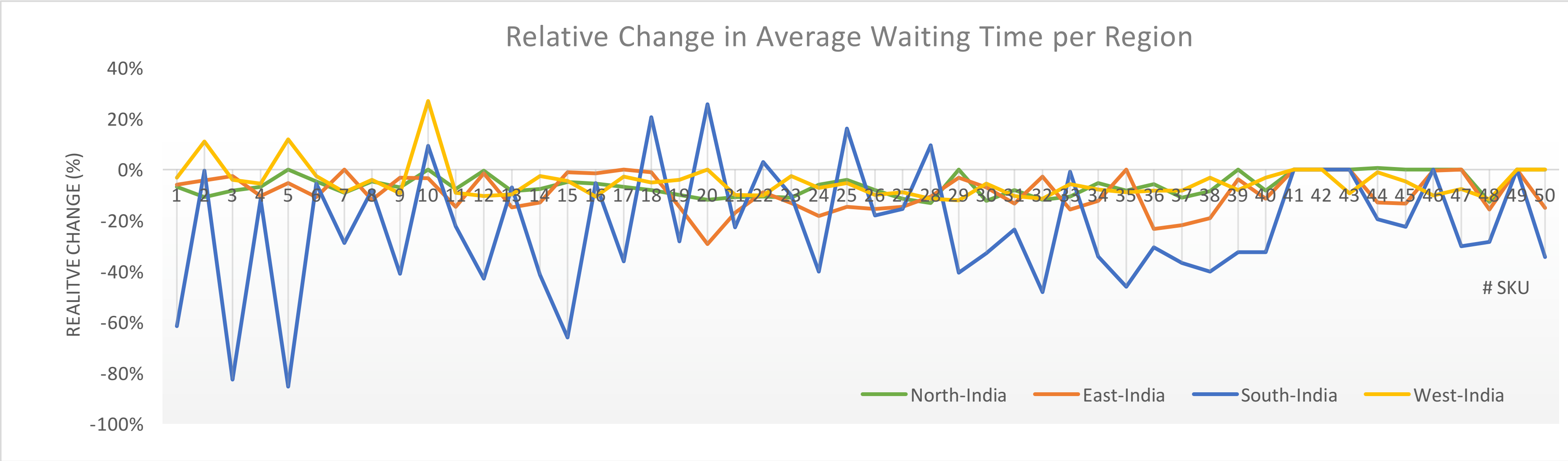

Figure 26: Relative Change in Average Waiting Time per Region

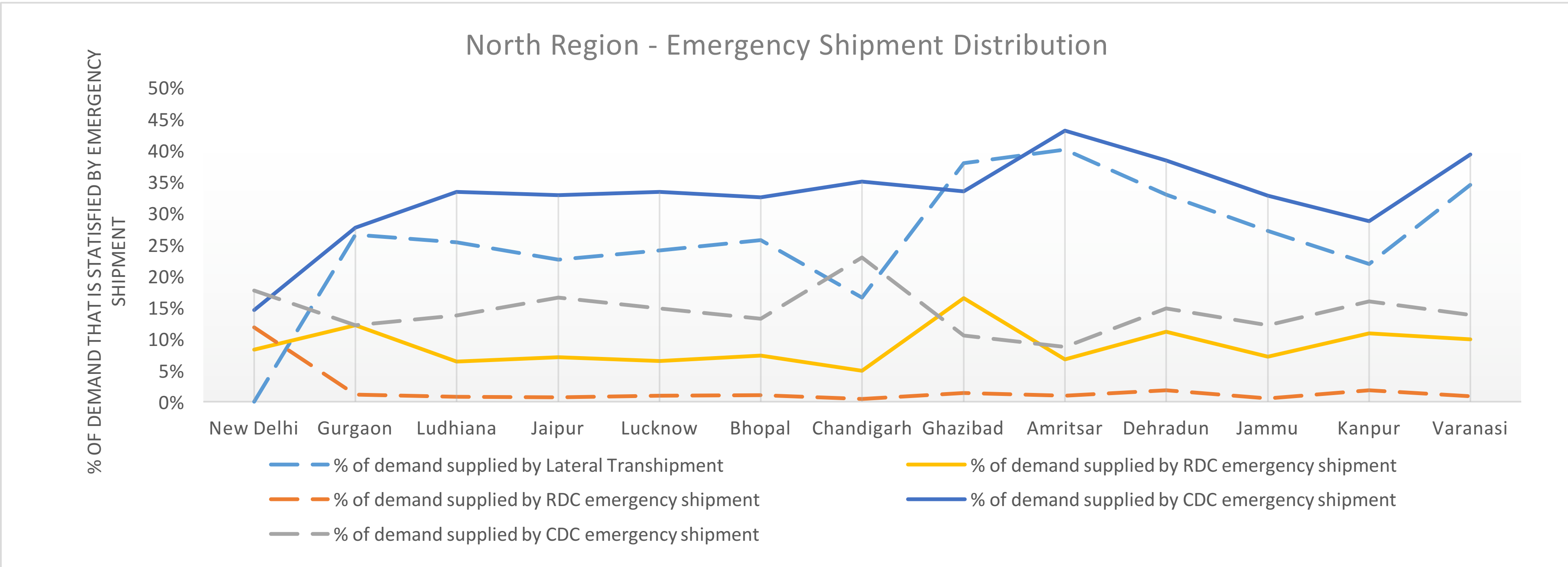

Figure 27: Change in Demand fulfilment, between Approach III and IV

Total Costs

As we have shown, introducing lateral transhipment in a system increases the inventory and reduces the waiting time. In order to get a view of the 'full' effects of these changes, we will now focus on the effects of these changes on the total costs. Hereby focusing on the two most important cost factors, that lateral transhipment effects, holding and emergency transportation costs. In figure 28, we graph the relative change between approach III and IV. We see that in all regions the inventory costs rise due to the extra demand arriving at the main WIC's. Additionally, in all regions the costs for emergency shipments decreases due to the availability of a cheaper alternative.

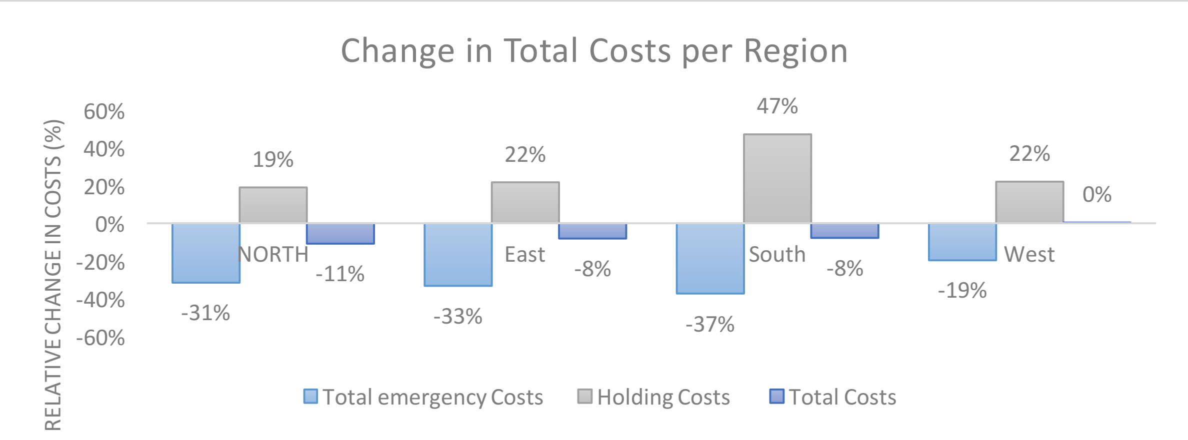

Figure 28: Change in total costs per region between Approach III and IV

In the North, East and South region approach IV leads to a decrease in total costs. Whereas, in the West region this approach does not effect the total costs at all.

In the North and East region the inventory increase was quite small. Combining this increase with a decrease in transport costs leads to a total decrease in costs. In the South region the inventory increase is substantial, but due to the fact that the average SKU price is low it is quite cheap to have inventory on stock. Furthermore, in the case that a WIC in the South region is not able to meet demand the only option for an emergency option is the most expensive option, having an emergency shipment from a CDC. Introducing lateral transhipment, which is a lower-priced option, leads to a significant emergency cost decrease. Which eventually also leads to a total cost decrease. In the West region the inventory increase is quite large as well, this can a result of the low service requirements and high number of large cities (high demand). The transport decrease is not large enough to lead to a decrease in total cost. However, by introducing lateral transhipment the waiting times decrease, while the total costs do not increase.

In conclusion in this section we looked at the differences between approach III and IV on three elements being inventory, service measure and total costs. We concluded that due to the redirecting of unfulfilled demand to the mains, the inventory rose at these WIC's led to an inventory increase. This inventory increase was necessary in order to meet demand from regulars. This in turn had no effect on the expected fillrate, however the waiting time reduced significantly. This reduction was especially visible in the South region as this region lacks a RDC. Besides the positive effects on the waiting time, the total costs deceased in the North, East and South Region. In the West region the total costs remained at the same level.

6.5.3 Item vs System Approach

In this section we will compare approaches V and VI. In Approach V we optimise each item to meet the service objectives, this approach is otherwise known as the item approach. While approach VI considers the system as a whole and looks for the combination of items that reaches the service objectives with the lowest costs, known as the system approach. Due to the fact that we have different service measures for each WIC makes it hard to compare both approaches in an appropriate way. As we cannot set multiple service measures for each item. Therefore, we will set the fillrate objective to 70% for each WIC and item. The second service measure, waiting time, is set at 3 days for both the items and the WIC's. Essentially, we are treating each WIC as an A-class city and set the service objective for the item approach equal to the objectives in an A-class city.

Inventory
First, in figure 29 we compare the change in inventory between both approaches. We see that there are large differences between the approaches. We see what we expected that the inventory would decrease substantially. The biggest decrease, in the inventory kept on stock is visible in the West region, where there is a 70% decrease in stock necessary. These inventory reductions rationally lead to a cost decrease, which we show in figure 30.

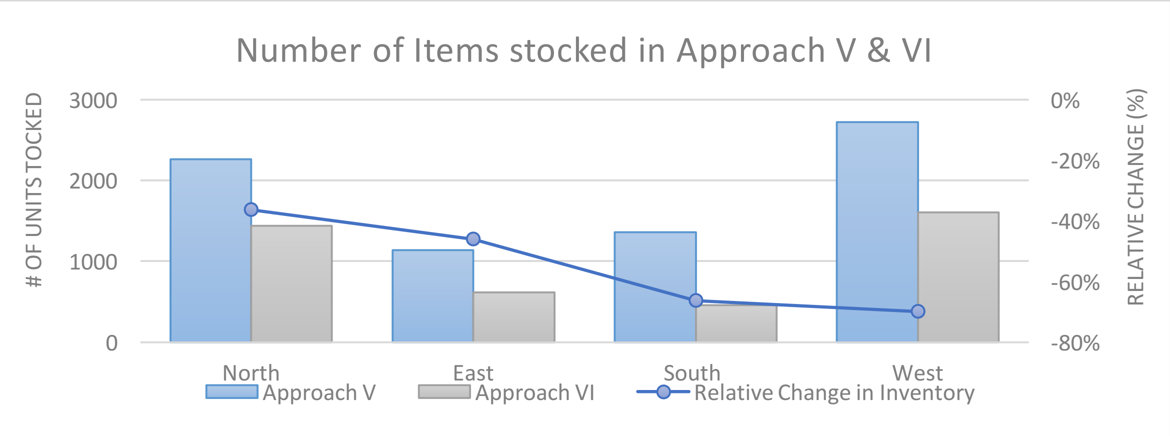

Figure 29: Number of Units stocked per region, in Approach V and VI

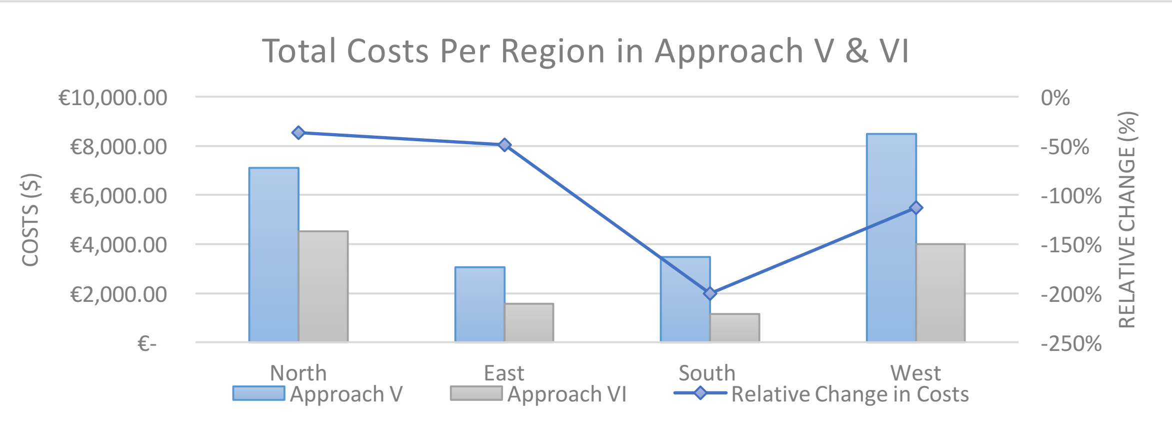

Figure 30: Total Costs Per Region in Approach V and VI

It is clear that the reduction of inventory reduces the total costs per region as well. The cost reduction are in the 50 to 200% range. The cost reduction in the South region is so large due to it being the region with the highest number of WIC and consequently the highest demand. In conclusion, we see that there are significant differences between both approaches. From our analysis we conclude that approach VI is the preferred approach in our setting, as it delivered the lowest total costs for each region. However, this is something that has been shown multiple times in studies regarding spare parts. We have several reasons for explicitly designing and implementing this approach in the tool. First, Logitech introduces several new products each quarter. It is not exactly clear how many of these products will be sold and subsequently how many returned. It is the task of the After Sales department to make a calculated guess of the necessary stock for the potential future warranty claims. This could be done by running the item approach with the new items and see how much stock is needed to meet expected demand. Hereby, focusing on these items and check the amount of stock needed for a certain service level. Second, due to the enormous demand differences between items it might be an interesting idea to set different (higher) service levels for the SKU's that are most requested. We address this possibility in the next section. Moreover, running a system analysis for the remainder of the items with lower service requirements. This way one could 'trick' the system in storing more products of the most returned products. Whereas, items which are not returned as often can be analysed by a normal system analysis. Third, SKU that are close to get marked EOL have a last production date. With the item approach the After Sales department could determine the necessary stock to reach a certain service objective. Knowing this information makes it possible to make a calculated guess for the size of the last production batch.

6.5.4 XYZ Approach

In the XYZ-Approach (Approach VII) we use an item approach with different service objectives per group. We use the following formula to determine the compensation value of each item.

$$consumption\ value = \frac{Demand}{Price}$$

The compensation value differs between 209 and 0.008. we create three groups based on the cut off points shown in table 17.

Group	Consumption Value Limit	Number of SKU	% of Total	Fillrate Objective
X	>15	15	9.86%	90%
Y	1≥ x ≤15	34	22.36%	80%
Z	<1	103	67.7%	65%

Table 17: Approach VII parameters.

We choose the fillrate objectives in a way that on average the fillrate objective coincides with the fillrate objective for an A-class city. This would make it less complicated to compare the different approaches in the next section. We create figure 31 and show the progress of the inventory and costs.

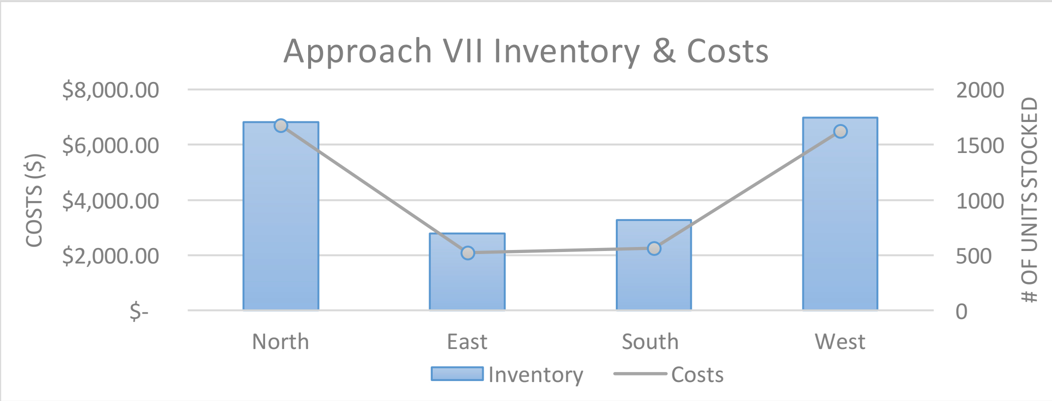

Figure 31: Inventory and Costs for Approach VII

In order to see the performance of approach VII we will compare this approach with approach V and VI, in the next section.

6.6 Scenario Analysis Discussion

In Section 6.5 we performed a number of scenario analysis, in this section we will summarize the results and compare the different approaches. We start by first determining the correct way of connecting the various echelons. We conclude that the integrated approach, approach II, is the correct of way of connecting the echelons. Furthermore, we, test the effects of the option of lateral transshipment. We show that the largest gains are reached in the regions where there is no RDC present. In figure 32 and 33 we compare three approaches V, VI and VII. It becomes clear that the VII approach falls between the two other approaches. This is due to the extreme case of the item approach where we set the service objectives for each item separately. By introducing groups with each their own service objective, we are able to reduce inventory and costs in comparison to approach V. However, approach VI still remains the best option on both the costs and inventory. Because, the algorithm by that particular approach is more sophisticated, as it applies a 'biggest bang for a buck' method.

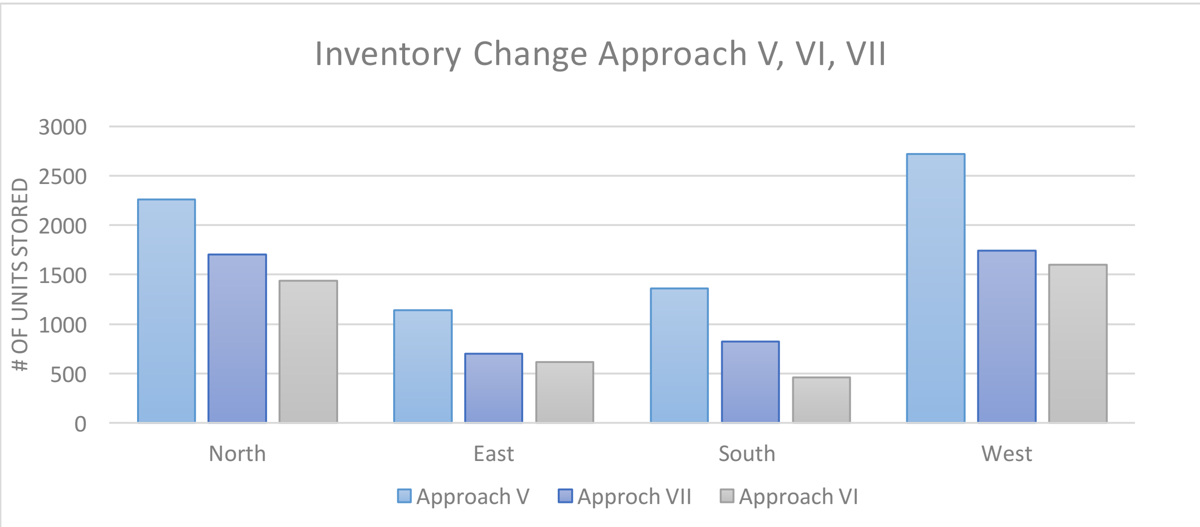

Figure 32: Inventory Changes for the Approaches V, VI and VII

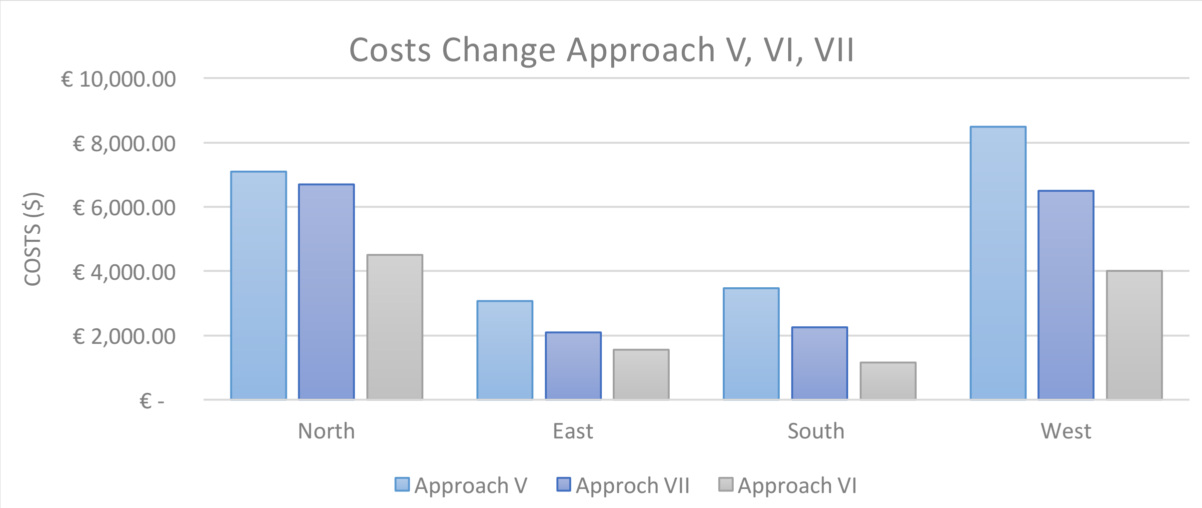

Figure 33: Costs Changes for the Approaches V, VI and VII

In order to gain more background of the distribution of stock and costs over the groups X, Y and Z we compare the inventory kept per group in Appendix F. For each approach we allocate the inventory regarding the SKU's in each group. It is clear that for group X there is hardly any difference between the three approaches. This is explained by the fact that approach VI will prefer to stock items in the first group as stocking an item of this group adds the most to the aggregate fillrate. If we look at group Y the differences between the approaches become more clear. Approach VI still stocks less units in all regions than Approach VII, however the differences are still small. The differences between approach VI and VII are the largest in group Z. Approach VI will stock only for a few SKU's, as these items are not requested as often. Only those SKU's are stored, that have a long lead-time due to a low fillrate at the CDC.

Chapter 7 Sensitivity Analysis

This chapter discusses the sensitivity of different parameters in our system. We will run the sensitivity analysis for each multi item model separately. The sensitivity analysis aims to test the robustness of a model. By executing the model on a large number of parameter values, we aim to see whether we will find unexpected relationships between input and output. Furthermore, it increases the understanding of the relationships between input and output in the model.

We start in Section 7.1 by analysing the sensitivity of the demand. Next, we focus on the holding costs in Section 7.2. In Section 7.3 we look at the sensitivity of the CDC lead-time and the lead-time between the CDC and the WIC's. In Section 7.4 we look at the service measures in the system. We conclude this Chapter by discussing the sensitivity of the CDC Emergency costs.

Table 18, show the different range of values for the parameters that we will use. In order to keep this section condense we will put a number of graphs in Appendix G.

Input parameter	Range of Values
Demand (%)	80%, 85%, 90%, 95%, 100%, 105%, 110%, 115%, 120%
Holding Costs (%)	15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
Leadtime	
Supplier lead-time to CDC (days)	50%,60%,70%,...,130%, 140%, 150%
Replenishment lead-time to WIC (days)	50%,60%,70%,...,130%, 140%, 150%
Service Measure	
Fillrate CDC (%)	10%, 20%, 30%,...,80%, 90%, 100%
Fillrate RDC (%)	10%, 20%, 30%,...,80%, 90%, 100%
Fillrate WIC (%)	10%, 20%, 30%,...,80%, 90%, 100%
Waiting Time WIC (days)	0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0, 2.5, 3.0, 3.5
Costs	
CDC Emergency costs ($)	50%,60%,70%,...,130%, 140%, 150%

Table 18: Parameter values for the Sensitivity Analysis

7.1 Sensitivity of parameter demand rate

This section discusses the sensitivity of the demand rates, which we will do in two ways. First, we differ all demand rates with the same percentage (80% to 120%). For each setting we recalculate the demand rates, optimise all base stock levels, and evaluate the system. The effects of the different demand rates on the inventory can be seen in figure 34. Each of these iterations are performed under the same settings, besides the change in demand. What we noticed in the case of decreased demand, that the number of units necessary to meet the fillrate objective was lower. This was due to the fact that for a majority of the items, the demand is so low that stocking one unit will result in a fillrate close to 100%. When demand is increased this overstocking is less of influence.

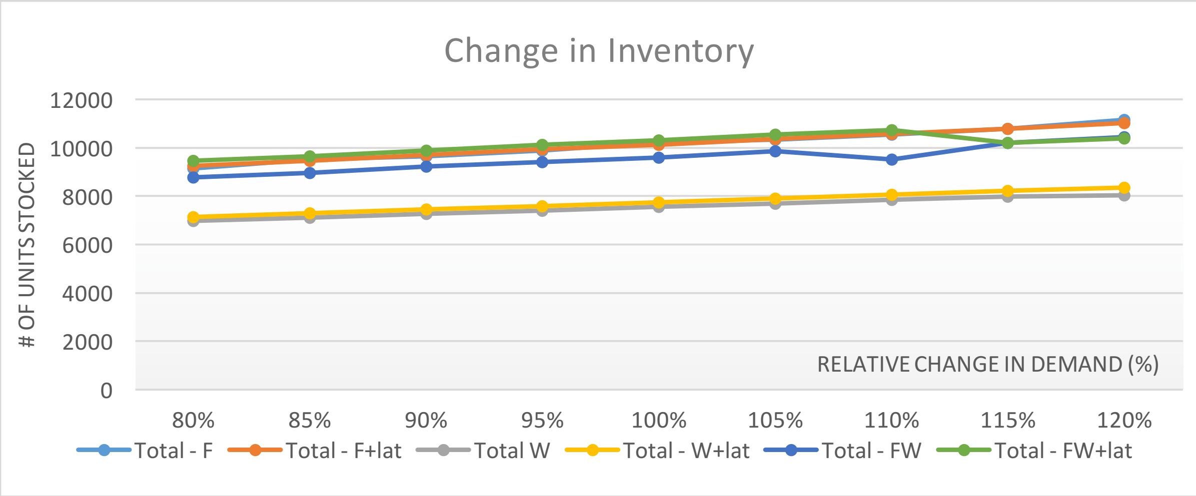

Figure 34: Change in Inventory due to change in Demand

Besides the change in inventory it is more interesting what the change in demand has on the total system costs. In order to see these effects, we created figure 35. The system costs in all models show a linear trend, which is to be expected. The six different models show the different values when we change the amount of demand. Hereby, the differences remain between the models.

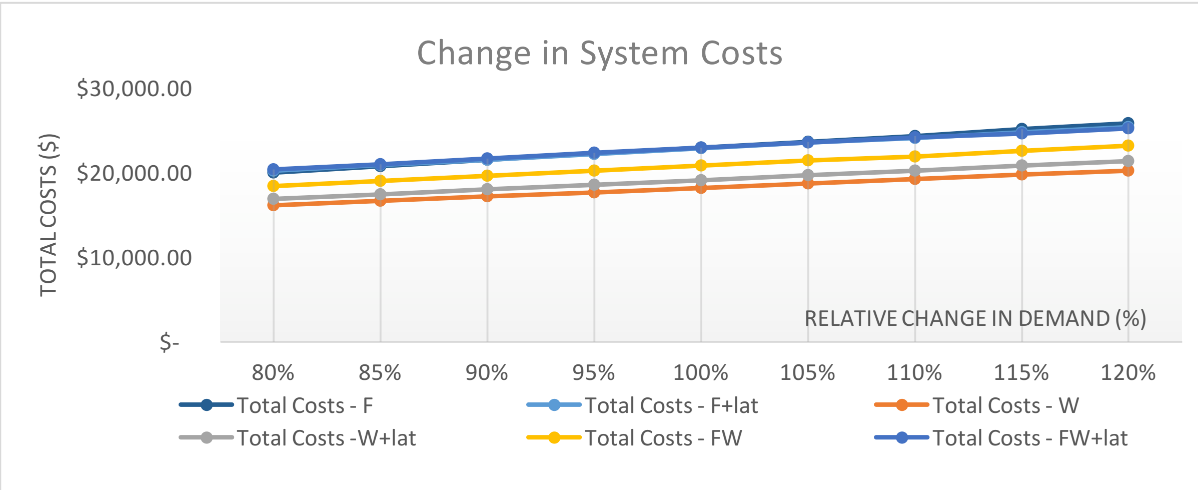

Figure 35: Change in Costs due to change in Demand

In order to get a better idea of the cost increase when demand increases or decreases and the effects it has on the total costs. We describe the relative cost differences between the various models, in table 19.

Relative Change in Costs	Fillrate	Fillrate +lat	Waiting Time	Waiting Time +lat	Fillrate + Waiting Time	Fillrate + Waiting Time +lat
-20%	-8,5%	2,8%	-11,8%	-11,3%	-11,3%	-8,8%
-15%	-5,7%	-9,5%	-8,8%	-8,5%	-8,6%	-5,8%
-10%	-2,8%	-6,3%	-5,9%	-5,7%	-5,7%	-2,9%
-5%	0,0%	-3,0%	-2,9%	-2,8%	-2,8%	0,0%
5%	3,2%	3,1%	3,0%	2,9%	2,7%	2,9%
10%	5,5%	6,0%	5,8%	5,7%	5,4%	5,3%
15%	8,3%	9,5%	8,8%	8,5%	7,1%	8,6%
20%	11,2%	12,5%	11,7%	11,3%	9,8%	11,4%

Table 19: Relative change in Costs due to change in Demand

We see that for example, if the demand increases with 20% and we have two objectives Fillrate and Waiting time we can expect a cost increase of 9.8%. Furthermore, it becomes clear that for a majority of the models the following can be said: for every 5% difference in demand we see approximately 3% change in costs.

7.2 Sensitivity of parameter Holding Costs

As described in Section 6.2.5, the holding costs percentage is a rough estimate. Therefore, we have to execute a sensitivity analysis on this this parameter. The results can be found in Appendix G. From this figure we can deduce that we are dealing with a linear relationship between the expected costs and the holding cost percentage. What we can deduct from this graph is that the savings potential for Approach VI is larger when the holding costs are higher. As this reflects reality we can conclude that these results do not harm our results.

7.3 Sensitivity of parameter lead-time

This Section describes the sensitivity of the lead-time parameter. We will evaluate the supplier, replenishment and emergency lead-time. For the supplier lead-time we made the assumption that the supplier can always supply with a constant lead-time. We test the sensitivity in the same way as we did for the arrival rates of the demand. The results are as expected, hence they do not harm our results.

7.3.1 Supplier lead-time

For the supplier lead-time we use the current lead-time of 21 days as the norm. In this study we made the assumption that this lead-time was deterministic. However, in reality lead-times can differ and therefore we will execute an analysis on the supplier lead-times. The results of this analysis can be found in figure 36.

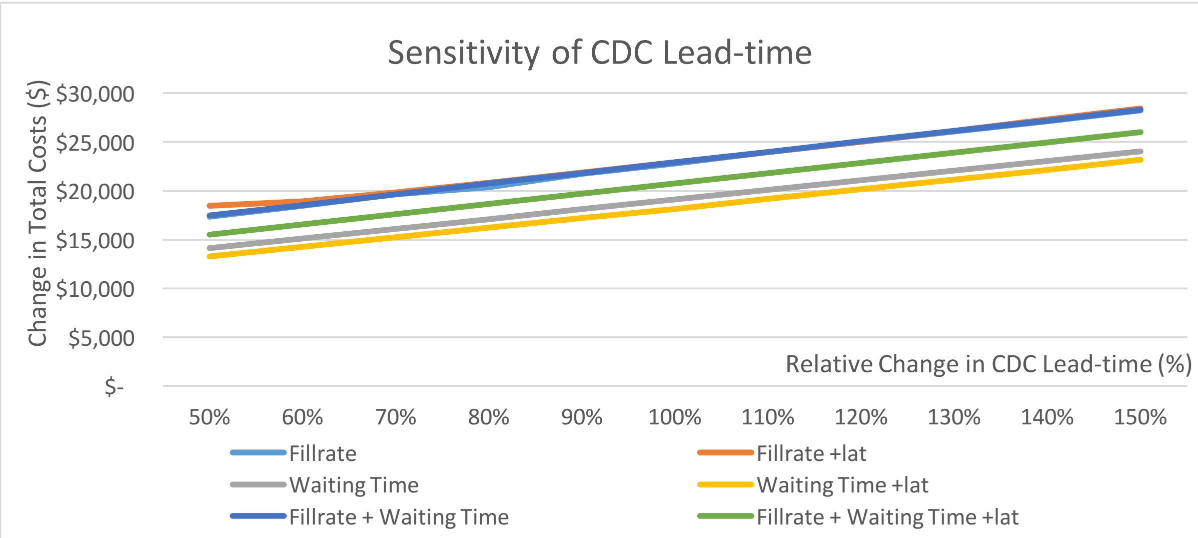

Figure 36: Relative Change in Costs due to Change in CDC Lead-time

As expected there is linear relationship between the lead-time and the total costs. This can easily be explained, as a short lead-time means that the amount necessary to overcome the lead-time is short. While the reverse is the case when the lead-time is increased. Table 20 shows this relationship where we set out the relative change in lead-time and the effect it has on the total costs.

Relative Change (%)	Fillrate	Fillrate +lat	Waiting Time	Waiting Time +lat	Fillrate + Waiting Time	Fillrate + Waiting Time +lat
-50%	-19%	-21%	-25%	-25%	-23%	-21%
-40%	-15%	-17%	-20%	-20%	-17%	-17%
-30%	-13%	-13%	-15%	-15%	-14%	-13%
-20%	-8%	-9%	-10%	-10%	-8%	-8%
-10%	-5%	-4%	-5%	-5%	-5%	-4%
10%	4%	4%	5%	5%	5%	4%
20%	7%	9%	10%	10%	9%	8%
30%	12%	13%	15%	15%	13%	13%
40%	15%	17%	20%	20%	18%	17%
50%	20%	21%	26%	25%	22%	21%

Table 20: Relative Change in Total Costs

In the table we quantify the effects of a change in lead-time, for example: we see that a 50% increase in the lead-time from 21 days to 31,5 days increases the total costs, in the case of a fillrate objective, with 20%. Next, that for each step taken of 10% the costs change approximately with 4%. This translates in reality to; if we either increase or decrease the lead-time with 2.1 days the costs will increase or decrease with 4%. As these results are as expected, they do not harm our results.

7.3.2 Replenishment lead-time WIC

In this section we address the replenishment lead-time to the WIC. Hereby, it should be remembered that lead-times between WIC's can differ. In this analysis we test whether the length of the replenishment lead-time will have major impact on the results. The results of our analysis can be found in table 21.

Relative Change (%)	Fillrate	Fillrate +lat	Waiting Time	Waiting Time +lat	Fillrate + Waiting Time	Fillrate + Waiting Time +lat
-50%	-4,39%	-2,76%	-1,28%	-1,59%	-3,20%	-3,02%
-40%	-3,85%	-2,13%	-0,94%	-1,20%	-2,42%	-2,30%
-30%	-3,13%	-1,56%	-0,64%	-0,76%	-1,26%	-1,77%
-20%	-2,64%	-1,00%	-0,37%	-0,50%	-1,45%	-1,06%
-10%	-1,58%	-0,18%	-0,04%	-0,25%	-0,69%	-0,28%
10%	1,65%	0,86%	0,46%	0,53%	0,30%	0,93%
20%	2,74%	1,44%	0,72%	0,86%	0,72%	1,10%
30%	3,05%	2,20%	0,94%	1,07%	1,71%	1,87%
40%	3,74%	2,84%	1,05%	1,41%	2,17%	2,42%
50%	4,20%	3,24%	1,35%	1,76%	3,00%	2,79%

Table 21: Relative Change in WIC Costs

From this table it is harder to see a specific relationship between costs and lead-time, besides the linear relationship mentioned in the previous section. However, we notice that the relative change in costs is not consistent for each step. The change in costs are linked to the change in holding costs. As we are dealing with low item price per SKU, the costs changes are not as large.

7.4 Sensitivity of parameter Service measures

7.4.1 Fillrate at CDC

In this section we will look at the relation of the CDC fillrate objective and the total system costs. In Section 6.5.2 we discussed the lack of a service requirement at this level and how we dealt with this issue. Essentially we created two methods to deal with this issue, either the aggregate fillrate objectives of the lower echelons is used or a user can input a fillrate objective. In order to gain insight in the how the total costs evolve we will fill in a range of values as a fillrate objective and analyse the total costs.
In this analysis we will follow Approach II, meaning that the first step is to make sure that the CDC matches its fillrate objective. Subsequently the underlying echelons are solved. In figure 37, we show how much stock is necessary given various CDC fillrate objectives. In this figure we use the Fillrate and Waiting Time objective model. The remaining models can be found in Appendix G.

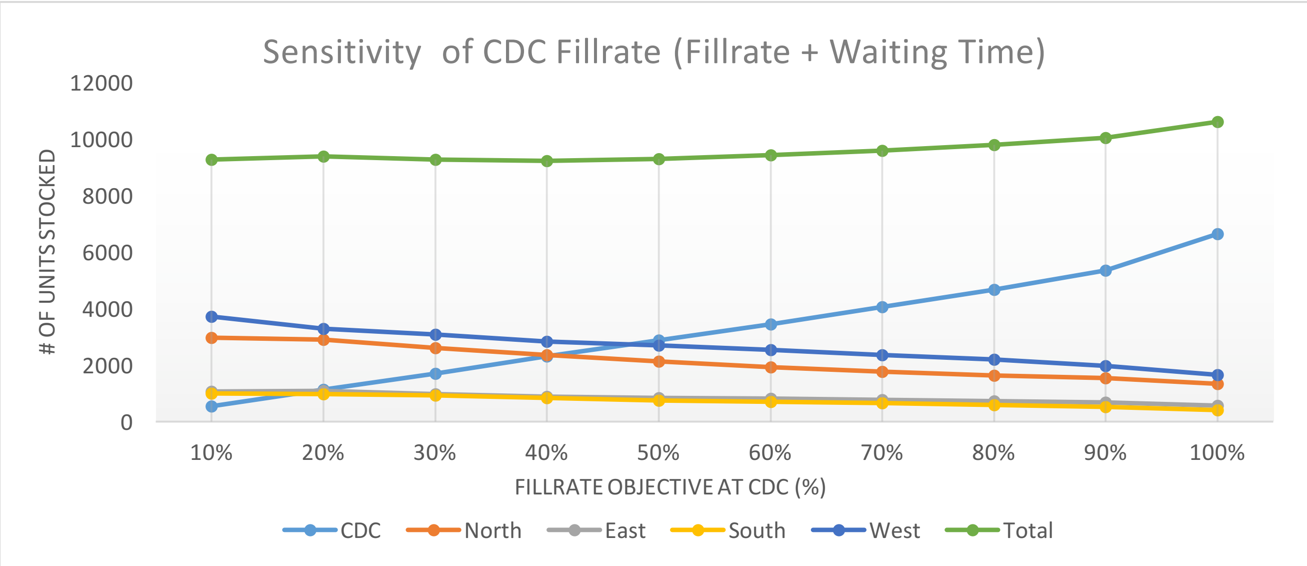

Figure 37: Sensitivity of CDC Fillrate

There are some interesting points that can be deduced from this figure. In the extreme case the fillrate objective at the CDC is set at 10%. The consequences of the low service requirements at this echelon become clear, when focus is paid to the underlying echelons. As the low service objective at the CDC, effects the lead-time to the lower echelons considerably. Consequently, the lower echelons have high stock levels to cover for the long item lead-times. As the fillrate objective at the CDC rises the number of units necessary to meet the service requirements at the lower levels is lower, due to the shorter lead-time. However, from this picture we cannot decide at what fillrate objective at the CDC the total costs are the lowest. In order to find the optimal fillrate objective we construct table 22. In table 22, we show the cost development with the various number of fillrate objectives in the different models. The bold marked numbers are the lowest total cost for that particular model.

Fillrate at CDC	Fillrate	Fillrate +lat	Waiting Time	Waiting Time +lat	Fillrate + Waiting Time	Fillrate + Waiting Time +lat
10%	$ 23.446	$ 24.062	$ 19.726	$ 18.741	$ 22.532	$ 21.382
20%	$ 23.387	$ 23.370	$ 19.467	$ 18.315	$ 22.672	$ 21.265
30%	$ 23.272	$ 23.261	$ 19.308	$ 18.203	$ 22.560	$ 21.048
40%	$ 23.105	$ 23.244	$ 19.252	$ 18.151	$ 22.467	$ 20.931
50%	$ 23.101	$ 23.114	$ 19.259	$ 18.169	$ 22.473	$ 20.858
60%	$ 22.982	**$ 22.911**	$ 19.176	$ 18.182	$ 22.487	$ 20.814
70%	$ 22.822	$ 22.913	$ 19.098	$ 18.159	**$ 22.472**	$ 20.789
80%	$ 22.695	$ 23.604	$ 19.063	$ 18.170	$ 22.493	**$ 20.765**
90%	**$ 22.645**	$ 24.408	**$ 18.970**	**$ 18.150**	$ 22.519	$ 20.772
100%	$ 22.711	$ 25.600	$ 20.161	$ 19.459	$ 23.228	$ 21.558

Table 22: Development of Total costs given CDC Fillrate

What we see is that the for each of the different models, the optimal fillrate objective can differ. For the fillrate objective we see an optimal fillrate objective at the CDC of 90%. While, if we include lateral transhipment with the fillrate objective model, the optimal fillrate objective at the CDC lowers to 60%. For Logitech's monthly use, the Fillrate + Waiting time objective model will be the most used model. In this case the lowest total costs are reached with a CDC fillrate objective of 70%

7.4.2 Fillrate at RDC

In this section we perform the analysis with the knowledge of the previous section, meaning the optimal fillrate at the CDC for each model. We vary the fillrate objectives of the RDC and examine the effects that they have on the service measures and the total costs. In this analysis we will limit ourselves to the 'fillrate objective' and 'fillrate + lat objective' model. As we are not interested in the waiting time at the RDC. In figure 38, we show the results of the analyses performed with the 'fillrate objective' model.

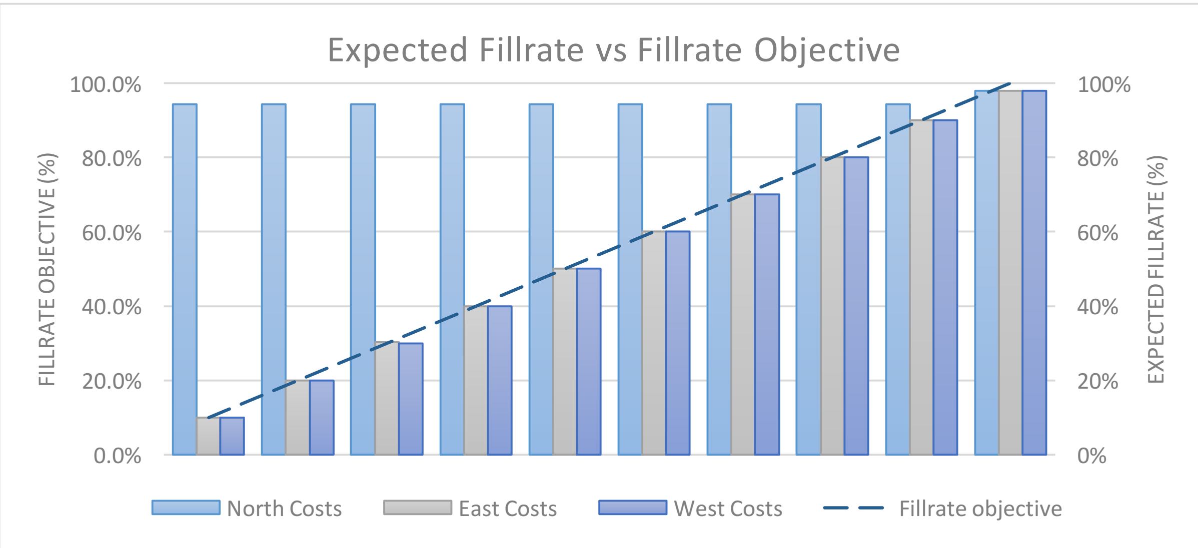

Figure 38: Expected fillrate vs the fillrate objective

From the figure it turns out that the tool in the case of the North region would 'overstock' considerably. This phenomenon was already discussed in Section 6.5.4, and the reason why this occurs. The fact that holding an item on stock is so inexpensive in comparison to requesting an emergency shipment, leads the tool to stock more than necessary. From this figure we can conclude that in the North Region the fillrate objective should be kept around the 90% region. We examine the second model, 'fillrate + lat objective', in the same manner in Appendix G. From this figure it turns out that both the North and the West region, overstocking tends to stop at approximately the 90% mark.

However, we should keep in mind that this overstocking occurs due to the assumptions we made regarding the holding costs percentage and the costs for an emergency lead-time. In order to examine the robustness of this claim we should examine both these parameters. We examined the sensitivity of the holding costs in Section 7.2, and will study the sensitivity of the emergency shipment costs in Section 7.5.

7.4.3 Fillrate at WIC

In this section we examine the sensitivity of the fillrate at the WIC's. Hereby, we should recall that the fillrate objectives differ among the different city classes. Consequently, we should address the cities separately. We will only show the graphs belonging to the A-class cities in this section and refer to Appendix G, to see the graphs belonging to the B and C- class cities. In figure 36, we see the same occurrence as in the previous section. The first step in the algorithm calculates that approximately 90% of the demand could be stocked before the costs start to rise.

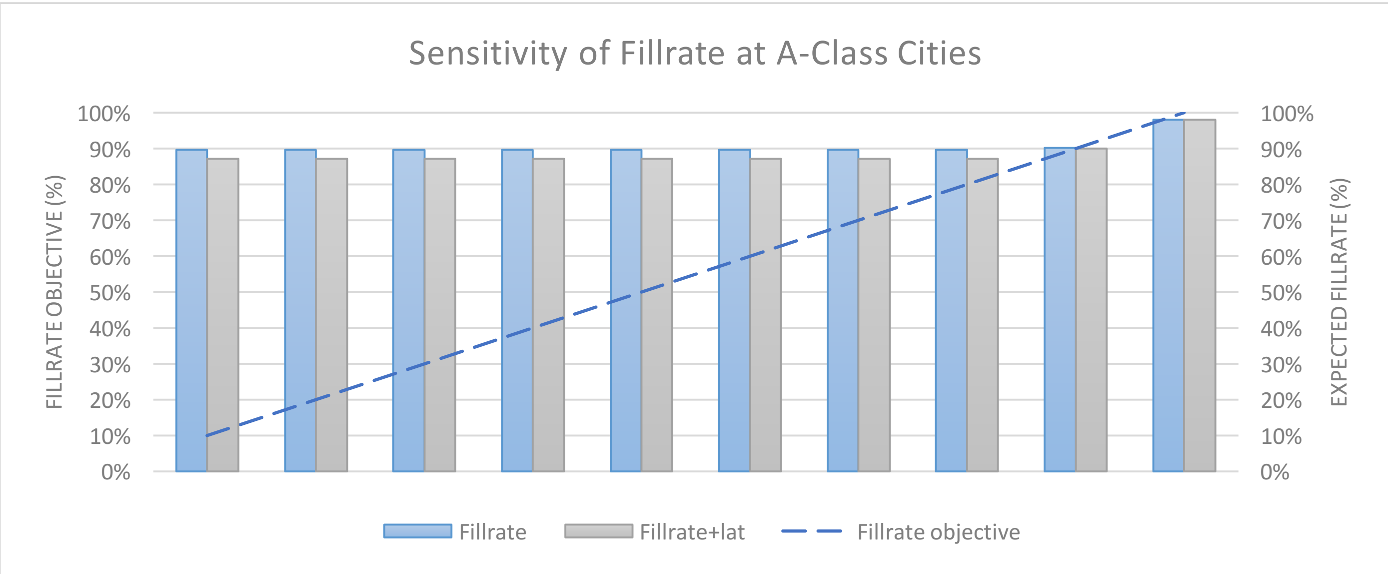

Figure 39: Sensitivity of Fillrate at A-Class Cities

In figure 40 we plot the total costs against the fillrate objective. In the case of the 'fillrate objective' model we see a minimum at 80% and in the case of the 'fillrate + lat objective' model we see a minimum at 90%.

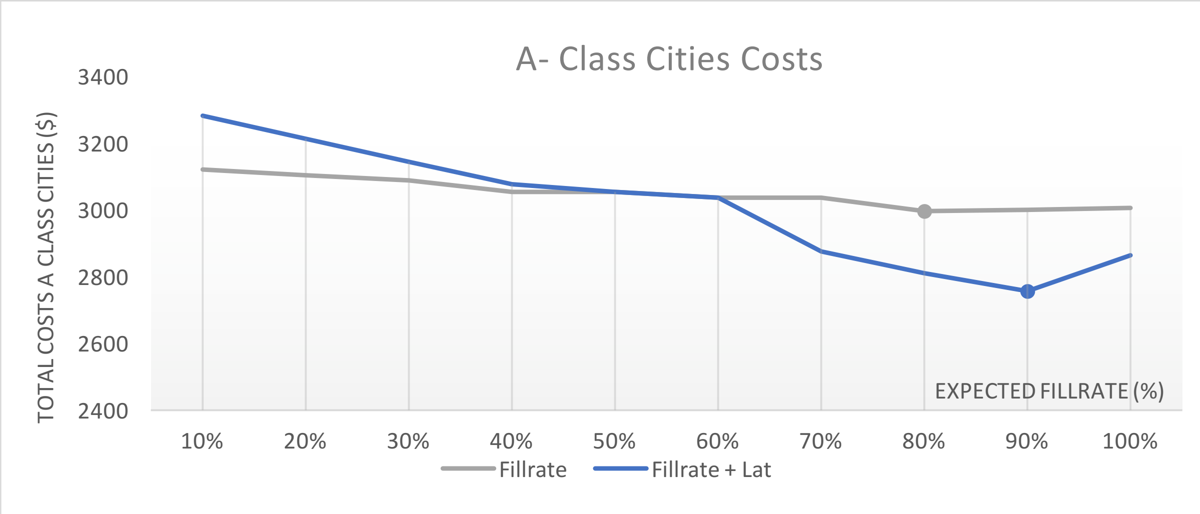

Figure 40: Costs Development in A-Class Cities

We perform the same analysis for the B and C-class cities. The results from the B-class cities are similar to the results found for the A-class cities. For the C-class cities, the lowest costs are achieved at even a higher level of service.

7.4.4 Waiting Time at WIC

In this section we will perform a sensitivity analysis on the second service measure, waiting time. In this analysis we will only use the two waiting time focused models in our tool. First, we will recall how we calculate the average waiting time. When a consumer arrives at a WIC the system can be in two states, it either has the product on stock or not. In the case that they are unable to meet demand, an emergency order will be requested. The average waiting time looks at the length, number of days, that the consumer has to wait. This number is closely related to the fillrate, as shown in figure 41. In this figure we graph track the movement of the fillrate when the waiting time objective changes.

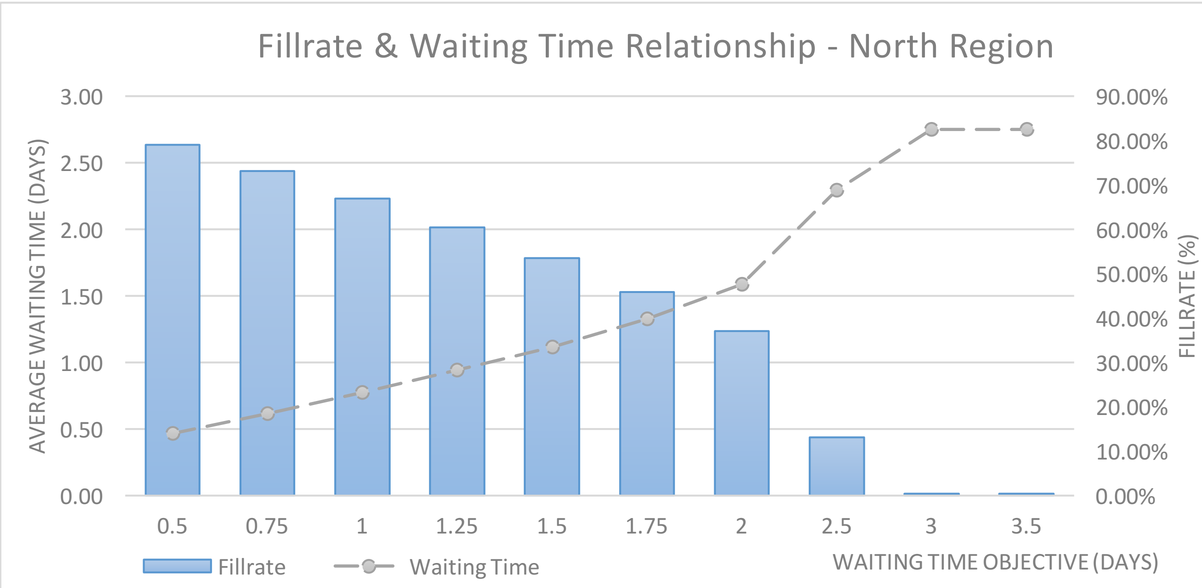

Figure 41: Fillrate and Waiting Time Relationship

In order to get a clear view of the Fillrate and Waiting time relationship we will look at several points in this graph.

Fillrate	Waiting Time objective	Remarks
79,1%	0.5	High Waiting Time objective, resulting in a fillrate close to 80%. This entails that 80% of the demand is immediately met. The remaining 20% is brought in by means of emergency shipment.
66.9%	1	When the Waiting time objective lowers to 1 day, the fillrate decrease equals 13%. However, still a majority of the demand is met by means of regular shipment.
37.1%	2	In this case we see a significant drop in fillrate. This drop can be associated to the fact that the longest emergency shipment(time) equals 2 days. Hence most of the demand is met by an emergency shipment of the CDC. This process is clearly visible in figure 42.
0.44%	3.5	Basically all demand is met by emergency shipment. The fillrate is a result of the first step in our algorithm, that increases the stock level as long as the costs do not rise.

Table 23: Background information that goes with Figure 38

This figure supports the claims made in table 23. It shows the sudden drop of inventory kept in the North region, at the two days' mark.

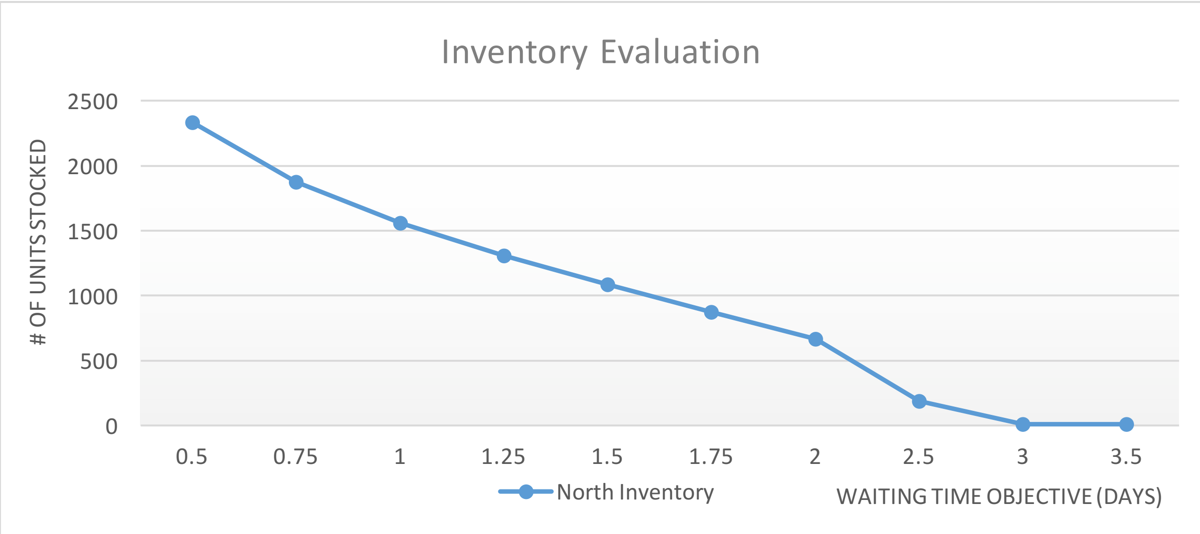

Figure 42: Inventory Progression given Waiting Time Objective

The analysis in this section shows the effect of the waiting time objective on the fillrate. Additionally, it shows the effects of the length of the emergency option on the amount of stock kept in a region. In this analysis we did not explicitly mentioned the costs related to these emergency shipments. The costs of the emergency shipment effect the number of inventory kept, especially in the case when the waiting time objective is high. Because, in this case the first step in our algorithm would decide to stock more in order to reduce total costs.

7.5 Sensitivity of the parameter Emergency Costs

In this section we study the sensitivity of the emergency costs, hereby focusing on the CDC emergency costs. One of the main findings of the previous analysis performed, was that our model tends to overstock. This due to the low holding costs compared to the emergency shipment costs. This phenomenon is something we want to examine; the question arises at which point this overstocking is less interesting. In order to find this value, we measure the 'relative distance' this is the difference between the objective fillrate and the expected fillrate. The results for this analysis can be found in figure 43 and table 24.

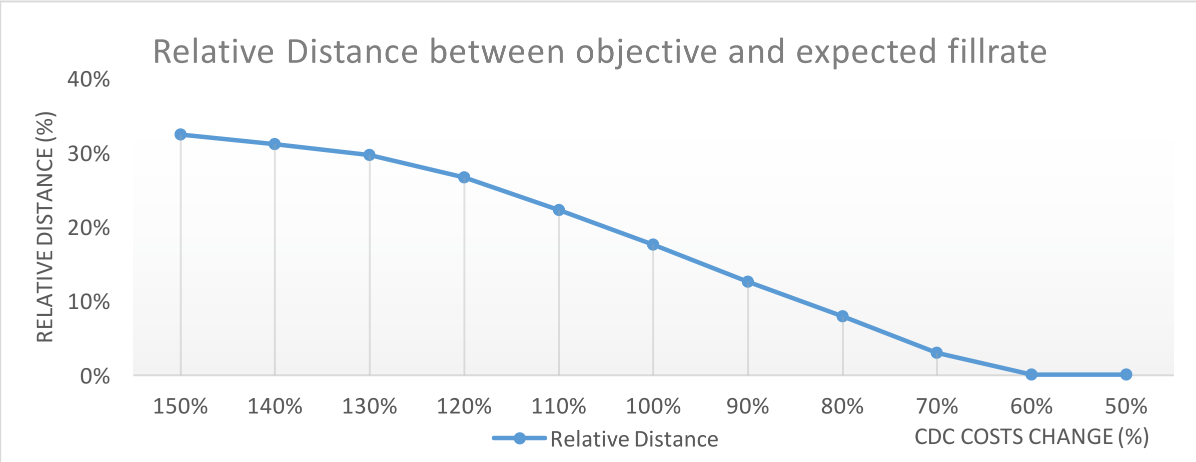

Figure 43: Relative Distance between Objective and Expected Fillrate

Regular costs ($)	CDC Costs($)	Relative Change (%)	Relative Distance
1	3	150%	32%
1	2,8	140%	31%
1	2,6	130%	30%
1	2,4	120%	27%
1	2,2	110%	22%
1	2	100%	18%
1	1,8	90%	13%
1	1,6	80%	8%
1	1,4	70%	3%
1	1,2	60%	0%
1	1	50%	0%

Table 24: CDC emergency costs vs regular shipment costs

We can observe from both the table and the figure that models overstocks in the case that the CDC emergency costs are 1.4 times higher than the regular costs. As their always will be a small percentage of overstocking. Furthermore, we see that for each 10% increase in CDC costs the relative distance increases with 5%. However, this linearity stops at the point 2.6 due to the fact that holding costs become part of the equation. As might not be clear from this table, the trade-off is between holding a part on stock or risk requesting an emergency shipment. As in the end of figure 40 there is no incentive to hold more on stock than necessary, because requesting an emergency shipment is inexpensive.

Chapter 8 Conclusion and Recommendations

The last Chapter discusses the main conclusions and recommendations that are the results of this study. We answer the research question and sub questions in Section 8.1. In Section 8.2 we discuss the recommendations that follow from this study. The possible model extensions are discussed in Section 8.3. Subsequently, we address possible future research opportunities. In Section 8.4 we state our contribution to the current scientific field regarding spare parts. This Chapter is concluded with how the tool could be implemented and used by the Logitech After Sales Department.

How much stock should be present in order to meet the service measures? And where should this stock be kept, given the various echelons present?

Sub Questions

- Which costs could be expected given a Walk-In-Centre type of warranty service model, and keeping the KPI setting as they are?
- What are the effects of changing the current settings of the Key Performance Index?
- What are the effects of including lateral transhipments into the model?
- What are the effects of having a RDC present in a region?
- How large are the costs benefit if chosen for a system approach over an item approach?

8.1 Conclusions

Below are the main conclusions that we found performing this study. We will follow the same order as the sub-questions, while addressing them.

One of the main challenges of this study was transforming the existing supply chain in India into a tool. Transforming the reality in the tool provides us with the ability to analyse the behaviour of the various parameters in the system. We start the analysis in Chapter 6, by first deciding how to approach this problem. In Section 6.6.1, we compare to approaches that form the basis for the rest of the study. From the analysis performed in this section we concluded that the 'Integrated Approach' closely matches the reality in India. We show that the optimal fillrate that Logitech should aim for at the CDC level lies at 70%. If Logitech would set the fillrate at the CDC at this level it would minimize the total costs in each region, given that a Fillrate and Waiting time approach is used.

In Chapter 7 we performed a sensitivity analysis with the aim of finding relationships between input and output variables. The analysis performed shows us some interesting insights regarding parameters involved. For the demand rate we show that for every 5% change in demand the costs change with 3%. For the supplier lead-time we found that if Logitech was able to reduce the lead-time with 10%, approximately 2.1 days, the total costs would decrease with 4% on a monthly basis. One of the important findings of this study was related to the current KPI settings. Due to the low item value we saw that our tool would overstock quite considerably. In most cases the WIC was stocked approximately at the 90% level, whereas only 70% was necessary (Section 7.4.2 and 7.4.3). This leads us to believe that the current KPI levels do not match with reality. We show that the fillrate levels could be set considerably higher and the total costs would not be effected significantly. This would in turn have a positive effect on the satisfaction of consumers.

We investigate the effects of including a possible extension to the current system, hereby referring to lateral transhipments in Section 6.6.2. Performing that particular analysis showed us positions where potential savings could be achieved. One of the effects of including lateral transhipments is that the inventory at them main warehouses increases. This increase can be linked to the limited number of mains and the fact that average demand is overall quite high. However, introducing lateral transhipment is done with the knowledge that a cheaper emergency option becomes available. The possibility of this cheaper option has as effect that the total transportation costs decline. This decline is large enough to eliminate the holding cost increase resulting in a total cost decrease. Besides the positive effects on total costs we also paid attention to the effects it has on the service measures. As the introduction of lateral transhipment has no effect on the fillrate we focused on the waiting time service measure. What was evident is that including lateral transhipment in the system, would decrease the waiting time significantly. For the top 20 SKU's we recorded waiting time decrease for a majority of the items. This decrease could be as high as 40% in some cases. However, the largest decrease can be found for items that are requested less often. Additionally, we discovered that these changes in average waiting time were most noticeable in the region without a RDC, being the South region.

Furthermore, in Section 6.6.3 we study an extreme case where an item vs a system approach is compared. As the item value is low, this lead us to the believe that it might be a possibility to introduce the requirement that each item should match the service objectives. However, even with the low item prices it turns out that the savings could be as high as 180% if the system approach is used over the item approach. Introducing the XYZ approach is a good approach that lies in between the item and system approach. The XYZ approach can be used as a simplification of the system approach and provides the ability of assigning a minimum service requirement for each item

Overall we can conclude that we developed a model that provides insight into the working and the savings potential in the WIC strategy. Our analysis show that the service requirements could be increased significantly, while having insignificant effects on the total costs.

8.2 Recommendations

1. ***Implement the tool as a support for decision-making.***

We approached this study by assuming that Logitech was fully responsible for all actions taken in the supply chain. However in reality, Logitech's responsibility ends at the Chennai warehouse and they appointed a third party that would take of the remaining processes. Our approach has the advantage that it provides Logitech with a better understanding of the processes inside India. We suggest that Logitech will implement the tool in steps, due to the inexperience of Logitech and the lack of real-life data. For example, there is only seven months of usable demand data available. Furthermore, the ASP needs to be convinced of the usability of the tool, as a large portion of the tool operates in their responsible fields (RDC and WIC's).

However, as a first step we advise that Logitech focus on the CDC, as Logitech is responsible of stock provisioning to this stocking point. This action can be taken immediately, whereas the actions related to the lower echelons require the involvement of the ASP.

The tool could be used to compare the current method with the suggestions that the tool makes. We would expect that there would be cost differences. Because the tool would go for the optimal combination of SKU's that would lower costs taking in account a various number of parameters, whereas the current method only looks at the demand factor. The next step would be to use the tool fully and have discussions with the ASP based on the results that the tool provides. At this point the stock levels at the RDC's and WIC's, emergency costs, emergency lead-time are all unknown. However, if Logitech would be able to obtain this information, it could be used to compare their decisions with the ones made by the tool. This could lead to a healthy discussion between both parties based on real-life data and quantifiable numbers resulting from the tool.

2. ***Evaluate current Supply Chain.***

There are a number of points that we believe that should be addressed in the current supply chain settings.

Number of WIC's. In January '15 48 WIC were opened across the whole of India, seven months later we can evaluate the first half year returns. After the initial start-up period of the WIC's, the months January and February, the number of returns were increasing each week, due to a more consumers learning about the WIC's. There are large differences between the number of returns per WIC, there are WIC's that see dozens of consumers each day and WIC that only have seen a handful of consumers during the first 7 months. We suggest that the WIC that faced hardly any demand during the first 7 months be abandoned. For example, the city Salem (South-India), Aurangabad (West-India) faced respectively 22 and 30 units demand in 7 months. Due to low demand arriving at these WIC's and the low service requirements at these C-class cities, it seems a better idea would be to close these centres and install drop-off points or refer these consumers to nearby cities.

Current Service requirements. In our analysis in Chapter 6 and 7 we noticed that our tool would over stock in some cases, meaning that the tool would stock more than required to meet a service measure. After analysing this behaviour, this occurred due to the low value of the items. The first step in our algorithm consists of increasing the number of item stocked as long as the costs do not rise. Due to the low value of the items, the costs of holding them on stock are quite low. Whereas, the cost of an emergency shipment is considerably higher. So, in the first step our algorithm would decide to stock more than might be necessary. From the sensitivity analysis performed we can deduce that the fillrate measures should be set at 90%. This increase would not harm the total costs.

Which SKU's to include in your analysis. One of the questions we asked our self was, which items should be included in our analysis, see Section 6.2. This is an important question to ask as the number of SKU's that are currently being sold in India is significantly lower that the number of different SKU's that are being returned. Items

that are not returned often could be excluded from the analysis, due to their limited contributed towards the service requirements
We suggest that Logitech focuses on the SKU's that are returned most often. From our analysis we know that the five largest SKU's account for 54% of the returns. The 63 SKU's that have the largest return volume account for 95% of the returns. In order to reach the full 100%, we need to add 90 more SKU's. These number show that, given the current low service requirements, Logitech should place more emphasis on focusing on the items that are returned more often. For the other items, Logitech might be able to switch the returned item with a newer model or a financial reimbursement can be made.

Investigate the real costs. In our approach we could not get a view of the real shipping costs within the country. The ASP is responsible for these decisions and the costs for these activities are included in the service fee that Logitech pays. In order to get better results from the tool, we suggest requesting this information from the third party and use them for the tool. In the end the usefulness of the tool depends on the accuracy of the input data.

3. ***Use tool in other regions.***

We approached the problem in the first chapters by generalizing the problem and disjoining it in smaller blocks. By addressing the problem in this way, we increase the general usability of the developed model outside of Logitech and increase the usefulness outside of India. The WIC warranty service model is used in other AP regions as well, China and South-Korea, but the supply chain differs. In India we have regions that have RDC's and a region without a RDC. Due to our disjoining in smaller blocks approach, the model could be build up for other regions quite easily. For example, in the case that there are two regions, one with a RDC and one without, the tool could be used in that case the regions North and South both fill this description. The remaining regions East and West should be left blank and will be left out of the equation. In China, there are no RDC's in the supply chain, which again can be associated with the South region. Leaving the other locations blank would make the tool usable in this region.

8.3 Model Extensions

The models that we developed can be used to determine the necessary stock to meet the service demand. However, the models have their limitations due to assumptions and the simplification of the reality. Therefore, we describe some models extensions that are possible and will improve the (future) usability and performance of the model.

- In our model, we assume an adjusted one-for-one replenishment policy for all locations. In reality, all locations have a review period in order to keep costs down. An interesting extension to the one-for-one replenishment strategy would be the use of batching at all locations. With batching both the size and combination of items are the most significant decision points. (Basten & van Houtum, 2014) discuss several papers that include batching at different levels. One could start by including batching at only the central warehouse, as proposed by (Topan, Bayindir, & Tan, 2010).

- In this study we address the opening of physical WIC and how they should be stocked. However, in today's world a majority of the products are sold online, and these people expect that their right for warranty can be claimed online. In India this is not a possibility yet, however this is one of the future plans. The scope of work for India discussed that in the future drop-off points would also become a part of the supply chain. This tool could include these drop-off points by including the demand stream for these items and directing to the right stocking point. The 'extra' demand stream that is formed by these online returns should be included in the existing demand stream. By redirecting this demand stream to the right locations, it is possible to include this in the current model, with very little adjustments.

- Currently in our model all items have the same criticality. Our analysis show that there are large differences between item based on demand and costs. We believe that the model could be more efficient by implementing a criticality scale (high-low-medium), which would place more emphasis on the items that lie in the high returns scale. Implementing this model extension can be done on multiple levels, besides the item level. In our system we have WIC with different service measures based on their class. Including these differences into the model would be an interesting extension. This would for example, lead to situation where stock is reserved for cities that have a higher criticality. One could for example reserve stock at the CDC and RDC that is explicitly meant for the A-Class cities. Deshpande et al. (2003) designed a 'separate stock' policy that differentiate between customer classes by holding separate stocks for each customer class.

8.4 Further Research

During the development and implementation of the different alternatives and the greedy procedure, we faced some issues which we will discuss and recommend to do further research on.

- It is not clear what the best method is to solve a multi-echelon system. In this study, we decompose this system in subsystems and solve these separately. We consider a top down approach where we consider the item fillrate at the upper echelon and update the item lead-time to the lower echelons subsequently. In our current method, we lose some efficiency because we optimize each locations separately. Future research should focus on developing an efficient and accurate approximation method for a full multi-echelon system. Optimizing several echelons at the same time will be a more efficient.

- In our approach we take a shortcut to include the risk of SKU's becoming obsolete, by increasing the holding costs with a factor to account for this risk. However, we apply this factor to each SKU and do not differentiate between products. We suggest that Logitech looks into the possibility of using the product life cycle and base the EOL risk factor on the position of the SKU in the life cycle. In this case products that are closer to their EOL should receive a higher risk factor, whereas newer products should be given a lower risk factor. If these settings are taken in account, the tool will see that products that are new are cheaper to stock in comparison to products that are close to their EOL. If Logitech will apply this method the risk of an item, in India, becoming obsolete is lower. Nevertheless, this is a hypothesis and should be tested.

8.5 Contribution to Scientific Field

One of the main purposes of a Master's thesis is to apply theory in practice. In this section we address our contribution to the current scientific field regarding spare parts. In this study we designed a mathematical model based on two scientific papers, the papers of Kranenburg (2006) and Axsäter (1993). The paper of Kranenburg(2006) form the basis of this study, in his paper he shows how to build up a spare parts model in the case of continous review. However, in our case we are dealing with periodic review, the paper of Axsäter (1993) is used Axsäter (1993) to transfom this continoous model into a periodic review model. This study contributes to the current spare parts scientific field on the following points. Fist, papers regarding spare parts in a periodic review settings are very rare. In this study we argue in which cases a periodic review is prefered over a contionous review model. As, their hardly any papers combining spare parts and periodic review, we believe that this study contributes on that level. Second, there is no consensus on how to correctly link different echelons as stated by Basten & van Houtum (2014). In Section 6.5.1 we test two different approaches how the different echelons could be linked. We concluded that the top down approach, where we first solve the upper echelons and using fillrate information at this level we update the lead-time to the lower echelons. We argue why we believe this is the correct way of connecting the different echelons.Third, in this study we show the added value of having a RDC present in a region. Due to our supply chain design we are able to quantify the added value of certain decisons in cases whether there is a RDC or not. Wit the the use of our tool one is able to calcultate in a matter of minutes the added value of a regional warehouse. As we show in Section 6.5.2 the added value of lateral transhipment is larger if the region lacks a RDC.

8.6 Tool Implementation

In order to have a successful implementation of the tool, we have to create a basis of support. Building a basis for support for the use of tool started during the Master Thesis project. During the development of the tool we consulted and discussed with the responsible persons in the After Sales department. We had interactive discussions with employees, from both the Nijmegen and India locations, who eventually would be working with the tool. During these discussion sessions, the main goal is to explain the relevance and potential benefits of the tool. Furthermore, the persons that will be using the tool should be instructed how the tool works. We create a user manual that will describe thoroughly what the tool is capable of and how changes can be made if necessary. In the user manual we show how to prepare the input date, subsequently we explain the differences between the approaches that can be used to determine SKU re-order levels. Besides this manual, we set up training sessions in order to explain the use of the tool in detail. We show examples and explain how to draw conclusions from the results.

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Lists of Concepts

Aggregate Service Measures see system approach.

Base stock policy is also known as the one-for-one replenishment policy, because once a SKU i is used to fulfil a consumer order, immediately a new SKU i is ordered to replenish the warehouse.

Echelon is a layer in the supply chain network that consists of stocking points with the same function.

Emergency Shipment is defined as a shipment by either the central or the regional DC in case the WIC's is unable to meet the demand for SKU i.

Fillrate defines the fraction of demand that van be met from stock, it can be measured both on the item and WIC level.

Greedy Algorithm is an approximate technique and is often referred to as the 'biggest-bang-for-the-buck' method. The method iteratively chooses the alternative that provides the largest increase in service measure while having the lowest cost increase until a certain stopping criterion is reached.

Lateral transhipment is defined as the provisioning of a part by a stocking point in the same echelon to a consumer of another stocking point when out of stock.

Item Approach is an inventory control mechanism that meets the requires that each item meets the service measures separately.

Regular shipment is the first option to fulfil demand by the stocking locations.

System Approach is an inventory control mechanism that sets a service measure for a whole stocking point and aims to reach it by a combination of all products.

Turn-Around-Time is defined as the time required to fulfil a consumer demand.

Verification is defined as the process to analyse whether the model is build right.

Validation is defined as the process of reaching an acceptable level of confidence that the model is a reasonable representation of the actual system. That the model is reproduces system behaviour with enough confidence to satisfy analysis objectives.

Waiting Time is used to define the average time needed to fulfil consumer demand, just like the fillrate this can be measured on the item and WIC level.

List of variables

Sets

I	:= Set of Stock Keeping Units (SKUs), indexed by $i = 1,2, \dots, \lvert I \rvert$	
N	:= Set of warehouses, $N = N_w \cup N_R \cup N_C$	
N_C	:= Set of Central Warehouses	
N_R	:=Set of Regional Warehouses	
N_W	:= Set of Walk-In-Centre's	

Input Variables

R_C	:= Review period at Central DC	(days)
R_R	:= Review period at Regional DC	(days)
R_W	:= Review period at WIC's	(days)
m_{i,n_w}	:= Poisson demand rate for SKU $i \in I$ at WIC $n_w \in N_W$	(#/month)
M_{n_w}	:= Total demand for all items $i \in I$ at WIC $n_w \in N_W$	(#/month)
m_{i,n_r}	:= Poisson demand rate for SKU $i \in I$ at WIC $n_r \in N_R$	(#/month)
M_{n_r}	:= Total demand for all items $i \in I$ at RDC $n_r \in N_R$	(#/month)
m_{i,n_c}	:= Poisson demand rate for SKU $i \in I$ at WIC $n_c \in N_C$	(#/month)
M_{n_c}	:= Total demand for all items $i \in I$ at CDC $n_c \in N_C$	(#/month)
$\hat{\beta}_{n_w}^{obj}(\hat{S})$	:= Aggregate Fill Rate objective at WIC $n_w \in N_W$	(%)
$\hat{\beta}_{i,n_w}^{obj}(\hat{S}_i)$	:= Fillrate objective for SKU $i \in I$ at WIC $n_w \in N_W$	(%)
$\widehat{W}_{n_w}^{obj}(\hat{S})$	:= Aggregate Waiting Time objective at WIC $n_w \in N_W$	(days)
$\widehat{W}_{i,n_w}^{obj}(\hat{S}_i)$	:= Waiting Time objective for SKU $i \in I$ at WIC $n_w \in N_W$	(days)
C_{N_C,N_R}^{reg}	:= The transportation cost for a regular shipment for SKU $i \in I$ from central warehouse $n_c \in N_C$ to regular warehouse $n_r \in N_R$	($/item)
C_{N_C,N_W}^{reg}	:= The transportation cost for a regular shipment for SKU $i \in I$ from central warehouse $n_c \in N_C$ to WIC $n_w \in N_W$	($/item)
C_{N_R,N_W}^{reg}	:= The transportation cost for a regular shipment for SKU $i \in I$ from central warehouse $n_r \in N_R$ to WIC $n_w \in N_W$	($/item)
$C_{n_w}^{c.em}$	:= The transportation costs for an emergency shipment for SKU $i \in I$ from central warehouse $n_r \in N_R$ to WIC $n_w \in N_W$	($/item)
$C_{n_w}^{r.em}$	:= The transportation costs for an emergency shipment for SKU $i \in I$ from regional warehouse $n_r \in N_R$ to WIC $n_w \in N_W$	($/item)

$C^{lat}_{n_w,k}$	:= The transportation costs for an lateral emergency shipment for SKU $i \in I$ from main warehouse $n_k \in N_W$ to WIC $n_w \in N_W$	(\$/item)
$t^{reg}_{N_C,N_R}$	:= The transportation time for a regular shipment for SKU $i \in I$ from central warehouse $n_c \in N_C$ to regular warehouse $n_r \in N_R$	(days)
$t^{reg}_{N_C,N_W}$	:= The transportation time for a regular shipment for SKU $i \in I$ from central warehouse $n_c \in N_C$ to WIC $n_w \in N_W$	(days)
$t^{reg}_{N_R,N_W}$	:= The transportation time for a regular shipment for SKU $i \in I$ from central warehouse $n_r \in N_R$ to WIC $n_w \in N_W$	(days)
$t^{c.em}_{n_w}$	:= The transportation time for an emergency shipment for SKU $i \in I$ from central warehouse $n_r \in N_R$ to WIC $n_w \in N_W$	(days)
$t^{r.em}_{n_w}$	:= The transportation time for an emergency shipment for SKU $i \in I$ from regional warehouse $n_r \in N_R$ to WIC $n_w \in N_W$	(days)
$t^{lat}_{n_w,k}$	:= The transportation time for an lateral emergency shipment for SKU $i \in I$ from main warehouse $n_k \in N_W$ to WIC $n_w \in N_W$	(days)
c^h_i	:= Interest percentage for holding one unit of item on stock	(\$/month)
P_i	:= Price of SKU $i \in I$	(\$)

Intermediate variables

$\hat{S}_i$	:= Vector of the base stock levels for SKU $i \in I (:= (S_{i,1}, \dots, S_{i,n}))$	
$\hat{S}$	:= Vector of the base stock levels$(:= (S_1, \dots, S_{\lvert I \rvert}))$	
e_{n_w}	:=Row vector with size $\lvert N_W \rvert$ with the n_w-th element equal to 1 and all other elements equal to 0	
$\Delta\beta(i, n_w)$	:= Increase in fillrate when one SKU $i \in I$ added at stockpoint n_w	
$\Delta C(i, n_w)$	:= Increase in costs when one SKU $i \in I$ added at stockpoint n_w	
$R(i, n_w)$	:= Ratio between decrease in distance and increase holding costs	
$\beta_{i,k}(\hat{S}_i)$	:= Fraction of demand of SKU $i \in I$ at main WIC k that is delivered immediately upon request.	(%)
$\alpha_{i,k}(\hat{S}_i)$	:= Fraction of demand of SKU $i \in I$ at main WIC k that is delivered from the main warehouse $k \in N_W$ as an emergency shipment	(%)
$\theta_{i,k}(\hat{S}_i)$	:= Fraction of demand of SKU $i \in I$ at main WIC k that is delivered by means of central emergency shipment from central warehouse $n_c \in N_C$	(%)
$\gamma_{i,k}(\hat{S}_i)$	:= Fraction of demand of SKU $i \in I$ at main WIC k that is delivered by means of regular emergency shipment from central warehouse $n_r \in N_R$	(%)
$\beta_{i,n_w}(\hat{S}_i)$	:= Fraction of demand of SKU $i \in I$ at WIC n_w that is delivered immediately upon request.	(%)

$\theta_{i,n_w}(\hat{S}_i)$	:= Fraction of demand of SKU $i \in I$ at WIC n_w that is delivered by means of emergency shipment	(%)

Output Parameters

$C(\hat{S})$	:= Total System Costs off all SKUs	(\$/period)
S_{i,n_w}	:= Base stock level for SKU $i \in I$ at WIC $n_w \in N_W$	(items)
S_{i,n_r}	:= Base stock level for SKU $i \in I$ at regular warehouse $n_r \in N_R$	(items)
S_{i,n_c}	:= Base stock level for SKU $i \in I$ at central warehouse $n_c \in N_C$	(items)
$\beta_{i,n_w}(\hat{S}_i)$	:= Fraction of demand of SKU $i \in I$ at WIC n_w that is delivered immediately upon request.	(%)
$\beta_{n_w}(\hat{S})$	:= Fraction of demand at WIC n_w that is delivered immediately upon request.	(%)
$\theta_{n_w}(\hat{S})$	:= Fraction of demand at WIC n_w that is delivered from the regional warehouse as an emergency shipment	(%)
$\alpha_{n_{w,k}}(\hat{S})$	:= Fraction of demand at WIC n_w that is delivered from the main warehouse $k \in K$ as an emergency shipment	(%)
$\gamma_{n_w}(\hat{S})$	:= Fraction of demand at WIC n_w that is delivered from the central warehouse as an emergency shipment	(%)
$W_{i,n_w}(\hat{S}_i)$	:= Mean Waiting Time of SKU $i \in I$ at WIC n_w	(days)
$W_{n_w}(\hat{S})$	:= Mean Waiting Time at WIC n_w	(days)
$CT_{n_w}^{reg}(\hat{S})$	:= Regular Shipment Costs at WIC n_w	(\$/period)
$CT_{n_w}^{em.c}(\hat{S})$	:= Regular Shipment Costs at WIC n_w	(\$/period)
$CT_{n_w}^{em.r}(\hat{S})$	:= Emergency Shipment Costs at WIC n_w	(\$/period)
$CT_{n_w}^{lat}(\hat{S})$	:= Lateral Shipment Costs at WIC n_w	(\$/period)
$CH_{n_w}(\hat{S})$	:= Holding Costs at WIC n_w	(\$/period)

Lists of Abbreviations

ABC	Activity Based Costing
AP	Asia Pacific
ASP	Authorized Service Partner
CDC	Central Distribution Centrum
DC	Distribution Centre
EMEA	Europe, Middle East and Africa
EOL	End of Life
EOQ	Economic Order Quantity
FCFS	First Come First Served
KPI's	Key Performance Indicators
METRIC	Multi-Echelon Technique for Recoverable Item Control
OEM	Original End Manufacturer
RDC	Regional Distribution Centrum
TAT	Turn Around Time
WIC	Walk-In-Centre

Appendices

Appendix A – Number of WIC per Region visualized

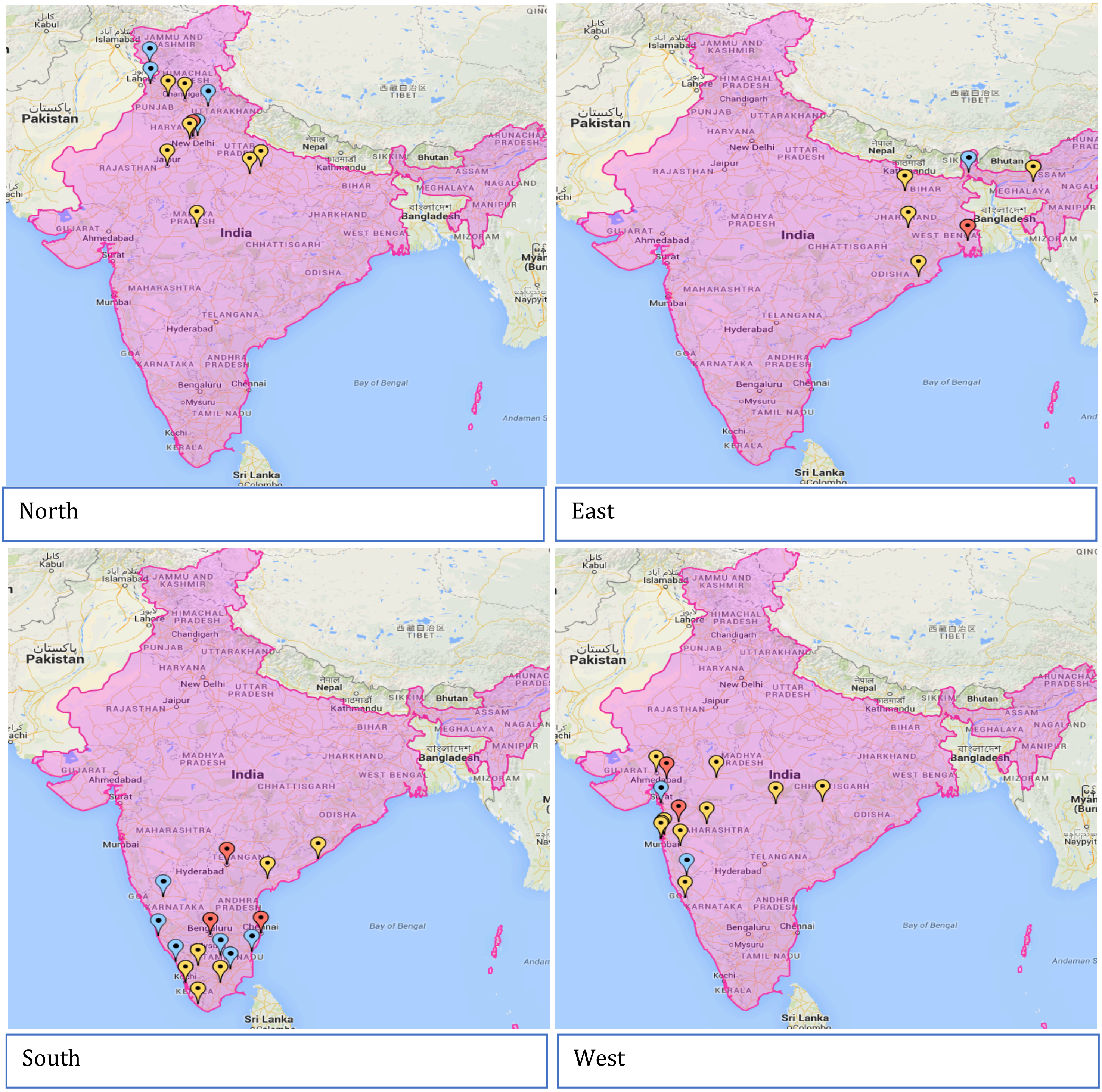


Figure 44: Geographical Location of WIC's in India

	North	Class	East	Class	South	Class	West	Class
1	Amritsar	C	Bhubaneshwar	B	Bangalore	A	Ahmedabad	B
2	Bhopal	B	Guwahati	B	Calicut	C	Aurangabad	B
3	Chandigarh	B	Kolkata	A	Chennai	A	Baroda	A
4	Dehradun	C	Patna	B	Cochin	B	Goa	B
5	Ghaziabad	C	Ranchi	B	Coimbatore	B	Indore	B
6	Gurgaon	B	Siliguri	C	Hubli	C	Kolhapur	C
7	Jaipur	B			Hyderabad	A	Mumbai	B
8	Jammu	C			Madurai	B	Nagpur	B
9	Kanpur	B			Mangalore	C	Nashik	A
10	Lucknow	B			Pondicherry	C	Pune	B
11	Ludhiana	B			Trichy	C	Raipur	B
12	New Delhi	A			Trivandrum	B	Surat	C
13	Varanasi	C			Vijaywada	B	Thane	B
14					Visakapatanam	B	Mumbai-Lamington Road	B
15					Salem	C		

Table 25: Distribution of WIC's over Region

Appendix B – Return Characteristics

B.1 Return Volume

We have data regarding the returns during the period February '14 until April '15, during these 14 months 69.160 units were returned. This Section focusses on analysing the returns, that occurred during this period, by plotting three graphs.

Figure 42, Graph A.
This graph depicts the number of returns per SKU during a period of a year. Immediately it becomes clear that only a small number of SKU have a higher return rate of 1000. There are 12 SKU's with a return volume above a 1000 units, which coincides with 4.5% of the total number of SKU's. The highest return volume, 11.318 units, occurs for the 'M100R'. Besides the striking number of high returns, it also becomes clear that the largest percentage of the SKU's have a return volume lower than a 100. In order to see what is going on with the majority of the SKU we change the maximum of the x-axis to a 100 and plot again.

Figure 42, Graph B
In this graph we show that 213 SKU's (80%) have a return volume lower than 100 units, and it becomes clear that a majority of the SKU's has a return volume lower than 10 units in approximately 148 SKU's have a return rate lower than 10, this fraction equals 53% of the total number of SKU's.

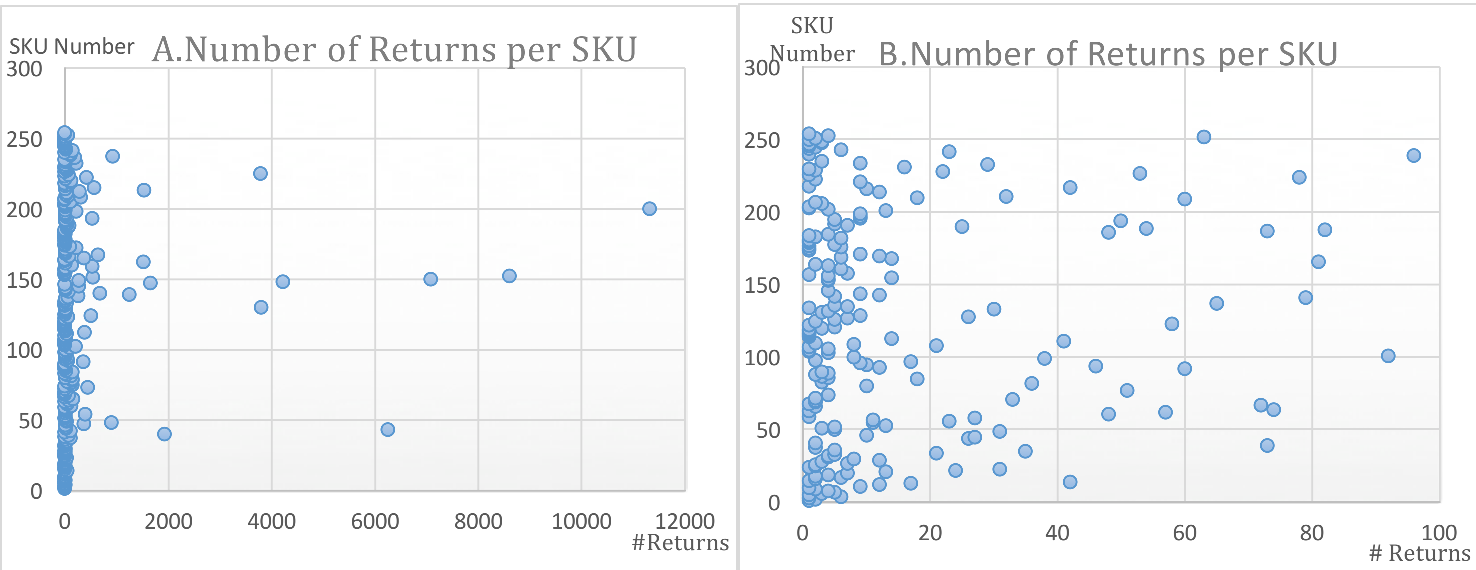


Figure 45: Return Analysis WIC, Volume

In Figure 43 graph C, we show how much of the SKU contribute to the total number of returns. The SKU's are sorted high-low and it becomes clear that six SKU's are responsible for 50% of the returns. In order to reach the 30% level we need 29 SKU's, while 50 SKU's are needed to reach the 95% level. From the three graphs, we concluded that there are large difference between SKU's; from graph C concluded that 2% of the SKU's are responsible for 50% of the returns.

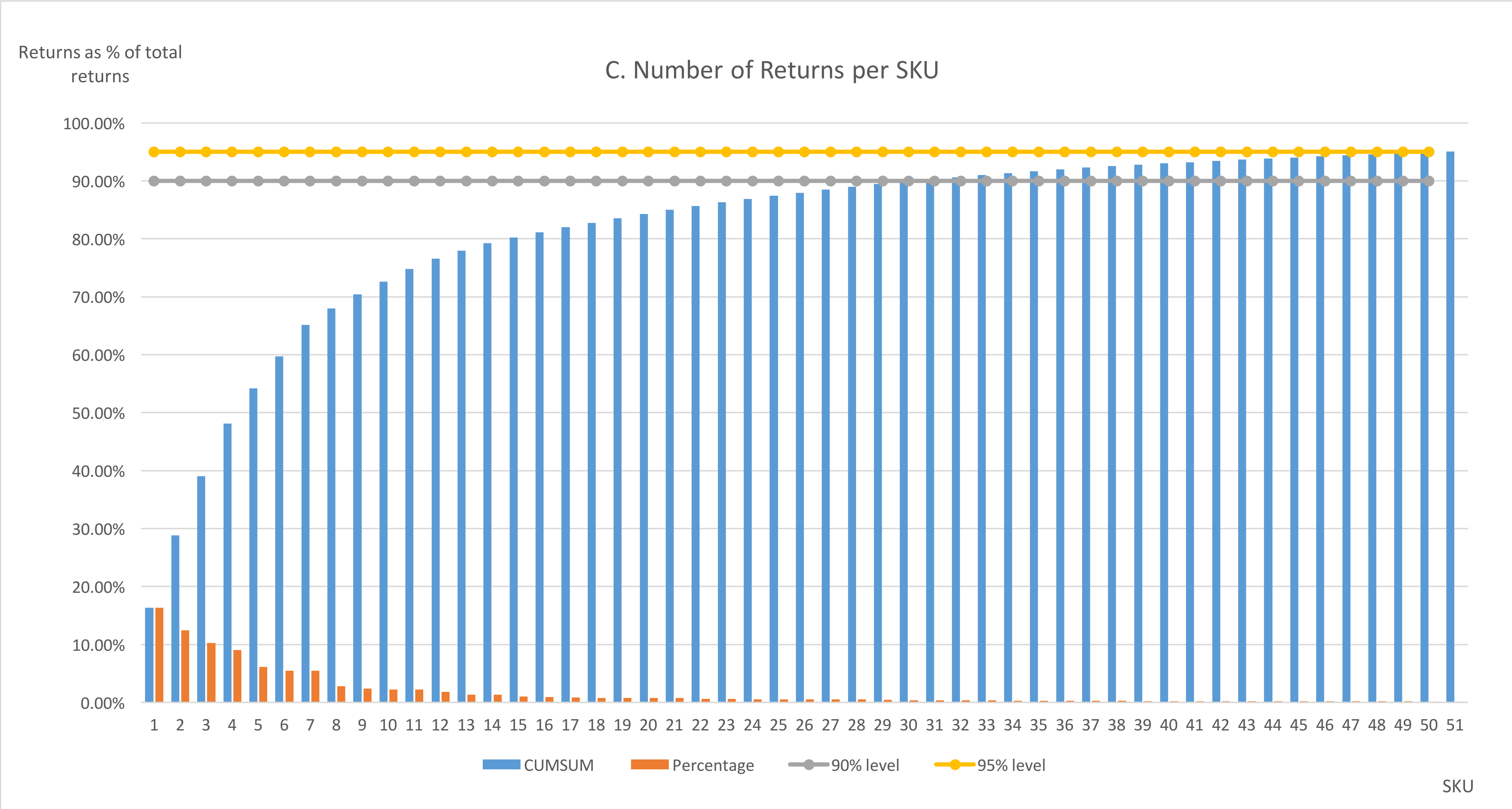


Figure 46: Top 50 SKU based on returns

B.2 Return Costs

In this Section we first look at the average price of the SKU's and by incorporating the previous Section we can show the costs that Logitech faces for replacing the defective items. In figure 44, two graphs have been plotted. The product price refers to the item costs, i.e. the costs for Logitech to make the item. In graph A it becomes clear that only a small amount of SKU's have an item cost higher than $XX, this means that we are dealing with relatively inexpensive items. The average item costs comes down to $XX.

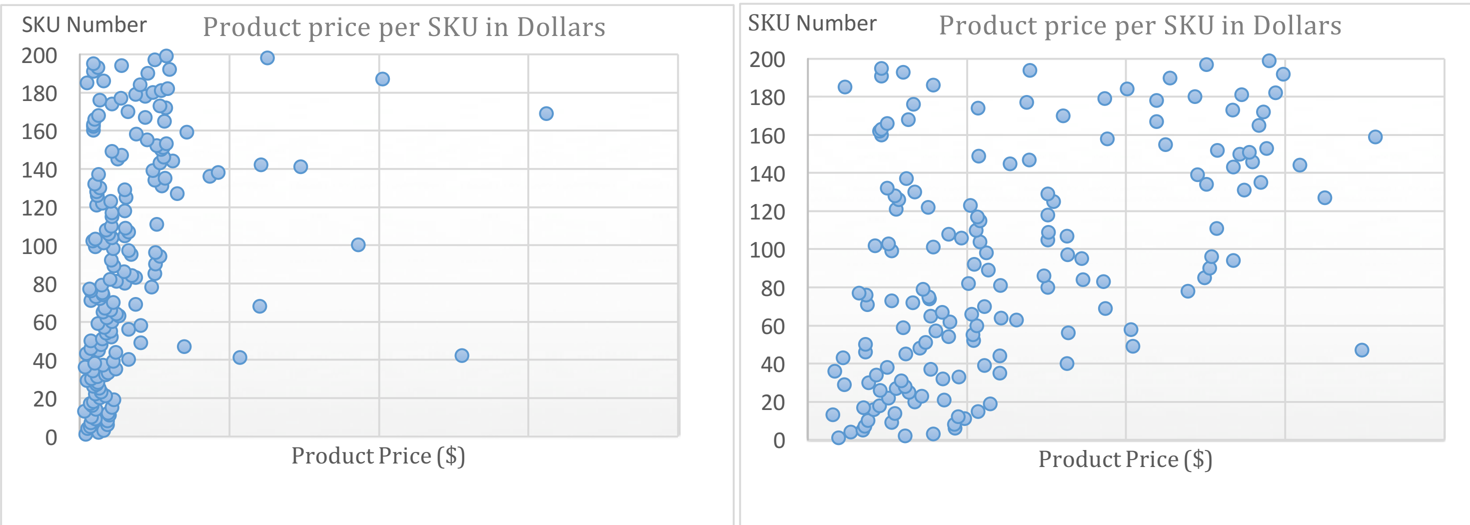


Figure 47: Return Analysis, Costs

It should be noted that we use the same numbering of the SKU' as in the previous graphs. It becomes clear, from figure 47, that the items with a low SKU number are cheaper than SKU's with a higher number. We may conclude that items that have a higher return volume are products which are quite cheap. If we take the average item costs of the 50 SKU's which are responsible for 95% of the returns, we conclude that this average of $XX is lower than the average item costs.

Appendix C – Analysis of Demand distribution per period

In our system we make the assumption that demand follows a Poisson distribution. A Poisson process is widely accepted in literature for describing the number of failures of an item per unit time. This is due to the time between failures can be described by an exponential distribution, then the number of failures in a certain period is described by a Poisson distribution. Because demand rates for spare parts are often related to part failures and they are low and erratic, the Poisson process can often be used to describe this demand.

The demand on item level at the warehouses has been analysed with a χ^2-goodness of fit test to check if the Poisson process can be proved. The Chi-square goodness-of-fit test is used to test the fit between the Poisson distribution and the registered demand. With the following hypothesis, we will try to reject H_0 in favour of H_1. In the case we fail in rejecting the null hypothesis, we cannot say it is not from a Poisson distribution and therefore it is reasonable to say that the data follows a Poisson distribution.

H_0: Demand data is from a Poisson distribution
H_1: Demand data is not from a Poisson distribution

We use a significance level of 5%. This means that the chance of rejecting H_0 is smaller than 5%. In our analysis we include demand from the period January 2015 till July 2015. The Chi-square test requires a minimum demand per period, in order to obtain reliable results. As we perform all our analysis on a monthly level we perform the Chi-square goodness of fit test on a monthly level as well.

The procedure uses discrete demand data and arranges it into several value classes. For each class the observed frequency is observed. Based on the hypothesized distribution an expected frequency is calculated for each class. Subsequently, the Chi-square statistic is used to determine whether the hypothesized distribution differs significantly from the actual distribution. The hypothesis that the distribution of the population is the hypothesized distribution is rejected if the chi-square test statistic is found to be significant.

The Logitech situation complicates the process of performing a Chi-square test. In reality two types of demand streams arrive at the WIC's, demand from the retailers and the end-user. Demand from the retailer consist of consumers that go to their respective retailer and expect them to go to a WIC to deal with the warranty claims. The retailer collects the claims in a whole month and makes a trip once a month to the closes WIC. Having this process distorts the real demand flow. This is shown in table 26, where we set out the demand arrivals per day, and the frequency of their occurrence.

Demand arrivals	Frequency
0	12
1	3
2	2
3	1
6	2
12	1
13	1
20	1
25	1

Table 26

We see significant differences between the demand process due to the arrival of accumulated demand from the retailers. When we perform a Chi-square analysis in this setting, we will not be able to confirm that the items follow a Poisson process. Unfortunately, we can not test the demand arrival process at the retailers' locations, in order to test our hypothesis. At the WIC's we can test the demand process by only focusing on de end-users that arrive at the WIC.

48 SKU's do not have sufficient demand to perform a Chi-square goodness of fit test. For the remainder of the SKU's, 104, we test the fit. Hereby, we see that for 65% of the SKU's we can not reject the Poisson distribution. These parts are often SKU that have low to medium demand. For the service parts with extremely high demand, the Poisson distribution could be rejected. Regrettably, no suitable demand distribution could be found for these items.

Appendix D – Evaluation Algorithm

This Section provides an explanation for algorithm 1 and 2 discussed in chapter xx. These algorithms formally describe the evaluation method of the performance of the system. Kranenburg (2006) designed the algorithm; we will follow his explanation in this appendix. We distinguish two types of WIC's, main and regular, shortly referred to as mains and regulars, respectively.

Decoupling the regulars from the mains

The first reduction step aims to decouple the regulars from the mains. The connection between the regular $n_w \in N_W \backslash K$ and all mains $k \in K$ is that the main is able to both send and receive lateral transshipments, whereas the regular can only receive lateral transhipments.

Demand for a lateral transhipment occurs when a regular n_w faces consumer demand for SKU i at a moment that SKU i is out of stock. In the approximation method, we assume that the overflow demand process at regular WIC $n_w \in N_W \backslash K$ behaves as a Poisson process that constitutes an additional demand stream at main k_j. In the extreme case regular WIC n_W has $S_{i,n_w} = 0$ the overflow demand follows a Poisson process as all demand is forwarded to main k_{n_w}.

The goal of decoupling the regulars from the mains is that we can analyse each regular individually. Having this assumption reduces the complexity of the analysis, it should be noted that this is only in the special case of partial pooling. This case was first introduced by Kranenburg and van Houtum (2009). We do not have to analyse a Markov process with a N-dimensional state space. Instead, we can now first focus on the fill rates at the regulars, and then proceed forward to the mains. The mains are left with a Markov process with a $|K|$-dimensional state space only. Finally, we can look at the other performance measures at the regulars (Waiting time), using the output of the analysis of the mains.

In the approximate evaluation, we make use of the loss probability in the Erlang loss model. We determine the probability that a WIC faces consumer demand at a moment it is out of stock. Let $L(n, p)$ denote this probability:

$$L(n, p) = \frac{\rho^n / n!}{\sum_{x=0}^{n} \rho^x / x!},$$

where n represents the number of servers in the system and ρ the occupation rate of the server.

Each regular warehouse is analysed separately using the Erlang loss model. The process in a regular $n_w \in N_W / K$ can be described as an Erlang loss system with demand rate M_{i,n_w}, S_{i,n_w}servers, and the mean replenishment time t^{reg} as a mean service time. The number of times of SKU i that are in stock in a regular WIC equals the number of empty servers in the Erlang loss model. This gives us $\beta_{i,n_w}(S_i)$(Which only depends on S_{i,n_w},

and not on the base stock levels at other local warehouses as) as $\beta_{i,n_w}(S_i) = 1 - L(S_{i,n_w}, M_{i,n_w} t^{reg})$. This formula determines the fill rates in the regular WIC exact.
Now we use our assumption, that the demand for lateral transhipment to regular n_w, can be modeled as demand at main k_{n_w} that follows a Poisson process, with rate $\left(1 - \beta_{i,n_w}(S_i)\right) M_{i,n_w}$. At this point we can analyze the system of mains, where each main $k \in K$ faces demand that follows a Poisson process which we define with parameter $\widetilde{M}_{i,k}$,

$$\widetilde{M}_{i,k} \coloneqq M_{i,k} + \sum_{n_w \in N_W | k_j = k} \left(1 - \beta_{i,n_w}(S_i)\right) M_{i,n_w}$$

The demand stream at mains includes both its own demand and the demand for lateral transhipments created at main k_{n_w} by the regulars that are assigned to this warehouse. From the analysis of the system of the mains we receive the values of the following parameters $\beta_{i,k}(S_i), k \in K$, $\alpha_{i,k,\tilde{k}}(S_i), k \in K, \tilde{k} \in K$, $\tilde{k} \neq k$ and $\theta_{i,k}(S_i), k \in K$.
As a last step, we can determine the remaining performance measure $\alpha_{i,n_w,k}(S_i), k \in K$, and $\theta_{i,n_w}(S_i)$ for all regulars $n_w \in N_W \backslash K$, based on the performance measures that we determined for the mains:

$$\alpha_{i,n_w,k}(S_i) := \left(1 - \beta_{i,n_w}(S_i)\right) \beta_{i,k_{n_w}}(S_i), \qquad k = k_{n_w}$$
$$\theta_{i,n_w}(S_i) \coloneqq 1 - \beta_{i,n_w}(S_i))\theta_{i,k_{n_w}}(S_i),$$

This finalizes the first reduction step, where we decoupled the regulars from the mains. The idea behind this decoupling lies in the goal of reducing the complexity of the analysis for the partial pooling situation. We do not have to analyse the Markov process for the regulars, but can analyse the regulars individually. At this point we are left with a Markov process with a $|K|$-dimensional state space only for the mains.

Analysing the Main WIC's

As we do not have a linkage between main WIC's this evaluation step is a simplification of the steps taken in the last paragraph. We analyse each main separately.
First, we will calculate $\theta_{i,k}(S_i), k \in K$ exactly. Given main WIC $k \in K$ with demand rates according a Poisson process with rate $\widetilde{M}_{i,k}$ and base stock levels $S_{i,k}$, the process in the aggregate system is as in the Erlang loss system with demand rate $\sum_{k \in K} \widehat{M}_{i,k}$, $\sum_{k \in K} S_{i,k}$ servers, and mean replenishment time t^{reg} as a mean service time, as the mains fully pool their inventory. The number of items of SKU i that are in stock in the aggregate system equals the number of empty servers in the Erlang loss model. Thus, we are able to calculate $\theta_{i,k}(S_i), k \in K$, as the Erlang loss probability of the aggregate system:

$$\theta_{i,k}(S_i) \coloneqq L\left(\sum_{k \in K} S_{i,k} \sum_{k \in K} \widehat{M}_{i,k} t^{reg}\right), \quad k \in K$$

In the approximate evaluation, each main WIC is analysed separately using the Erlang loss model. For each main $k \in K$, $\beta_{i,k}(S_i) \coloneqq 1 - L\left(S_{i,k}, \widehat{M}_{i,k} t^{reg}\right)$, and $\theta_{i,k_{n_w}}(S_i) = 1 - \beta_{i,k}(S_i)$. Which means that both $\beta_{i,k}(S_i)$ and$\theta_{i,k_{n_w}}(S_i)$ depend on $\widehat{M}_{i,k}$.

Appendix E- Verification and Validation

In this section we attempted to validate the model and tool that we created. There a number of opportunities to validate the system. In table 27 we show the different steps we take to validate our model. As a majority of the analysis are performed throughout the study we will refer to the particular Section that will satisfy our expected results. In this section we will focus on expectation 2. Item Costs.

Focus	Change	Expected result	Section
1. Lead-time	Increase Lead-time	The basestock levels should be higher, to be able to meet extra demand during longer lead-time.	7.3
2.Item costs	Increase/Decrease item costs of item x	Item x will be more/less stocked based on the item costs	Appendix E
3.Holding costs	Increase/Decrease holding costs of item x	Item x will be more/less stocked based on the holding costs	7.2
4.Demand	Increase/Decrease demand of item x	Item x will be more/less stocked based on demand	7.1
5.Lateral Transhipment	Difference between having lateral transhipment opportunity and not	In the case of Lateral Transhipments the holding costs at main WIC's will rise as they will stock more. Furthermore, the waiting time at the regular WIC's will be lowered due to the extra emergency option.	6.3

Table 27: Processes that will be validated

In order to test that our system would prefer to stock items that are inexpensive we design an example to test this phenomenon. In table 28, we show the demand per SKU per location.

SKU/Location	1	2	3
1	15	8	6
2	7	22	24
3	24	12	10
4	21	12	7
5	16	19	13
6	12	7	7
7	6	7	5
8	6	9	13
9	24	14	5
10	12	17	16

Table 28: Demand per SKU per Location

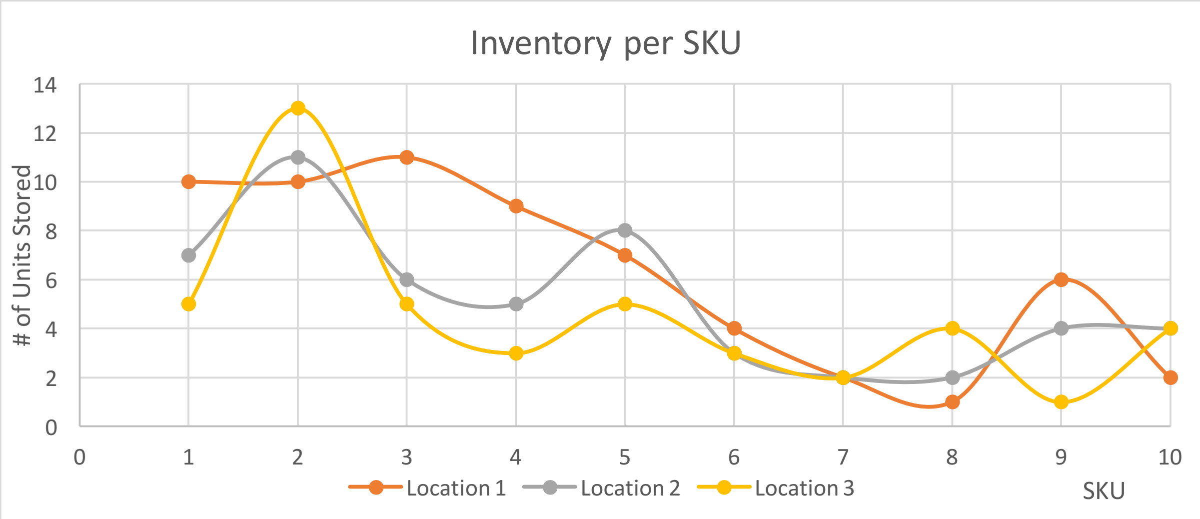


Figure 48: Inventory per item per location

Furthermore, the item costs are as followed, item 1 costs $1, item 2 costs $2 until item 10 which costs $10. What we would expect to see is that the number of items stocked for the lower SKU number should be high. And the number of items stocked for the higher numbered SKU should be low. In figure 45, we show the results from the tool.

We can clearly see that our expectations are confirmed by the tool results. Especially as the higher numbered SKU are asked more frequently, still the tool stocks as minimum as possible for these items. From this analysis we can conclude that this part of the tool works as it should. Again, for the remaining analysis we refer to table 27.

Appendix F – Case study Results

Approach 1 vs Approach 2

In figure 49, we plotted the basestock levels for SKU number 20 to 152, in order to compare the both approaches.

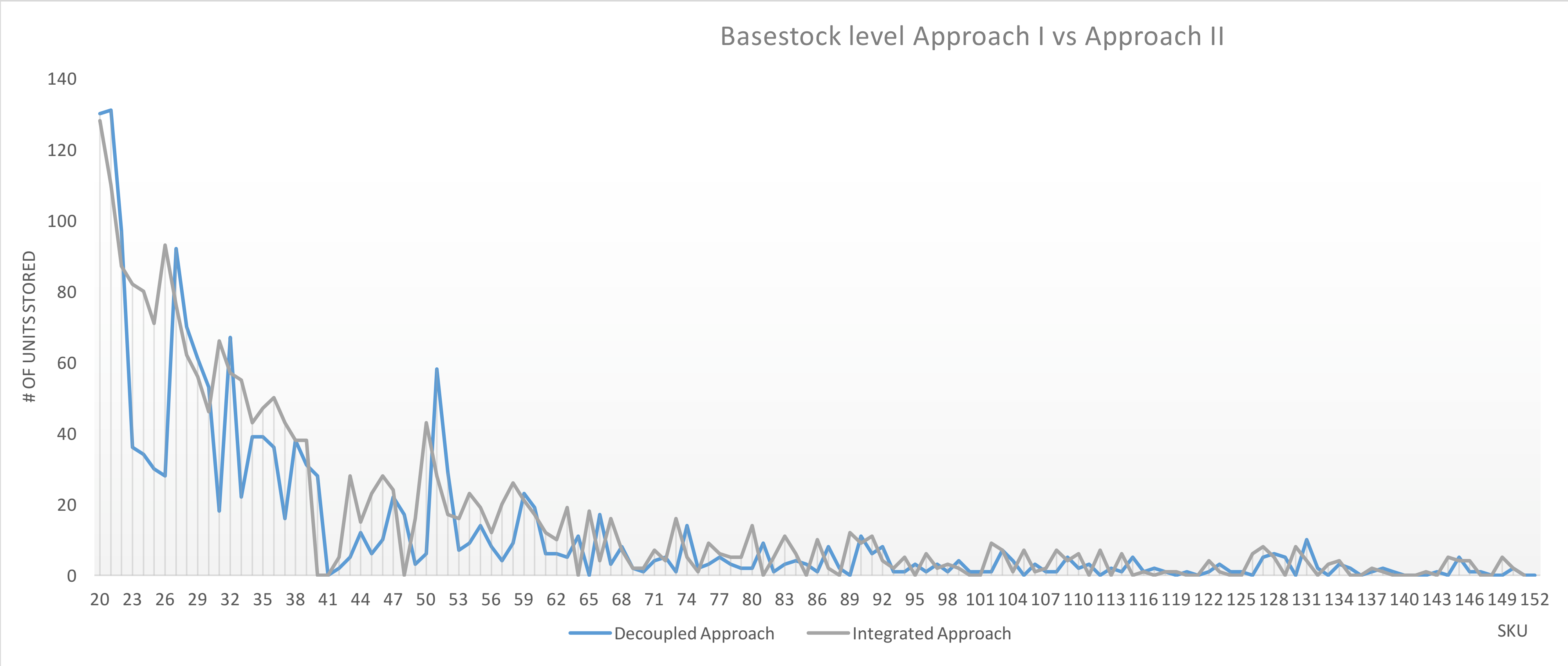


Figure 49: Basestock level for SKU 20 to 150

We visualize the change in both Total costs and Waiting time, by comparing approach 3 vs 4.

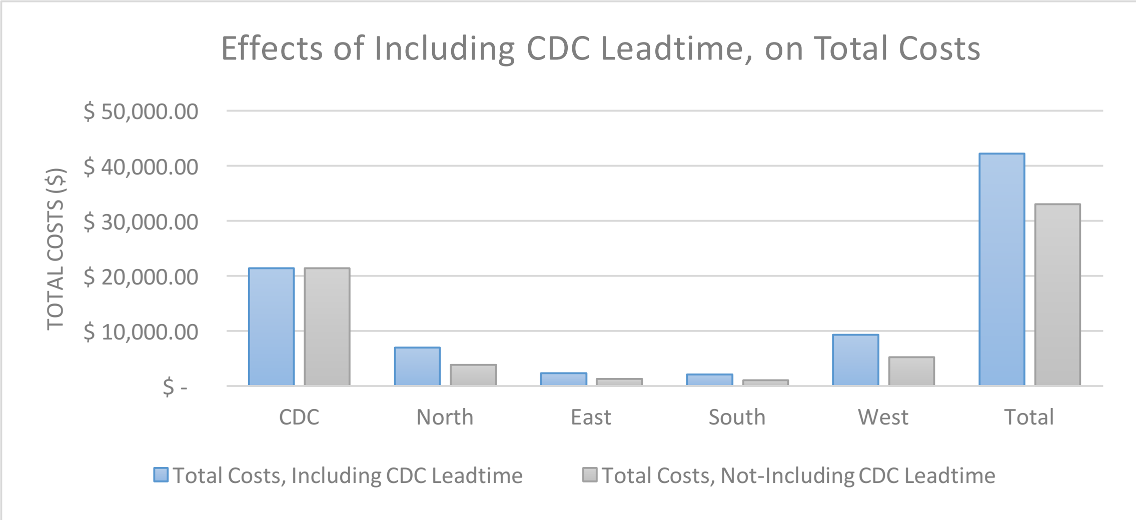


Figure 50

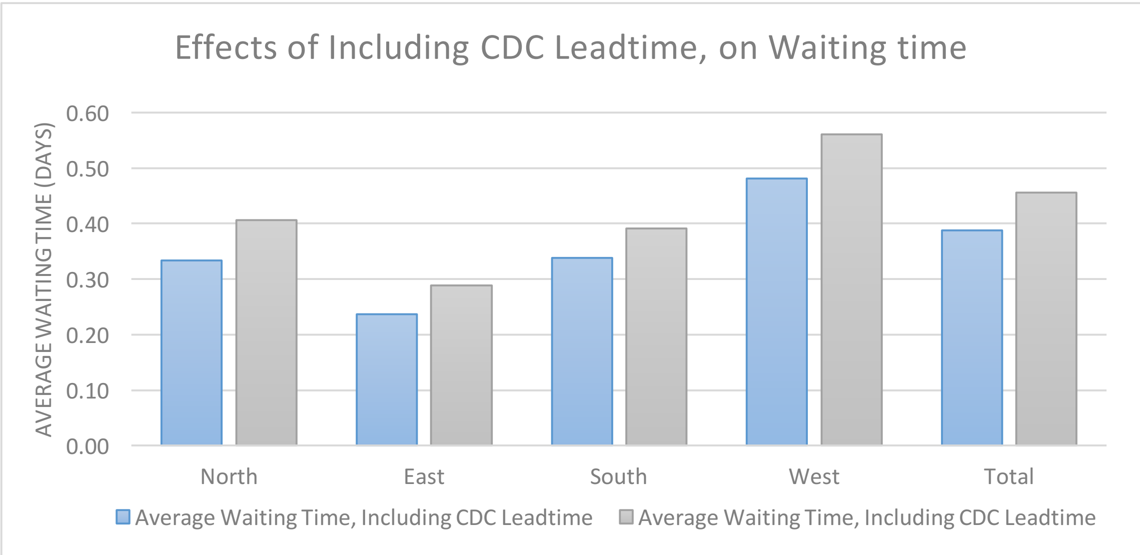


Figure 51

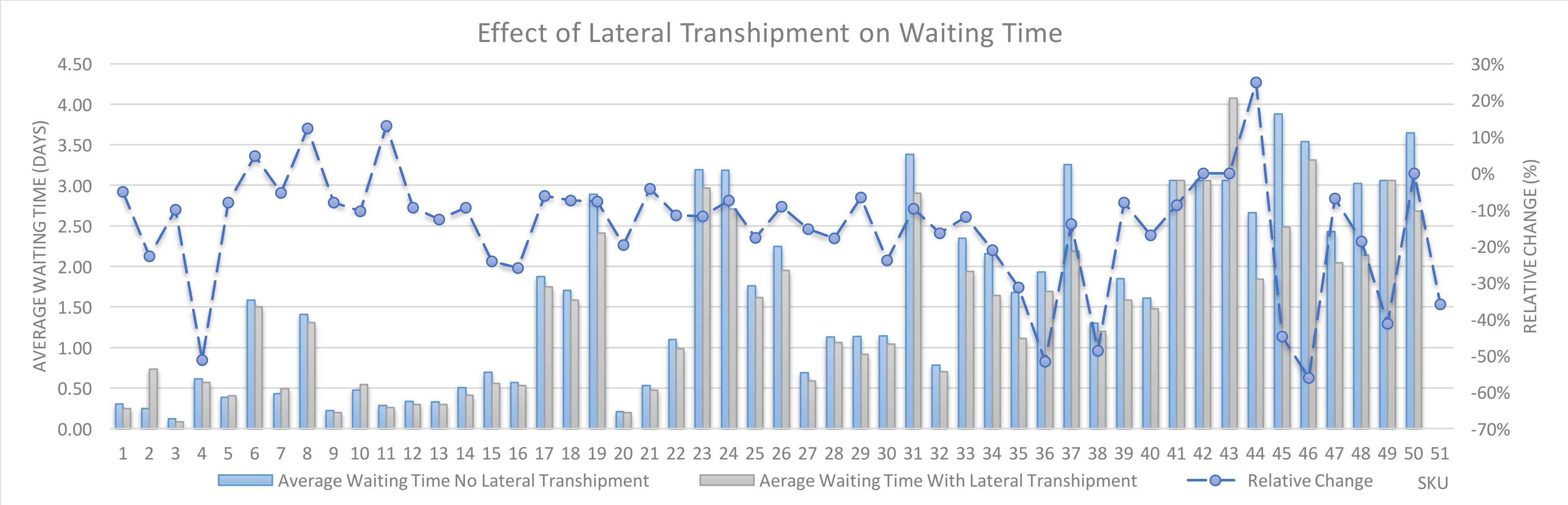


Figure 52

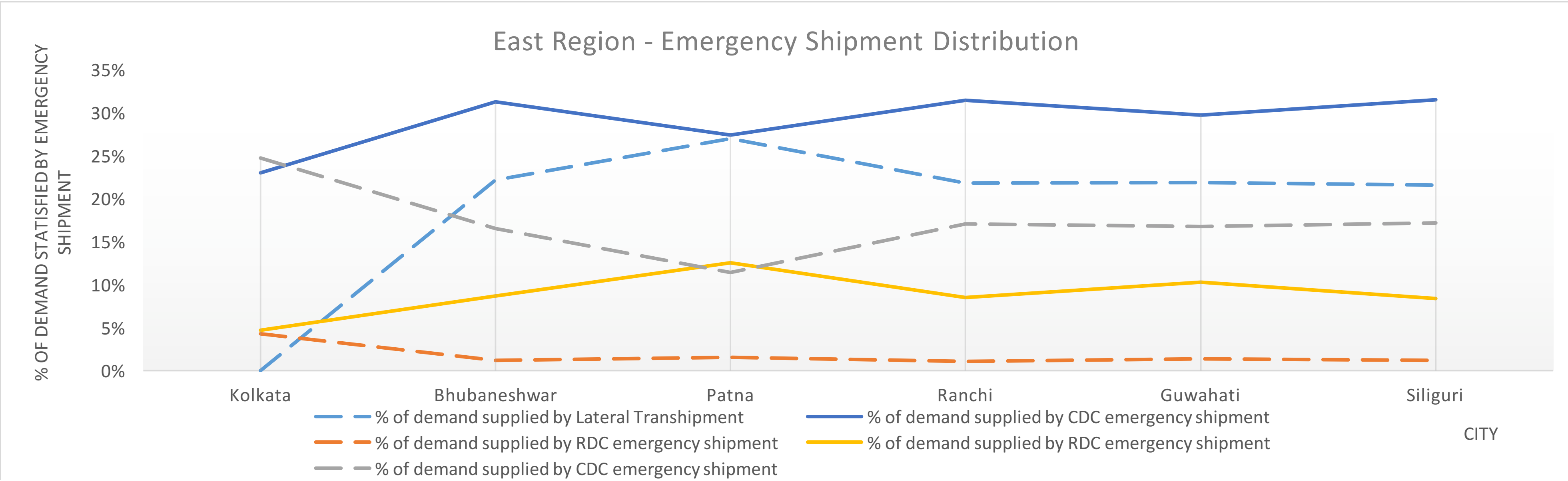


Figure 53

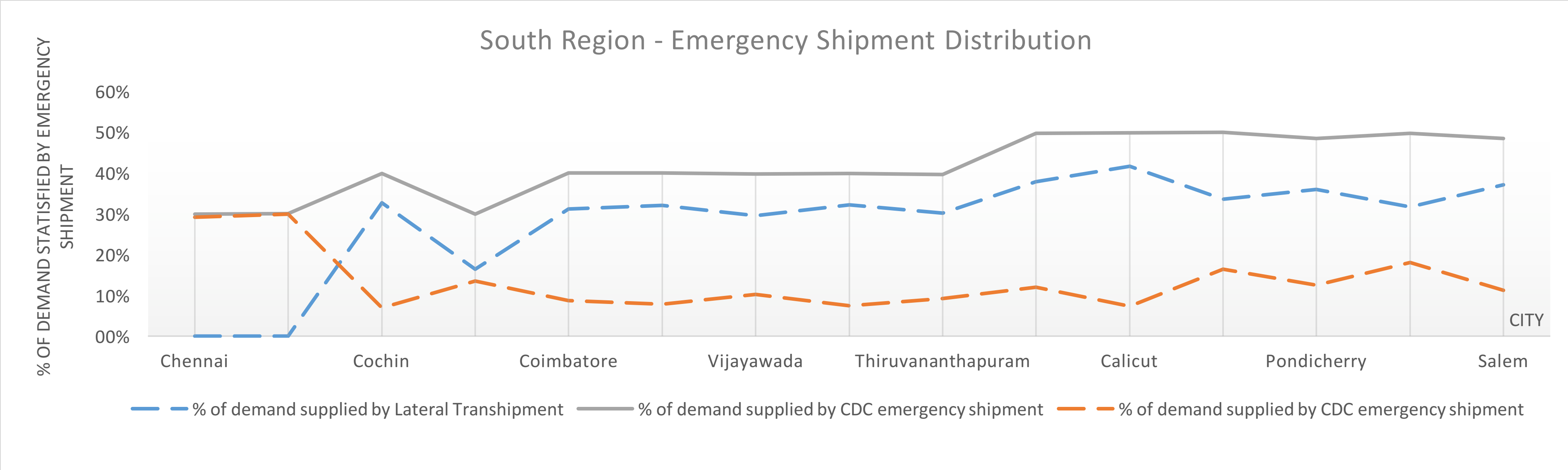


Figure 54

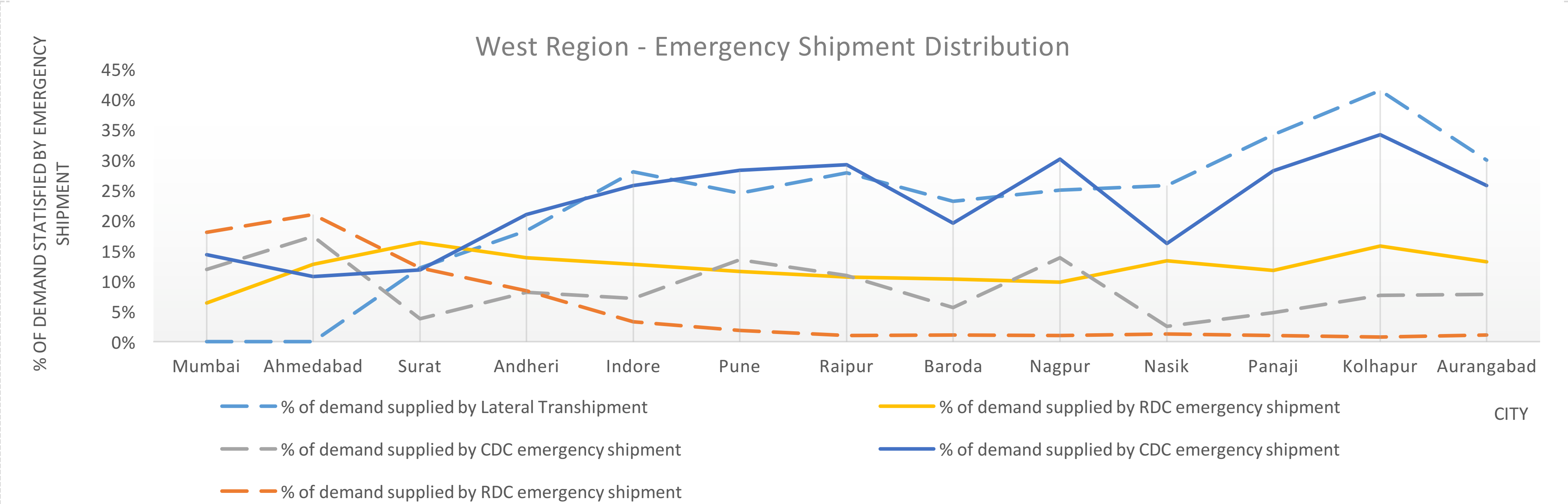


Figure 55

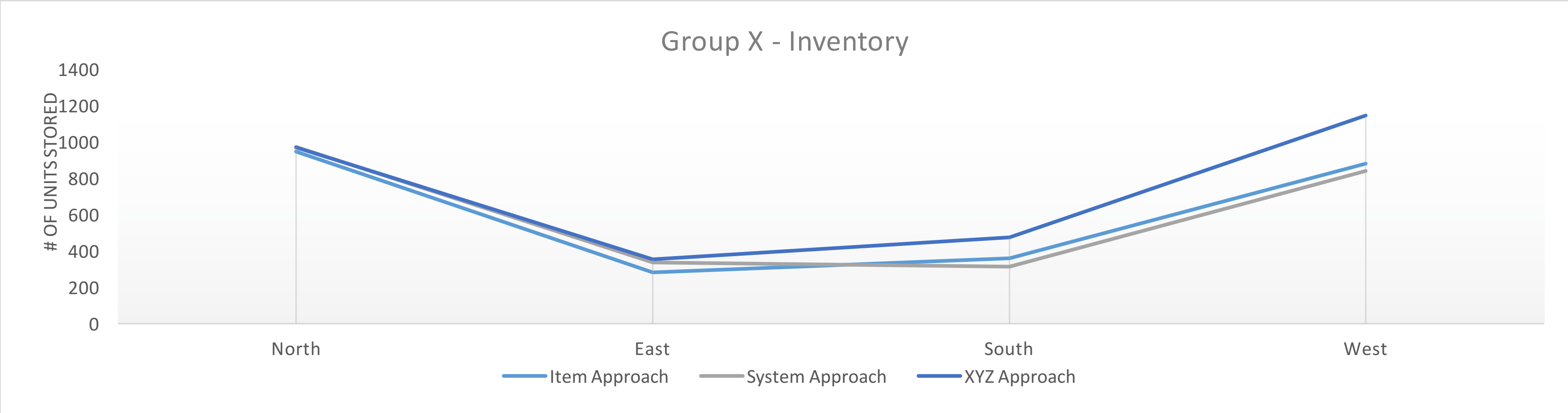


Figure 56

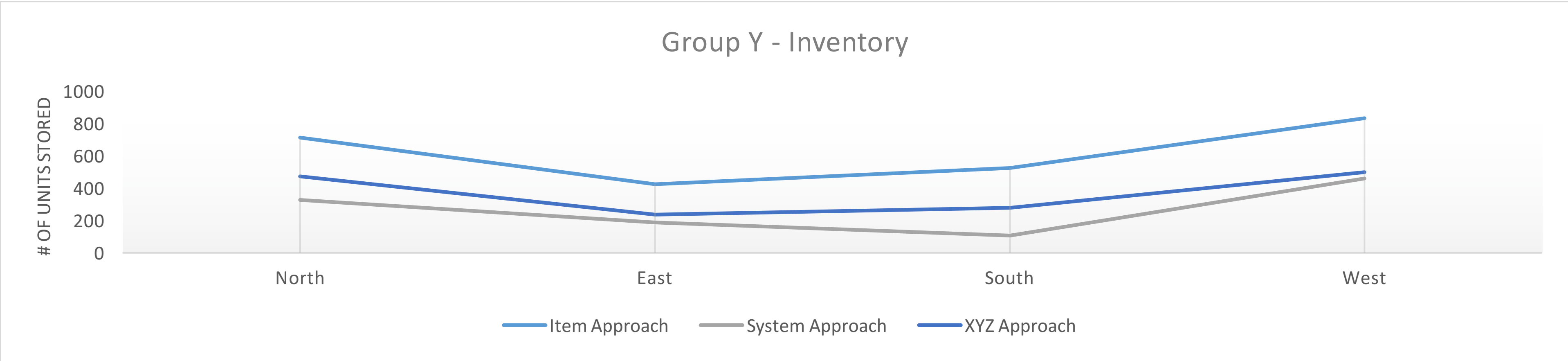
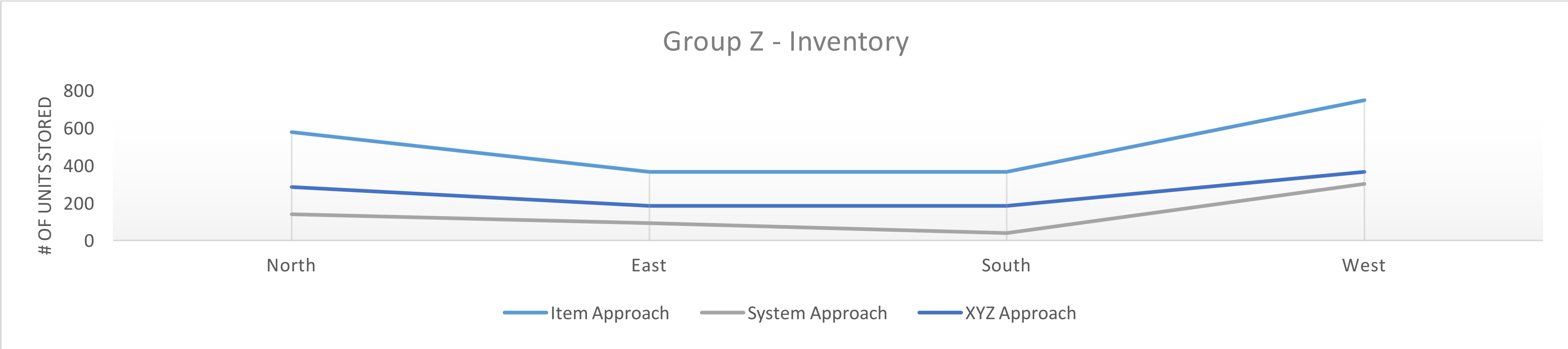


Figure 34


Group Z - Inventory
OF UNITS STORED
800
600
400
200
0
North
East
South
West
Item Approach
System Approach
XYZ Approach
Figure 58

Appendix G – Sensitivity Analysis

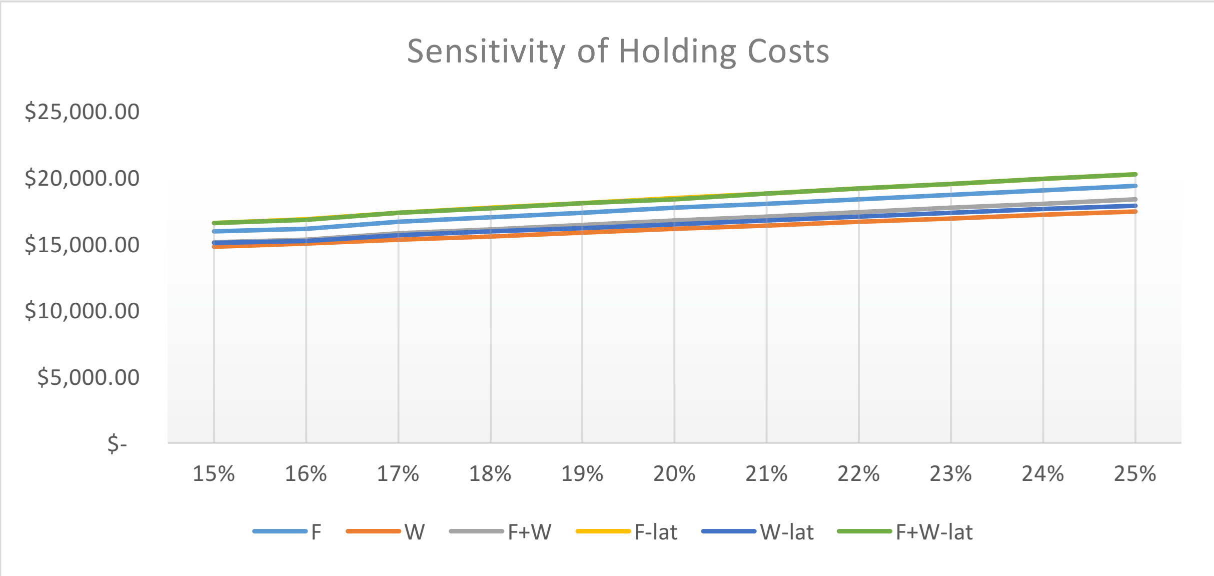


Figure 59

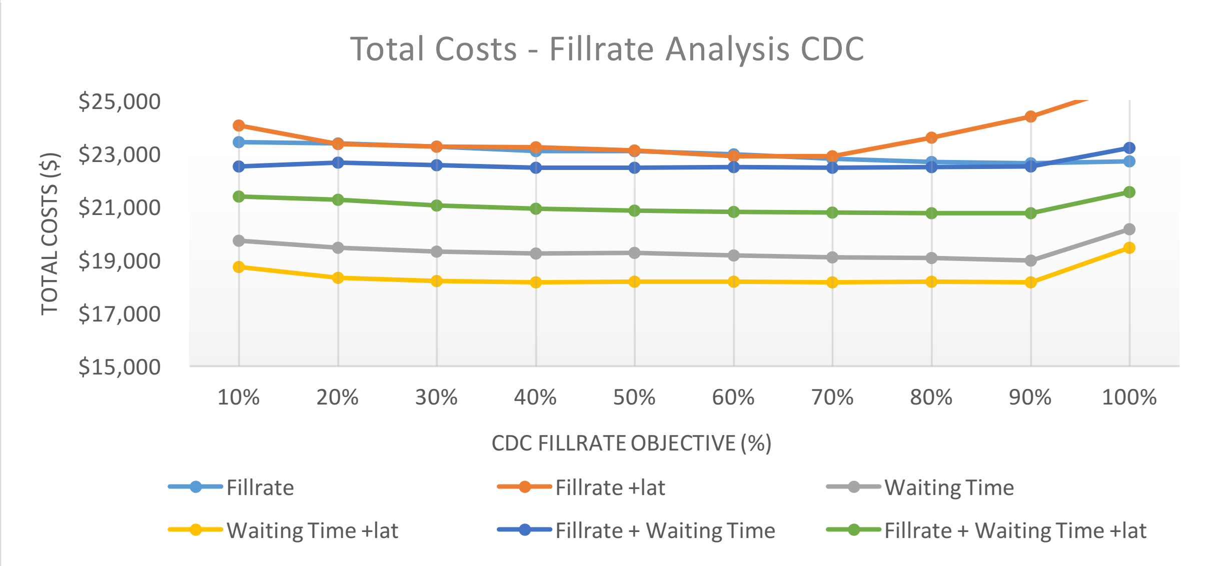


Figure 60

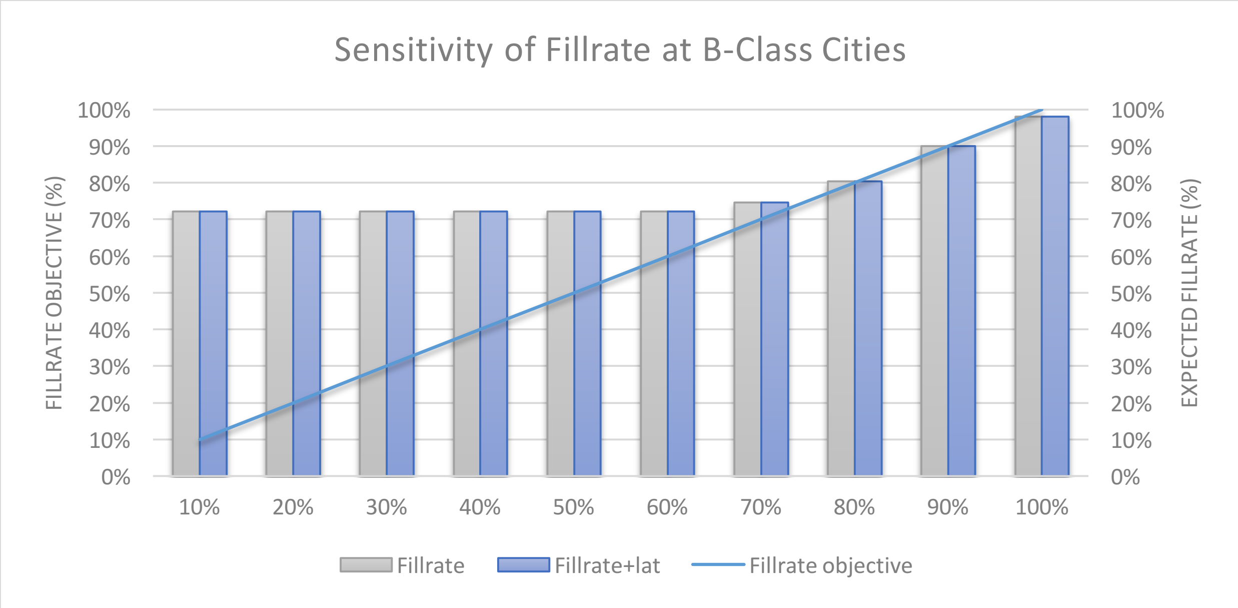


Figure 61

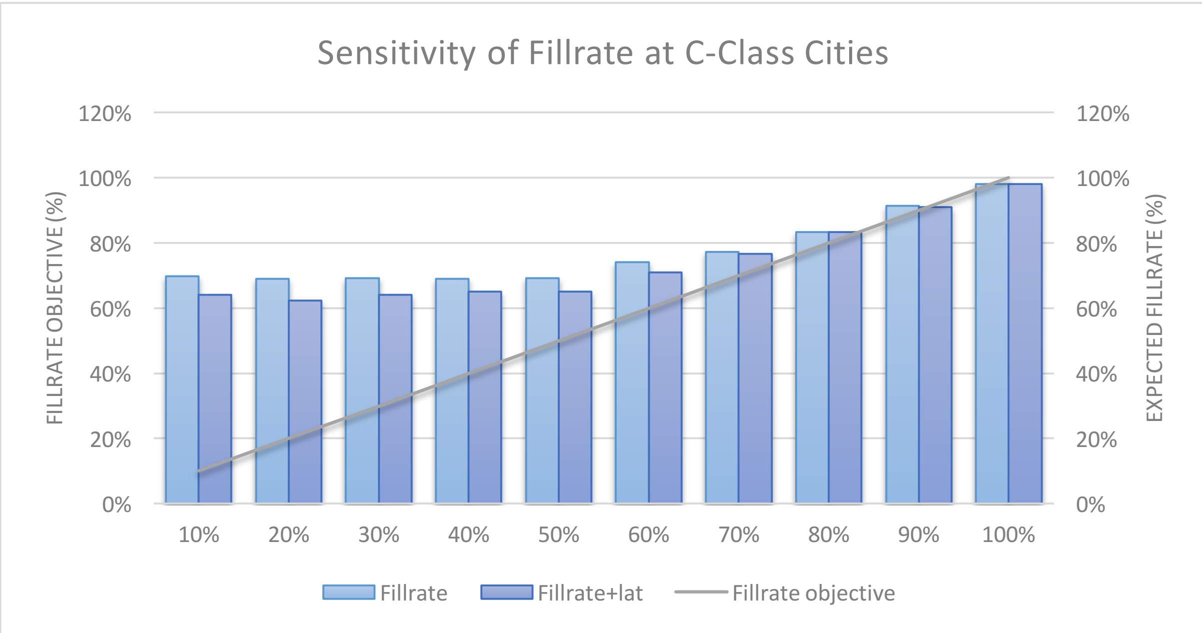


Figure 62

Appendix H –Tool working

In this Appendix we will explain in short the working of the tool, for a broader discussion we refer to the user manual created for the After Sales department of Logitech. The user of the tool can perform a multitude of different analysis. When the tool is opened the '**Home Menu**' will be exposed first, shown in figure 63.

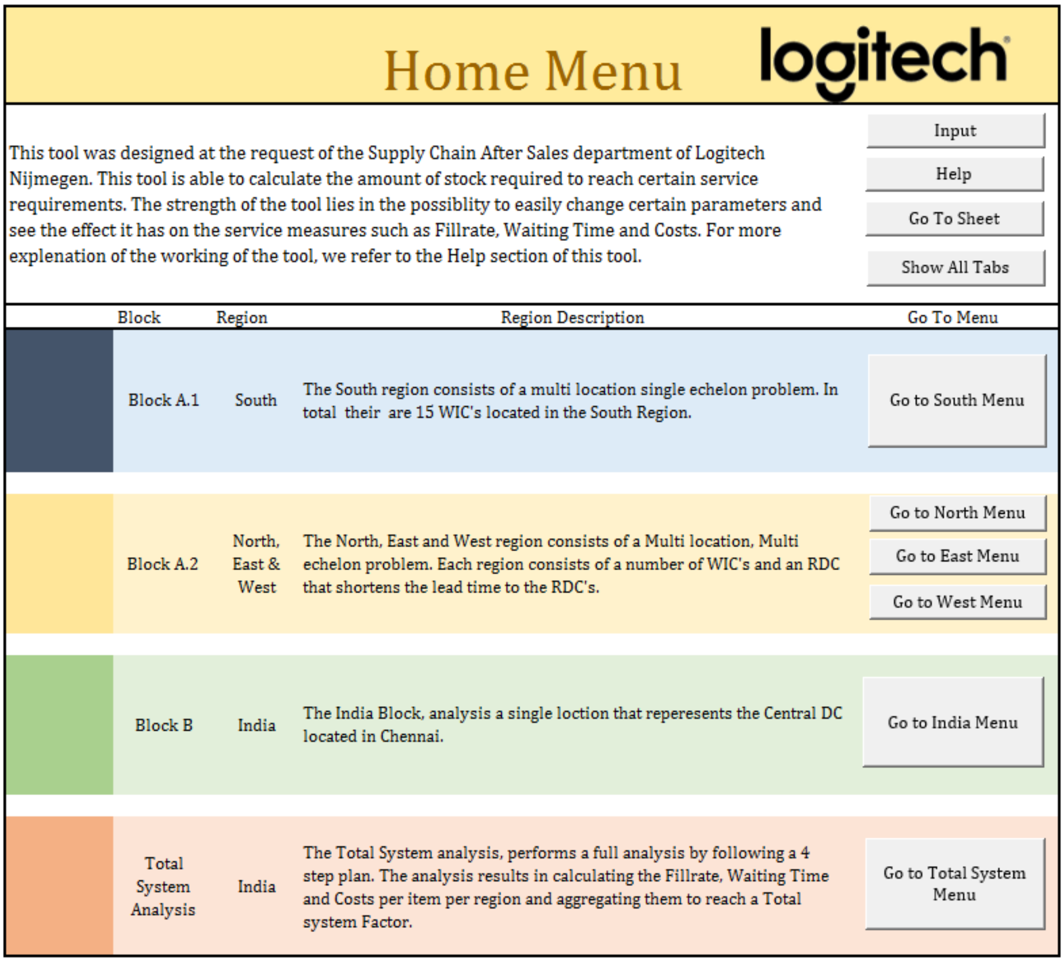
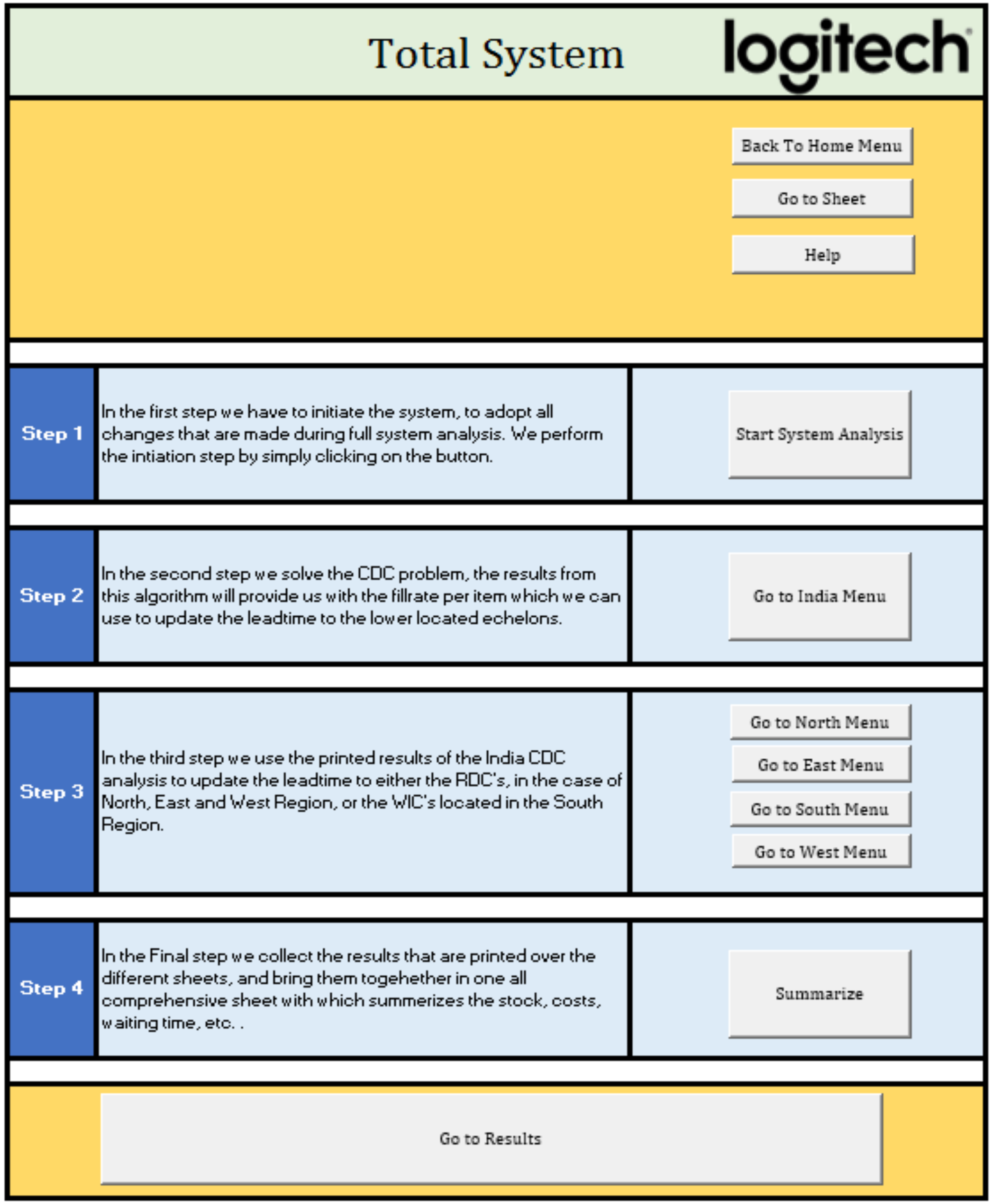


Figure 63

Before we can start an analysis we need to input the data necessary to perform the analysis. There are two different kind of datasets that are required in order to execute the analysis. First, we require data about the data that does not change month to month for example: the different service objectives, holding costs, lead-times etc. The second set of data is the demand data per SKU per WIC, this data should be updated as soon as new data becomes available. Before every run the user is required to input the data using the **input** button in the top right corner. All data will be automatically transferred to the right sheets.

As mentioned in this study there are several different models included in the tool. We will explain the main model where we perform an analysis of the total system. From the '**Home Menu'** we choose to perform a '**Total System Analysis'**. This will lead to the sheet showed in figure 64.


Total System
Back To Home Menu
Go to Sheet
Help
Step 1
In the first step we have to initiate the system, to adopt all changes that are made during full system analysis. We perform the intiation step by simply clicking on the button.
Start System Analysis
Step 2
In the second step we solve the CDC problem, the results from this algorithm will provide us with the fillrate per item which we can use to update the leadtime to the lower located echelons.
Go to India Menu
Step 3
In the third step we use the printed results of the India CDC analysis to update the leadtime to either the RDC's, in the case of North, East and West Region, or the WIC's located in the South Region.
Go to North Menu
Go to East Menu
Go to South Menu
Go to West Menu
Step 4
In the Final step we collect the results that are printed over the different sheets, and bring them togehether in one all comprehensive sheet with which summerizes the stock, costs, waiting time, etc. .
Summarize
Go to Results

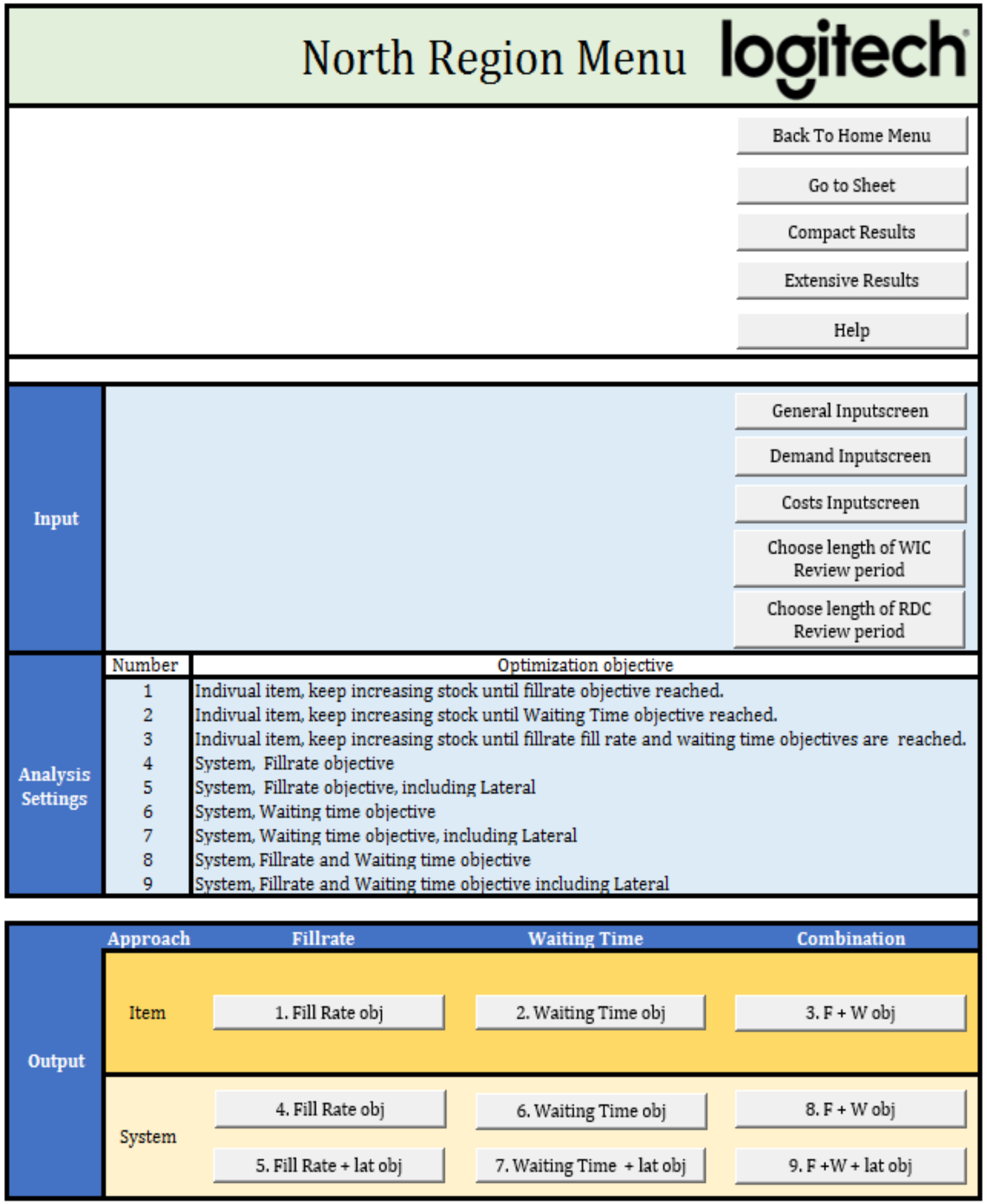

North Region Menu
Back To Home Menu
Go to Sheet
Compact Results
Extensive Results
Help
Input
General Inputscreen
Demand Inputscreen
Costs Inputscreen
Choose length of WIC Review period
Choose length of RDC Review period
Analysis Settings
Number
Optimization objective
1 Indivual item, keep increasing stock until fillrate objective reached.
2 Indivual item, keep increasing stock until Waiting Time objective reached.
3 Indivual item, keep increasing stock until fillrate fill rate and waiting time objectives are reached.
4 System, Fillrate objective
5 System, Fillrate objective, including Lateral
6 System, Waiting time objective
7 System, Waiting time objective, including Lateral
8 System, Fillrate and Waiting time objective
9 System, Fillrate and Waiting time objective including Lateral
Output
Approach
Fillrate
Waiting Time
Combination
Item
1. Fill Rate obj
2. Waiting Time obj
3. F + W obj
System
4. Fill Rate obj
6. Waiting Time obj
8. F + W obj
5. Fill Rate + lat obj
7. Waiting Time + lat obj
9. F +W + lat obj

Figure 64

The steps shown in this sheet follow the procedure explained in Section 5.9.3. As visible from the sheet is that each Region has his own menu. In this figure we focused on the 'North Region'. The first choice that user needs to be make is, which approach the user wants to follow. When the user makes a choice by clicking one of the buttons the evaluation algorithm will start to run. The algorithm will run until the userform shown in figure 65 will show up. We discussed the absence of a service objective for the RDC in Section 6.5.2.

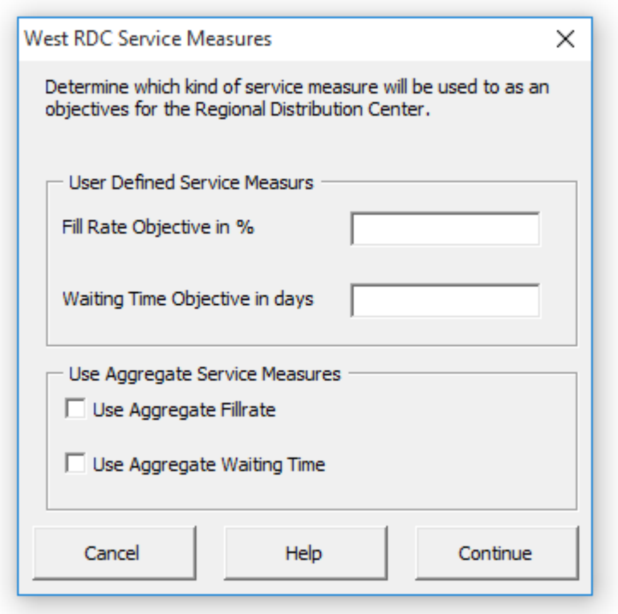


Figure 65

After the user makes a choice the model will run until a message appears, which will tell the user that the calculations are done(figure 66).

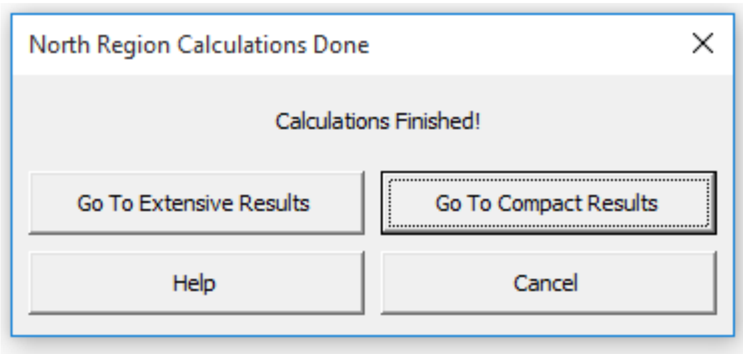


Figure 66

The user is given two different kind of output possibilities, if chosen for the compact results the user will be lead to the sheet shown in figure 67. We will explain the output possibilities in more detail in Appendix I.2. Eventually after performing the analysis for each region, the user should return to the total system menu. In this menu the user should click on the 'Summarize' button, this will retrieve the results from all the different regions and add them up in one output sheet.

WIC Results

WIC	Name	Fill Rate (%)	Fill Rate objective (%)	Regular Shipping Costs ($)	Waiting Time (days)	Waiting Time Objective (days)	% of demand supplied by Lateral Transhipment	Lateral Shipping Costs ($)	% of demand supplied by RDC emergency shipment	RDC Emergency Shipping Costs ($)	% of demand supplied by CDC emergency shipment	CDC Emergency Shipping Costs ($)	Holding Costs ($)	Total WIC Costs ($)
1	RDC													
2	New Delhi													
3	Gurgaon													
4	Ludhiana													
5	Jaipur													
6	Lucknow													
7	Bhopal													
8	Chandigarh													
9	Ghazibad													
10	Amritsar													
11	Dehradun													
12	Jammu													
13	Kanpur													
14	Varanasi													

Total Region Results

WIC	Name	Aggregate Fill Rate (%)	Aggregate Waiting Time (Days)	Regular Shipping Costs ($)	Lateral Shipping Costs ($)	RDC Emergency Shipping Costs	CDC Emergency Shipping Costs ($)	Holding Costs ($)	Total Costs ($)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
Total Region		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

Absolute Values

Relative Values

Figure 67

H.1 Tool Input

SKU Related input:

- **SKU ID**: In order to differentiate between items, we need the unique ID that is given to each SKU
- **Item costs**: The price per item ($)
- **Demand Rate**: This is the expected demand for the SKU's (items/month)
- **Holding Costs**: The costs of keeping a part on stock, expressed as a percentage of the item costs. (%/month)

Lead-Time and Costs

- **CDC Replenishment lead-time**: Lead-time between Singapore DC and the Chennai DC (days)
- **RDC lead-time**: Lead-time between Chennai DC and the Regional DC's (days)
- **WIC lead-time**: Lead-time between the Regional DC or Chennai DC to the WIC's. (days)
- **Emergency Lead-time**:
    - Central Distribution Centrum: The time required for an emergency shipment originating from the Central Warehouse. (days)
    - Regional Distribution Centrum: The time required for an emergency shipment originating from the Regional Warehouse to a WIC. (days)
    - Lateral Transhipment: The time required for an emergency shipment between two WIC's. (days)

- **Shipment costs**:
    - Central DC Emergency shipment: The costs for an emergency shipment originating from the Central Warehouse ($/Shipment)
    - Regional DC Emergency shipment: The costs for an emergency shipment originating from the Regional Warehouse to a WIC ($/Shipment)
    - Lateral Transhipment: The costs for an emergency shipment between two WIC's ($/Shipment)

Warehouse Related Input

- **Fillrate objective**: The desired percentage of orders that need to be delivered from on-hand stock. (%)
- **Waiting Time objective**: The desired waiting time for demand that could not be met form stock. (days)
- **Review period**: The review period per warehouse. (days)

H.2 Tool Output

We generate output on four levels:

- **a.** For each SKU per WIC in each region,
- **b.** Aggregate per WIC in each region
- **c.** For each SKU in Total System
- **d.** Aggregate in Total System

We will only mention the first two output levels, as the latter two are summed up over each region and presented in a separate sheet.

a. For each SKU per WIC in each region

- **Number of Units Stocked** (#items/WIC)
- **Fillrate per SKU**: percentage of item orders that can be delivered from on-hand stock. (%)
- **Average Waiting Time per SKU**: The average waiting time for an item (days)
- **Total item costs**: Total costs per item per WIC. ($)

b. Aggregate per WIC in each region

- **Aggregate Fillrate**: The percentage of demand that can be filled from stock (%)
- **Aggregate Waiting Time:** The mean waiting time per WIC (days)
- **Holding costs**: Total costs of holding inventory ($)
- **Fraction of demand** filled by
  - **Lateral emergency shipment:** Fraction of demand that is filled by means of lateral emergency (%)
  - **Regional emergency shipment:** Fraction of demand that is filled by means of regional emergency shipment (%)
  - **Central emergency shipment:** Fraction of demand that is filled by means of central emergency shipment (%)
- **Lateral transhipment costs**: Costs related with demand filled by means of lateral transhipment ($)
- **Regional Emergency Shipment Costs**: Costs related with demand filled by means of regional emergency shipment ($)
- **Central Emergency Shipment Costs**: Costs related with demand filled by means of central emergency shipment ($)
- **System costs**: The sum of all previous entries added up lead to the total costs ($)